CHALMERS

Traffic Network Evaluation using Microscopic Simulation and Analytical Modelling

A Study of the Traffic Situation Arising after a High Profile Event at a Planned Football Stadium in Falkenberg

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

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Cover:
Figure depicting a 3D-view of the traffic situation at the roundabout on Kristineslättsallén during a PTV VISSIM simulation.

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ABSTRACT

Due to stricter regulations from the Swedish Football Association regarding demands on football arenas, a new stadium is planned to be constructed in Falkenberg. This master thesis aims at evaluating the traffic situation arising around the planned stadium after a high profile event, using the traffic simulation software PTV VISSIM. The influence of pedestrians on the overall performance of the traffic network are also studied as well as possible differences in results and added values gained by using PTV VISSIM, when compared to a previously conducted Capcal investigation. A literature study is conducted in order to gain knowledge concerning traffic simulation theory as well as become familiarised with the two software PTV VISSIM and Capcal. The inputs used during model construction are based on a previous investigation conducted by Norconsult AB and an event study at Kinnarps Arena. Since the stadium in Falkenberg is not yet constructed, the data collected during the event study are used to calibrate behaviours such as vehicle and pedestrian interaction in the model. After completion of the model, multiple simulation runs are performed and relevant output values are collected and evaluated. The traffic system is most affected by pedestrians in a period shortly after the end of an event when pedestrians have a direct influence on the traffic flow. When the pedestrians have exited the model, an improvement of the traffic network performance is observed. Consequently, pedestrians have an influence on the performance of the traffic network. In general PTV VISSIM and Capcal results are similar but, due to differences in calculation procedures, the two software do not correlate completely. The possibilities in PTV VISSIM to recreate and analyse complex traffic systems, enables an overall network performance analysis as well as the study of specific situations occurring in the network, which cannot be conducted using Capcal. However, PTV VISSIM is a more time consuming and computationally demanding tool than Capcal, why it is important to consider the scope of the project before deciding which software to use.

Key words: Microscopic traffic simulation, Traffic system evaluation, Pedestrian influence, PTV VISSIM, Capcal, Falkenberg.

Utvärdering av ett trafiksystem med hjälp av mikrosimulering och analytisk modellering

En studie av trafiksituationen kring en planerad fotbollsarena i Falkenberg efter ett välbesökt arrangemang

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SAMMANFATTNING

På grund av striktare regler från Svenska Fotbollsförbundet angående krav på fotbollsarenor, planeras en ny arena att byggas i Falkenberg. Detta examensarbete syftar till att utvärdera trafiksituationen som uppstår kring den planerade arenan efter ett välbesökt arrangemang, med hjälp av trafiksimuleringsprogramet PTV VISSIM. Fotgängares inverkan på den övergripande prestandan på trafiknätet studeras. Dessutom studeras eventuella skillnader i resultat och erhållna mervärden genom användning av PTV VISSIM, jämfört med en tidigare utredning genomförd i Capcal. En litteraturstudie har genomförts för att få kunskap om trafiksimuleringsteori samt för att kunna hantera de två programvarorna PTV VISSIM och Capcal. De indata som används vid uppbyggnaden av modellen är baserade på en tidigare genomförd undersökning av Norconsult AB och en arrangemangstudie vid Kinnarps Arena. Eftersom stadion i Falkenberg ännu inte är konstruerad används de data som samlas in under arrangemangstudien för att kalibrera fordons- och fotgängarbeteenden. När modellen färdigställts utförs ett flertal simuleringar och relevanta utdata samlas in samt utvärderas. Resultaten visar att trafiksystemet är mest påverkat av fotgängare strax efter slutet på ett arrangemang, då fotgängare har en direkt påverkan på trafikflödet. Efter att fotgängarna lämnat modellen sker en klar förbättring av trafiksystemets prestanda. Följaktligen har fotgängare inflytande på den övergripande prestandan på trafiknätet. Generellt överensstämmer resultaten från PTV VISSIM och Capcal väl, men skillnader i beräkningsmetodik medför att de inte korrelerar fullständigt. Möjligheterna i PTV VISSIM att återskapa och analysera komplexa trafiksystem möjliggör för mer övergripande analyser av nätverksprestanda samt utvärderingar av specifika situationer som uppkommer i trafiksystemet, jämfört med Capcal. PTV VISSIM är dock ett mer tids- och beräkningsmässigt krävande verktyg än Capcal, varför det är viktigt att ta hänsyn till projektets omfattning innan det avgörs vilket program som skall användas.

Nyckelord: Mikroskopisk trafiksimulering, Utvärdering av trafiksystem, Påverkan av fotgängare, PTV VISSIM, Capcal, Falkenberg.

Contents

Preface

In this study, the traffic situation surrounding a planned football stadium in Falkenberg is evaluated using the microscopic traffic simulation software PTV VISSIM. This Master Thesis is conducted at the Department of Civil and Environmental Engineering, Chalmers University of Technology in collaboration with Norconsult AB.

The study has been carried out from January to May 2014 by the authors Erik Eidmar and Johan Hultman, with support from supervisor Jan Englund at the Road and Traffic Research Group at Chalmers University of Technology. Valuable support has also been received from retired University lector Gunnar Lannér.

We would like to thank all people working at the Trafik and Väg- & Järnvägsteknik divisions at Norconsult AB for contributing to a positive workplace and a special thanks to our supervisors Anders Axenborg and Erland Kjellson. Your experience and guidance have been helpful throughout the study.

Finally, we would also like to thank our opponent Victoria Liljedahl for your valuable feedback.

Göteborg, May 2014

Erik Eidmar and Johan Hultman

Abbreviations

AADT	Average Annual Daily Traffic
PT	Public Transport
SHL	Swedish Hockey League
HGV	Heavy Goods Vehicle

Glossary

Allsvenskan	Swedish top division in football
Falkenbergs kommun	Falkenberg municipality
Nationell vägdatabas	National road database
Statens Vägverk	Swedish Road Administration (prior to 1983)
Svenska Fotbollsförbundet	Swedish Football Association
Trafikverket	Swedish Transport Administration
Transportpolitiska målen	Swedish Transport policy
Vägverket	Swedish Road Administration (1983-2010)

Notations

AX	Desired distance at standstill to a lead vehicle in Wiedmann 74
BX	Safety distance to a lead vehicle depending on travelling speed in Wiedmann 74
C	Calculated capacity for a specific intersection approach
$d(n)_{t+\Delta t}$	Travelled distance for a lead vehicle during a time interval Δt
$d(n+1)_{t+\Delta t}$	Travelled distance for a following vehicle during a time interval Δt
$h(n+1)_t$	Time headway to a following vehicle at a time t
$h(n+1)_{t+\Delta t}$	Time headway to a following vehicle after a time increment Δt
min	Specific time interval duration
OPDV	Threshold when a following vehicle start to accelerate during a car-following state in Wiedmann 74.
$N_{Vehicles}$	Number of vehicles using a specific intersection approach during a high profile event simulation
$s(n+1)_t$	Space headway to a following vehicle at a time t
$s(n+1)_{t+\Delta t}$	Space headway to a following vehicle after a time increment Δt

SDV	Threshold for car-following state in Wiedmann 74
SDX	Maximum desired following distance in Wiedmann 74
V	Calculated pedestrian/vehicle input volumes
Δv	Difference in velocity between a following and a lead vehicle in Wiedmann 74
Δx	Difference in distance between a following and a lead vehicle in Wiedmann 74
x	Desired number of pedestrians/vehicles in a specific time interval

1 Introduction

According to the Swedish Government (2010), the overall objective of the Swedish transport policy is to ensure the economically efficient and sustainable provision of transport services for people and businesses throughout the country. In order to facilitate the analysis of the transportation system efficiency, either in large or small scale, computer aided evaluation tools have been developed. Microscopic and analytical traffic simulators are two examples of such tools.

According to Fellendorf & Vortisch (2010), microscopic traffic flow simulators have become more common in the professional world in recent years when studying traffic networks. A wide range of such simulators are available on the market and are used by a variety of consultants, researchers and public agencies. One of the most commonly used microscopic traffic simulations today is PTV VISSIM developed by the German company Planung Transport Verkehr AG, according to Elefteriadou (2014). This software enables an extensive assortment of urban and highway applications and integrates the public and private transport as well as pedestrians into the model. By incorporating the possibility to simulate different transportation means, PTV VISSIM can replicate complex traffic situations, such as roundabouts and intersections, where numerous conflicts between modes of transport exist.

Another method to evaluate traffic network components, explained in Statens Vägverk (1981), is to use an analytical model. The capacity evaluation software Capcal is one such model, which was developed during the 1980s and is based on previous non-computerised calculation methods used in Sweden. The Capcal software has since been updated multiple times. Capcal enables evaluation of individual intersections and roundabouts in terms of accessibility, delay and queue build-up.

This master thesis aims at evaluating a specific traffic situation that arise around a planned football stadium in the city of Falkenberg, by creating a microscopic traffic model using the above mentioned software PTV VISSIM. The emphasis lies on the creation of a realistic microscopic simulation representing the actual situation. The use of microscopic traffic simulations and analytical evaluation methods each have benefits and disadvantages, depending on the scope of the project. Differences in results of the two methods and possible added values gained by using a microscopic traffic simulation compared to the less complex analytical model Capcal will also be analysed.

1.1 Background

The Swedish Football Association has decided to implement new demands on football arenas (e.g. number of seats under roof and working-places for media) housing teams in the top two divisions in Swedish football, stated by Svenska Fotbollsförbundet (2013). In the town of Falkenberg, located on the west coast of Sweden, the local football club Falkenberg FF is affected by these requirements according to Falkenbergs kommun (2012). The club currently plays in the Swedish top division and the arena on which they play their home games, Falkenbergs IP, does not fulfil these demands. Therefore, according to Falkenbergs kommun (2013), there is an ongoing planning process to construct a new football stadium, with a maximum capacity of 6 000 spectators, at Kristineslätt located south east of Falkenberg town centre. An ice arena and a number of practice pitches for football exist at the location today and these sporting facilities will form a new sport centre together with the new football stadium. Furthermore, two parking lots are planned, one to the west of the arena and one to the east. However, these parking lots will not be sufficient during a high profile event (i.e. an event with 6 000 spectators), why vehicles will have to park north of Kristineslättsallén and enter the road network via August Bondessons väg. A football game with the local team is an example of one such event. In Figure 1 an overview of Kristineslätt and the planned sport centre can be seen.

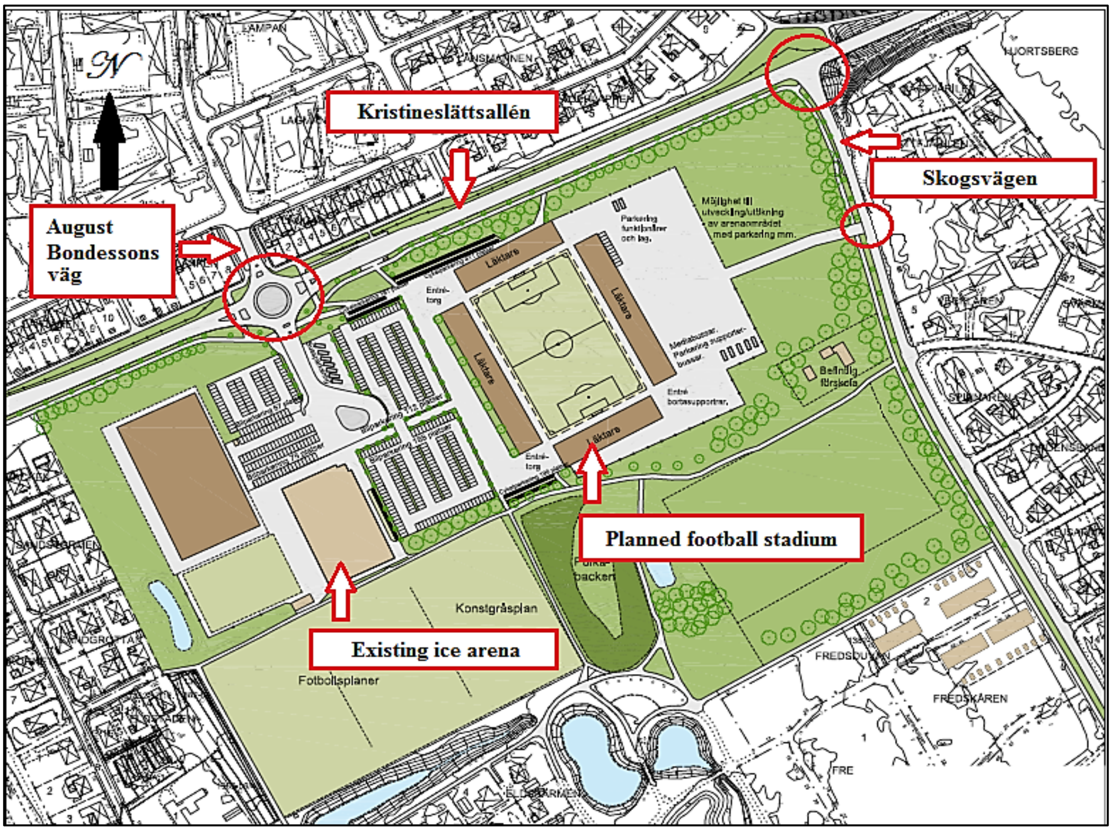

Figure 1 Overview of the planned football stadium and sport centre at Kristineslätt (Falkenbergs kommun, 2012)

The construction of the football stadium and the development of the sport centre will increase the traffic flow in the area, especially during a high profile event at the stadium. A traffic investigation, including a capacity calculation in Capcal of the roundabout and the T-intersection at Kristineslättsallén, was made in 2013 by Norconsult AB on behalf of the municipality of Falkenberg to study how the stadium will affect the local traffic situation after its completion, according to Kjellson & Salomonsson (2013). Kjellson & Salomonsson further states that the largest strain on the traffic network will occur shortly after an event has ended, when the majority of the spectators leave the area at the same time.

In a situation where a large amount of people leave the area at the same time, all kinds of modes of transportation (i.e. pedestrians, bicyclists, cars and PT) will share the transport network, stated by Falkenbergs kommun, (2012). These can be divided into motorised (i.e. cars and PT) and non-motorised (i.e. pedestrians and bicyclists). The motorised and non-motorised modes will interact with each other and compete for the same space at different points in the traffic system, pedestrian crossing are an example of such a point. Another situation is when the same communication means (e.g. cars) have to co-operate with other road users, intersections and roundabouts are examples where this type of interaction takes place. Both types of interactions exist at three points in the studied area along Kristineslättsallén and Skogsvägen, marked in

Figure 1 with black circles. The situations that arise at these points affect the traffic system and influence the efficiency of the road network.

1.2 Purpose

The purpose of this master thesis is to evaluate the traffic situation after a high profile event at the planned football stadium in Falkenberg using a model created in the traffic simulation software PTV VISSIM 6. The evaluation comprises of a number of selected performance measures. The influence of pedestrians on the overall performance of the traffic network will also be studied as well as possible differences in results and added values gained by using PTV VISSIM compared to Capcal 3.9 when studying the specific traffic situation.

1.3 Limitations

Since the new football stadium only exists on the planning stage, no real situation can be observed in order to calibrate the model. It must instead be calibrated by observing an event at a similar scale at another location. The traffic volume used during the simulations is based on numbers collected from a traffic flow measurement conducted in Falkenberg in 2010. An assumption is made that the traffic volumes have not changed during this period and therefore no further investigations regarding the present volumes will be made during this study. The traffic volume that normally exists in the traffic system (i.e. background traffic) will be entered into the simulation together with the vehicle traffic leaving the sport centre after an event (i.e. parking lot traffic). However, the number of pedestrians entered into the simulation will only be the amount estimated to leave the stadium.

The topography of the modelled area is mostly flat, why the model will be constructed without any difference in height. This may influence the simulation output as acceleration/deceleration parameters are influenced by the inclination of the roadway. However, due to the small difference in the topography the effects on the final output are deemed as marginal.

The model is limited to contain parts of the traffic network surrounding the sports centre, seen in Section 1.1. More specifically the network consists of a 635 meter section of Kristineslättsallén and a 345 meter stretch of Skogsvägen containing three points of interaction, one roundabout and two T-intersections.

This investigation will only concentrate on the traffic situations that arise within the simulation. The traffic situation outside the modelled area will not be taken into account and will not influence the output of this study. The results will be based on the outcome from the model created in the traffic simulation software PTV VISSIM 6 with the add-on pedestrian simulation module VISSWALK.

The performance of the traffic network will be evaluated according to a number of performance measures. The measures are selected in order to investigate the transport system efficiency from an overall network perspective as well as the progression for the visiting spectators through the network. Average speed and travel times through the system are measured in different time intervals to evaluate the network over time. The numbers of vehicles able to leave the parking lots during time periods with and without direct pedestrian influence as well as the total evacuation time from the parking lots are measures used to describe the spectator progression. Furthermore, capacity and load rate are measures to evaluate the non-signalised intersections which can be used to compare the results between Capcal 3.9 and PTV VISSIM 6. Since a previous Capcal evaluation has been conducted by Kjellson & Salomonsson in 2013, the results from this investigation will be used in the comparison. Hence, no separate investigation using Capcal will be undertaken in this master thesis.

1.4 Method

Since an analytical investigation has been carried out using Capcal, the focus of this master thesis is to create a representative model in PTV VISSIM of the traffic situation in the studied area. In order to achieve this, a literature study will be conducted. The aim of this literature study is to learn how to handle the simulation software PTV VISSIM and understand which parameters are important to achieve a relevant result. Previously written master theses and journal articles on the subject of traffic simulation are examples of literature of relevance. To get familiarised with the PTV VISSIM 6 and Capcal 3.9 software, instructional literature, such as the software manuals and tutorials, are incorporated into the literature study.

To insert road geometry into PTV VISSIM, a map illustrating the planned sport centre is inserted and scaled. This image is used as a background, upon which the road network can be replicated, ensuring that the geometry of the modelled network is correct according to scale and layout.

As mentioned in Section 1.1, an investigation of the area has been conducted by Norconsult AB in 2013. Information from this investigation (e.g. traffic volume) is used as input values to the model. For the necessary traffic regulations (e.g. speed limits) the national road database, provided by the Swedish Transport Administration, is used.

The calibration of the model is important to make the results relevant and applicable to the traffic situation surrounding the planned sport centre. In order to calibrate the model, a traffic situation surrounding an event at Kinnarps Arena in Jönköping is studied. This event, an ice hockey game between two teams in the Swedish Hockey League (i.e. Sweden´s premiere hockey division), is selected because of its similarities to the planned stadium in Falkenberg regarding spectator numbers and interactions between communication means around the arena. Studied behaviours are vehicle and pedestrian interaction as well as the time it takes for spectators to exit the arena.

After completion of the model, multiple simulation runs are performed and relevant output values are collected and evaluated. The values are transformed into different performance measures with which the arising traffic situation is evaluated. Some measures describe the system during different time periods (e.g. average speed and travel time) while others describe the overall performance of the system (e.g. time to exit the different parking lots). To study the influence by pedestrians on the traffic network, performance measures with and without pedestrians in the system are compared. Furthermore, PTV VISSIM results will be compared to the Capcal output in order to analyse similarities and differences between the two software.

2 Theory

Traditionally, analytical traffic models have been used to study mobility at interaction points in the road network, according to Allström et al. (2008). In recent years however, microscopic traffic simulations have been used as a tool to understand the complex interactions between different modes of transport and to identify problem areas during large events. Ahmadi (2011) states that most of the research has been focused on large-scale events in big cities, but simulations can also be applied on smaller events.

Different behaviour models for microscopic vehicle traffic and pedestrians have been developed over the years. A general introduction to microscopic vehicle and pedestrian modelling will be presented in this chapter, as well as a short explanation on the specific models used by PTV VISSIM to simulate vehicle and pedestrian behaviour. A few examples on previous applications of microscopic simulations during large events are thereafter presented, followed by a short introduction to analytical traffic modelling and the analytical software Capcal. A brief description of the traffic network elements (i.e. intersection and roundabouts) that are of interest in this report and a description of general input data will follow. Finally, the importance of a calibration, as well as different evaluation methods, is described at the end of the chapter.

2.1 Microscopic traffic modelling

A microscopic model of traffic flows is based on the description of movements for each individual vehicle in the traffic stream, according to Barceló (2010). This means that the model aims to describe the reactions of an individual driver (i.e. acceleration, deceleration and lane changes) in response to the surrounding traffic situation.

To model the interactions between vehicles in a microscopic traffic simulation, *car-following* theory is used. Barceló (2010) explain that the development of these theories began in the 1950s and evolved during the 1960s. The aim is to describe how vehicles behave when following another vehicle and what actions they may perform. A vehicle is in car-following state when it has to adjust its speed, acceleration and spacing to a leading vehicle, according to Elefteriadou (2014). Elefteriadou (2014) also states that the sensitivity of the reactions for the following vehicle to the actions of the lead vehicle increases when the distance between the two vehicles decreases or the speed increases. Furthermore, the behaviour of a vehicle depends significantly on the driver and the vehicle characteristics. More aggressive drivers tend to have shorter distances to a lead vehicle and heavy vehicles tend to have longer distances because of their limited breaking capacities.

The car-following process is modelled using car-following algorithms. Elefteriadou (2014) explain that these algorithms determine the movement of a following vehicle at time *t+dt*, as a function of the relationship to a leading vehicle at time t. In Figure 2, a conceptual model for the relationship between a following vehicle (*Vehicle n+1*) and a leading vehicle (*Vehicle n*) is illustrated.

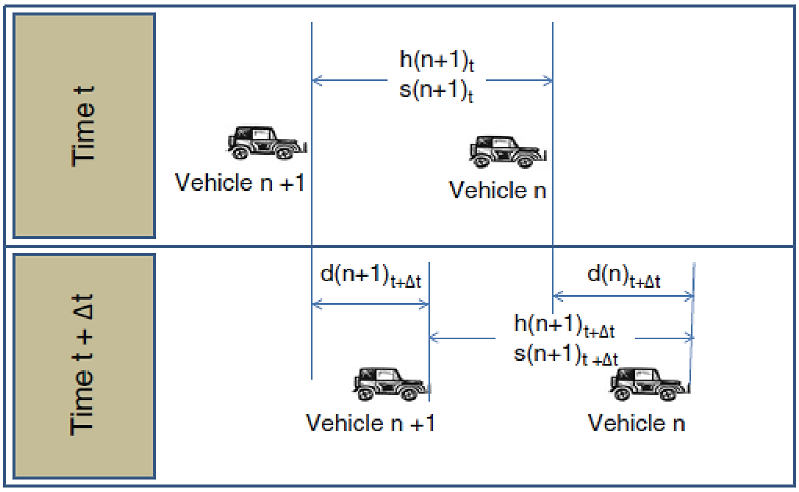

Figure 2 A conceptual model for car-following (Elefteriadou, 2014)

Elefteriadou (2014) further explain that at time *t*, *Vehicle n+1* is following *Vehicle n* with a time headway $h(n+1)_t$ and a space headway $s(n+1)_t$. Time headway is defined as the time difference between two vehicles passing the same point and the space headway is usually measured as the distance from the front of the leading vehicle to the front of the following. When a time interval Δt has passed, the leading *Vehicle n* has moved a distance $d(n)_{t+\Delta t}$ and the following *Vehicle n+1* has moved a distance $d(n+1)_{t+\Delta t}$. The relation between the travelled distances after the total time $t+\Delta t$ affect the time and space headways, $h(n+1)_{t+\Delta t}$ and $s(n+1)_{t+\Delta t}$, between a leading *Vehicle n* and a following *Vehicle n*+1. If $d(n)_{t+\Delta t} > d(n+1)_{t+\Delta t}$ the headways increase and vice versa.

If *Vehicle n* is undisturbed by other vehicles, its speed will be determined by the geometry of the road, the desired speed and behaviour of the driver as well as the characteristics of the vehicle according to Elefteriadou (2014). The actions of the following *Vehicle n+1* on the other hand are largely influenced by *Vehicle n* in front as well as the characteristics of the vehicle.

PTV (2011) states that the traffic model used in PTV VISSIM is a discrete, stochastic, time step based model on the microscopic level with driver-vehicle-units as single entities. Fellendorf & Vortisch (2010) explain that the car-following algorithm used in PTV VISSIM is the psycho-physical “Wiedemann 74” model. The model is defined as psycho-physical because it uses thresholds based on driver perception and actions to determine what regime, mode in the model, they belong to.

According to Elefteriadou (2014) and PTV (2011), there are four regimes that a vehicle can belong to in the Wiedemann model. These are:

- *Free driving*: There is no influence from a preceding vehicle. A driver seeks to reach and maintain a desired speed.
- *Approach*: This regime is entered when a driver passes the threshold to start perceiving the actions of a leading vehicle and starts to adapt its speed to the speed of the preceding vehicle. During an approach, a driver applies a deceleration so that the speed difference between the two vehicles is zero when a desired safety distance is reached.
- *Following*: A driver of a following vehicle unconsciously accelerates and decelerates to keep a desired safety distance to a lead vehicle.
- *Braking*: The regime is entered when a driver is forced to apply medium to high deceleration, this occurs when the distance to a lead vehicle becomes less than the desired safety distance. This situation may arise if a lead vehicle changes speed abruptly or reacts to the actions of a vehicle further in front.

Algorithms used in other traffic simulation software may implement, for example, fixed-value thresholds (i.e. a deterministic approach) for spacing to determine the regimes. The Wiedemann approach on the other hand considers the distance when a following driver can perceive changes in the relative velocity to a lead vehicle, stated by Elefteriadou (2014). If a following driver cannot perceive a change in relative velocity to a lead vehicle, it is no longer in a *car-following* state.

An illustration of the regimes described by PTV (2011) and Elefteriadou (2014) can be seen in Figure 3, where a driver closes in on a leading vehicle.

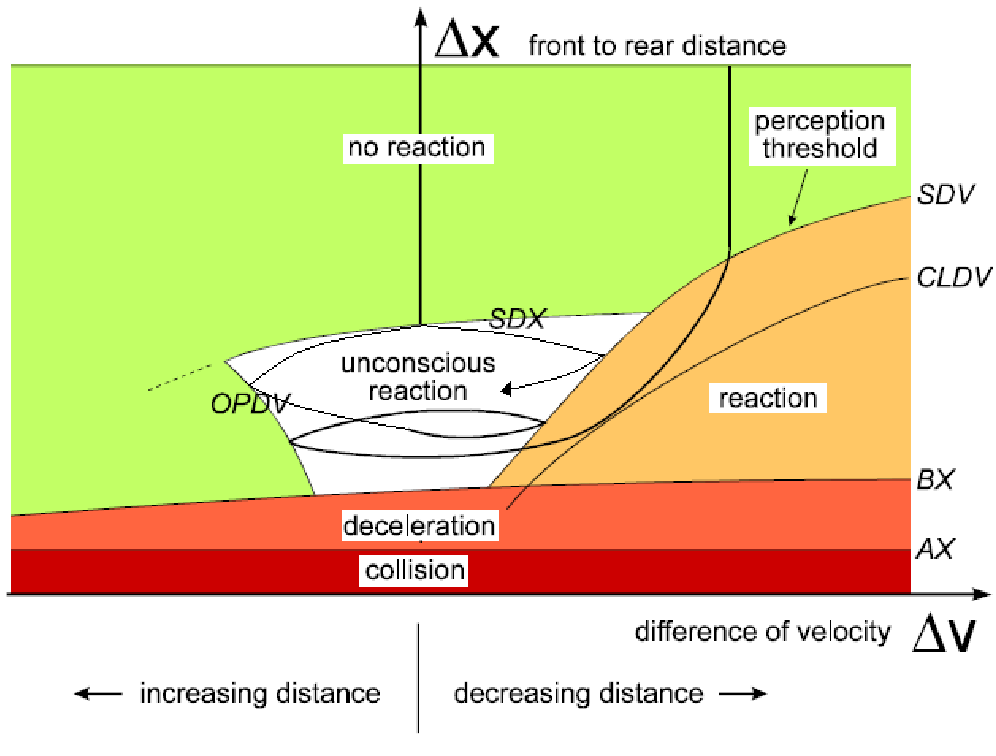

Figure 3 Car-following logic, Wiedemann 1974 (PTV, 2011)

Until the driver passes the perception threshold (SDV) the driver is unhindered by the preceding vehicle and exist in the *free driving* regime, where the driver maintain a desired speed. When the SDV threshold is passed the *approach* regime begins and the driver decelerates to reach a desired safety distance (Δx) when the relative speed difference (Δv) is zero. The driver then enters the *following* regime and unconsciously changes his/her velocity by acceleration and deceleration in an iterative process. The deceleration continues until the driver reaches the point where he/she notices that he/she is slower than the leading vehicle (OPDV) or the maximal desired following distance (SDX) is attained. The driver then starts to accelerate again to reach the desired following distance and speed. The minimum desired following distance is composed of two factors, the desired distance at stand still to the lead vehicle (AX) and a safety distance depending on the travelling speed (BX). If the distance to the preceding vehicle is less than AX+BX for a certain speed, the driver enters the previously explained *braking* regime.

2.2 Microscopic pedestrian modelling

Pedestrian movement and behaviour patterns differ compared to other modes of communication (i.e. cars, bicyclists and PT). One example is that pedestrians can move in a lateral direction without a forward motion, why another movement model than the one presented in Section 2.1 is needed to allow a more area-based movement pattern, according to Barceló (2010). Teknomo (2006) states that microscopic pedestrian models are based on detailed representations of space, where every pedestrian is an individual with personal abilities. The pedestrians are modelled individually in order to measure and simulate the pedestrian interaction.

PTV (2011) explains that the PTV VISSIM software uses the Social Force Model described by Helbing & Molnár (1995), through the add-on VISSWALK, to simulate pedestrian behaviour. According to Helbing & Molnár (1995), the "forces" in the Social Force Model are not actual forces acting on the pedestrians, but instead a measure of the internal motivations that make an individual perform certain actions (e.g. movements). Thereby, the model tries to simulate the erratic behaviour of pedestrians interacting with each other and their surroundings. In Helbing & Molnár (1995) it is stated that the main influences that determine the movements of a pedestrian are; the will to reach a destination as fast and effective as possible, the interaction with other pedestrians and the surrounding environment as well as the possibility to be attracted by other people or objects.

In Figure 4, a conceptual illustration of the Social Force Model can be seen.

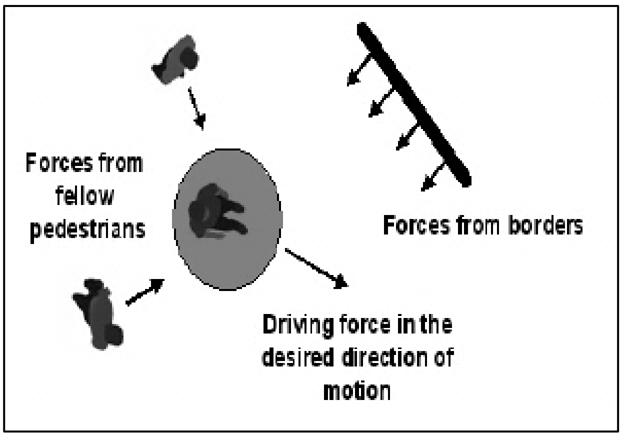

Figure 4 Conceptual illustration of the Social Force Model (Laufer, 2009)

The desire to reach a certain destination as fast and comfortable as possible means that detours are seldom made, instead the shortest possible way is used. If a pedestrian move unhindered, they walk with a desired speed towards the intended destination. However, the act of keeping clear of other pedestrians, objects, obstacles or borders (e.g. walls) often influence the motion and/or speed. Another factor that can affect the movement is the possibility that a pedestrian is attracted by something, e.g. a friend or an object of interest, which alters the originally intended movement. Helbing & Molnár (1995) explain that since all the mentioned effects influence a pedestrian simultaneously, the total influential "force" is the sum of all these effects.

2.3 Previous research using PTV VISSIM

A study by Yu et al (2008) on the 2008 Olympic Games in Beijing used PTV VISSIM to simulate how different traffic operation plans would work in reality. Recommendations were given to optimise these plans as a result of this study. These recommendations were also justified by observing the actual event and drawing the conclusion that the optimised traffic operation plans worked as they were intended. Another part of the study by Yu et al. (2008) was the traffic situation surrounding the area where the Wukesong indoor stadium and adjacent baseball fields were located. This part was focused on the capacity for the car screening stations intended for cars going to the area, set up outside. The conclusion of this part of the study was that some of the stations created a queue which blocked intersections further downstream. Consequently, the car screening stations causing this problem were expanded and moved further from the intersection to alleviate this problem.

Another event studied with PTV VISSIM was the 2012 Olympic Games in London. According to Dosunmu (2012), operational models were created in PTV VISSIM around each competition venue and different scenarios were tested and evaluated. Some of the traffic situation scenarios tested included; traffic during a normal summer month, background traffic together with Olympic Games traffic both with and without traffic management measures in place. It was identified that the interactions between pedestrians and vehicles were problematic at a number of locations. This type of modelling provided an opportunity to identify these problem areas and develop possible improvements.

The Singapore Grand Prix held in 2008 also used PTV VISSIM together with the mesoscopic simulation software PTV VISUM to model the traffic situation around this big Formula 1 event. A model of the network was developed in PTV VISUM by Laufer et al. (2010), which included all the major land uses and junctions in the area together with the significant PT system in Singapore that plays a large part in the transport network. This larger scale model was imported into PTV VISSIM to model the critical parts of the network, such as roundabouts and intersections, on a smaller scale. The calibrated and validated model could then be used to study traffic management solutions, such as signal operations and road closures, for this event.

2.4 Analytical traffic modelling

Allström et al. (2008) explain that analytical methods have traditionally been used to calculate intersection and roundabout capacities. Allström et al. (2008) further state that a large number of analytical traffic models are based on queue-technique models in combination with gap time models. In these models roads are defined as either minor or major depending on the traffic rules at the studied intersection, where a vehicle flow approaching an intersection from a minor road are interpreted as a queue instead of an actual traffic flow. Vehicles leave the queue by either crossing or joining an intersecting major vehicle flow.

At non-signalised intersections the service time (i.e. the time from arrival at the intersection until the opportunity to enter or cross the major flow) are usually determined by the gap time approach, according to Allström et al. (2008). *Gap time* is defined as the time interval between vehicles in the major traffic stream that allows entry for a minor traffic stream vehicle at an intersection or roundabout, according to the Transportation Research Board (2000). The minimum time needed for a minor road vehicle to enter the major road is called the *critical gap time*, which is a parameter of great influence since it determines which gap times are acceptable. The service time depend on the number of gaps in the major traffic stream as well as the critical gap time, according to Statens Vägverk (1981).

Capcal is an analytical and deterministic traffic model software based on calculation methods developed in Sweden during the 1970s, which were presented in the publication TV 131, according to Statens Vägverk (1981). It is further stated that the calculation methods used for non-signalised intersections are based on the previously explained *gap time* approach. A critical gap time is calculated by the program based on parameter definitions in the model, such as vehicle speeds, inclination of minor road way, amount of heavy traffic and geometry of the intersection. The calculated critical gap time enables and influence service time and capacity calculations.

Statens Vägverk (1981) explains that the service time is defined in Capcal as the time a vehicle from a minor traffic stream must wait until a large enough gap appears in the major traffic stream to allow the vehicle to enter it. The service time factor is dependent on the minor and major traffic flow distributions as well as the critical gap time parameter mentioned above. Capcal calculates the capacity for a one way traffic lane as the inverted value of the average service time factor, according to Statens Vägverk (1981). It further explains that Capcal determine average queue length and queuing time, by first calculating the service time distribution and average service time together with the arrival distribution of the minor traffic stream. These parameters are then used together with a queue-model to determine average queue length and queuing time for a minor traffic stream.

2.5 Road network elements

A road network consists of many different elements serving different purposes. In this section the elements relevant for the study conducted in this master thesis (i.e. roundabouts, T-intersections as well as pedestrian and bicycle crossings) are presented along with a short description of their purpose in the traffic network. The described elements can be implemented in the PTV VISSIM software as well as Capcal, but the latter have limited ability to take non-motorised traffic modes into account during calculations, since crossing pedestrian and bicycle flows are only considered for minor traffic streams.

2.5.1 Roundabouts

Elefteriadou (2014) defines a roundabout as traffic circles where the circulating traffic has priority over the traffic about to enter the roundabout. According to Vägverket (2004), roundabouts are designed to reduce the speed of the approaching vehicles without making them stop. The approach angle to the circulating traffic flow allows for vehicles entering the roundabout at a higher speed compared to a four-way intersection. Consequently, the capacity of a roundabout approach would be higher than the comparable right-turn movement in a stop controlled intersection. In addition to this, the delay to the roundabout approach vehicle would be lower than that of a stop-controlled intersection.

The characteristics mentioned above suggest that roundabouts are an important component in an urban transportation system and are effective under a low level of traffic volume, according to Li et al. (2011). Another benefit of using roundabouts, which is illustrated in Figure 5, is that there are less conflict points compared to a typical four way intersection. Roundabouts improve traffic safety according to Bergman et al. (2011). This is due to that the speed of the vehicles entering the roundabout is reduced and eliminates the risk of head-on collision. However, the Federal Highway Administration (2000) states that when a roundabout is at or near its designed capacity, it does not work very efficiently, resulting in queues forming and delay times increasing exponentially.

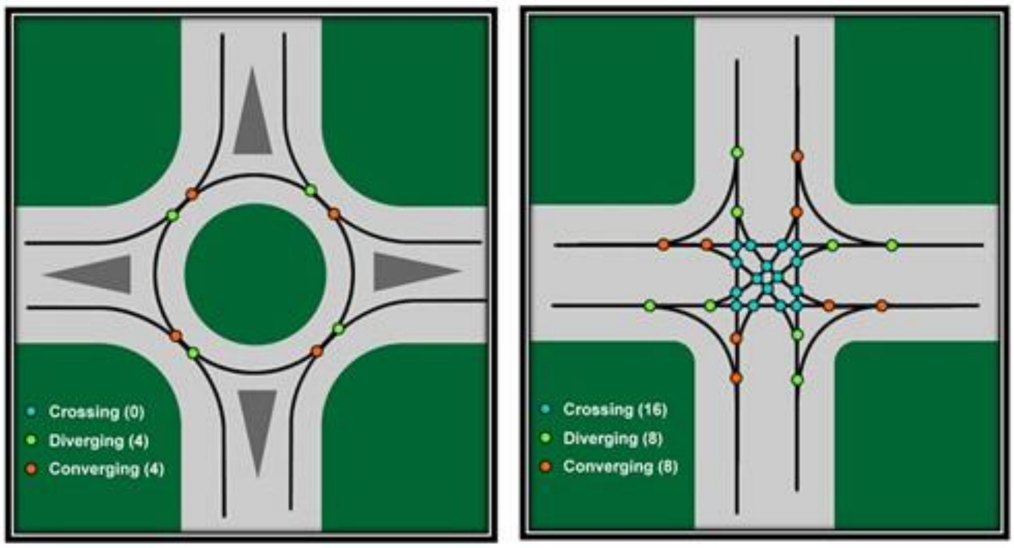

Figure 5 Conflict points in a roundabout compared to an intersection (U.S. Department of Transportation, 2013)

According to Trueblood & Dale (2003), roundabouts are based on the capability of drivers to accept or deny gaps. The critical gap, explained in Section 2.4, is therefore an important parameter when describing vehicle behaviour in roundabouts. Another important parameter to consider in roundabouts and intersections is the follow-up time. It is defined as the time between the departure of one vehicle from a minor street and the departure of next vehicle using the same major-street gap.

2.5.2 T-intersections

T-intersections exist in different executions in the transportation network. According to the classification by Vägverket (2004), the T-intersection on Kristineslättsallén is a *type B* intersection, meaning an intersection with a traffic island. An example of this intersection type can be seen in Figure 6. The purpose of the traffic island on the minor road is to prevent vehicles to make shortcuts when turning left, increase the visibility on the major road from the minor road and to give non-motorised communication means the opportunity to cross the road in two stages. The T-intersection on Skogsvägen is a *type A* intersection, described by Vägverket (2004) as a T-intersection without traffic island.

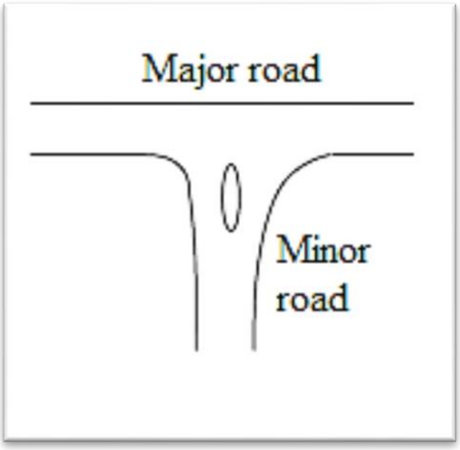

Figure 6 Example of a type B T-intersection (Vägverket, 2004)

The capacity of a priority T-intersection is mainly dependent on three parameters, according to O´Flaherty (1997). These are; the ratio of the flows on the major and minor roads, the critical gap in the main road traffic stream and the maximum acceptable delay to minor road vehicles. As traffic flow increases on the main road, the acceptable gaps becomes less and less. Consequently, the delay for the vehicles on the minor road increases theoretically to infinity.

2.5.3 Pedestrian and bicycle crossings

When placing and designing pedestrian and bicycle crossings, it is, according to Vägverket (2004), important to consider a few aspects. The crossings should be placed to provide the shortest path possible. Furthermore, the crossings should be easy to follow and understand in order to promote safe traffic behaviour. The visibility should be good in all weather conditions including good night visibility. Lastly, the conflict zones between motorized and non-motorized modes of transport should be minimised and clearly visible.

In 1998, Sweden introduced a law forcing vehicles to yield at un-signalised zebra crossings leading to an increase in vehicles giving way to pedestrians and thereby reducing the flow capacity at intersections and roundabouts, according to Bergman et al. (2011). When pedestrians and bicyclists cross the legs of the roundabout, they affect both the entering and exiting flows of the roundabout. Bergman et al. (2011) states that the exiting flow is the most crucial since the exiting vehicles can cause a queue spill-back effect where the vehicles in the roundabout prevent the entering flow, thus blocking the other legs of the roundabout

2.6 Calibration of model

A simulation is a way to perform a sampling experiment on a real dynamic situation through a computer model, according to Barceló (2010). Therefore, the computer model should be as representative to the real system as possible so that it simulates the behaviour of the true system adequately. To establish if the simulation is adequately representative, a validation process is needed where the results from the model is compared to the real situation. Barceló (2010) explain that validation is an iterative process during which parameters that influence the output are methodically altered to find values that produce a valid result that corresponds well with the observations. This process can also be referred to as the calibration of the model. It is important to note that no parameters based on field data should be altered during the calibration process if it is confirmed to be accurate, stated by Elefteriadou (2014).

Elefteriadou (2014) explains that one or more performance measures should be decided. The choice of performance measures depend on what situation the model tries to replicate. These measures are compared to the model result to evaluate its ability to represent the reality. Elefteriadou (2014) further explains that it is nearly impossible to get exact matches on multiple measures because the model is not an exact representation of the real situation. Therefore, the model maker needs to be aware of the assumptions that are made in the simulation to select an appropriate calibration measure that can be used to fulfil the purpose of the simulation.

2.7 Evaluation methods

When evaluating a traffic system the performance measures mentioned in section 2.6 are used. Fellendorf & Vortisch (2010), states that some common measures for evaluation are queues, delays, travel times and stops. An important measure is the travel time, defined as the time it takes to travel from a given origin to a given destination. Mathematically, travel time is calculated as the distance from an origin to a destination, divided by the average speed throughout the trip.

Travel time is for the individual traveller the most relevant criterion for route planning. Furthermore, traffic planners often study the average travel time in a region over a time interval, according to Treiber & Kesting (2013). Travel time can be easily measured by the traveller himself, but for a transportation analyst it is harder to measure a large group of vehicles due to the requirement for identification of individual vehicles and matching these vehicles to an origin and a destination point, according to Elefteriadou (2014). Travel times are easier to quantify in a microscopic traffic simulator where measurements gives the travel times directly for each individual vehicle in terms of the duration of routes, explained by Treiber & Kesting (2013).

The definition of delay, both according to Elefteriadou (2014) and the Transportation Research Board, (2008), is the excess travel time it takes to traverse a particular segment of the road relative to free-flow travel or the speed limit on the actual road segment. Delay are often measured or estimated in units of seconds per vehicle. As with travel time, delay is difficult to measure in the field for the same reasons.

Queue length is another performance measure to evaluate the transport network. It describes the number of vehicles waiting to be served, stated by Elefteriadou (2014). Queue length can have major impacts on the overall performance of the network due to the spill-back effect where, for example, a left turn queue can block through traffic in an intersection.

In order to understand how to calculate capacity in PTV VISSIM, it is necessary to introduce the concepts of *flow* and *volume*. According to Elefteriadou (2014), *flow* is the rate at which vehicles travel through a particular segment of the road often expressed as vehicles per hour. Traffic *volume*, on the other hand, is expressed in units of traffic moving through a road segment during a particular time interval.

In the book written by Elefteriadou, (2014), it is explained that *capacity* and *demand* are two key measures in traffic management which are expressed in vehicles per hour. Both capacity and demand are based on previously mentioned concepts of flow and volume. *Demand* describes the number of vehicles that want to use a traffic facility and during non-congested conditions this is equal to the flow. However, as congestion builds up, the demand arriving to the facility cannot be fully processed and queues form at the location where this bottleneck exists. Elefteriadou (2014), further states that the vehicles able to pass the traffic facility are equal to the *capacity* in this saturated condition. It is a measure of the maximum throughput a traffic facility (e.g. an intersection or highway segment) can handle per hour under a set of predetermined conditions. The definition of capacity according to the Transportation Research Board (2000), is the maximum hourly flow rate at which persons or vehicles can be expected to traverse a point or section of a roadway during a given time period under existing roadway, environmental, traffic and control conditions.

3 Methodology

In order to meet the purpose for this master thesis, seen in Section 1.2, a model of the traffic network around the planned football stadium in Falkenberg is created in the microscopic traffic simulation software PTV VISSIM. The emphasis of this chapter is the description of how a representative microscopic model is constructed in PTV VISSIM, with regards to input parameters and model element descriptions and usage.

Since the arena in Falkenberg does not exist, an event of similar size is selected to be studied to gather information concerning vehicle and pedestrian behaviour and interactions which can be utilised in the model construction. The performed event study is described in the beginning of the chapter, followed by a presentation of the elements used to create a model of the existing traffic network in PTV VISSIM. Simplifications used during creation of the model replicating the traffic network in Falkenberg as well as a detailed description of how the model is constructed and evaluated in this master thesis are then presented. Thereafter, the defined simulation parameters are presented followed by a short description of how the previous Capcal investigation conducted by Kjellson & Salomonsson (2013), was performed.

3.1 Event study at Kinnarps Arena

As mentioned in section 2.6, calibration is an important way to validate if the model is a representative simulation of the real situation. Since the sport centre does not exist at present, the traffic situation in the surrounding network after a high profile event cannot be studied and used for calibration. Therefore, another event with similar properties at a different location has been chosen. Hence, Kinnarps Arena in Jönköping is chosen as the study object. This is due to the similarities in spectator numbers and the surrounding traffic network layout, which allows for interaction between pedestrians and cars in a comparable manner.

The evaluated event was the Swedish Hockey League (SHL) game between HV71 and Örebro Hockey that took place at 19:00 the 6th of March 2014. The game was attended by 6 246 people which is comparable to the maximum attendance of 6 000 at the new football arena in Falkenberg. The aim of the study of this particular event was to obtain a notion of how fast an arena of this size is evacuated and the interaction between pedestrians and cars at a zebra crossing.

The survey was carried out at two locations in the area, marked with white circles in Figure 7.

Figure 7 Overview of study area surrounding Kinnarps Arena (Google)

At location A, which is the exit of the arena, a timer was started when people began to leave the arena. In addition to this, an estimation of the pedestrian flow intensity (i.e. passing pedestrian per time unit) in different time intervals was carried out. Due to difficulties in establishing the specific intensities, the intensities were approximated according to a scale from 1 to 5, 5 being the highest and 1 the lowest. At location B, a zebra crossing over a major road, the interaction between pedestrians and vehicles were observed. Specifically, the number of vehicles able to pass through the different pedestrian flow intensities in different time intervals was noted. Due to the same difficulties in establishing the intensities as described above, both vehicle and pedestrian were approximated using a scale from 1 to 5.

The time it took to evacuate the arena, studied at location A, was approximately 11 minutes, with the highest intensities occurring between minute 2 and 6. Furthermore, after the 11 minute mark, only smaller groups of spectators exited the area, why the arena are considered to be evacuated at this time. The protocol used for the evaluation at location B can be seen in Appendix 1. A diagram, presented in Figure 8, summarise the results from this location showing passing vehicles depending on pedestrian and vehicle density at the zebra crossing. It is evident that an increased density of pedestrians results in fewer vehicles able to pass the crossing. The amount of vehicles, which are allowed to pass at different vehicle and pedestrian densities, will be used as a guideline when modelling the interaction between pedestrians and vehicles at the zebra crossings in the model.

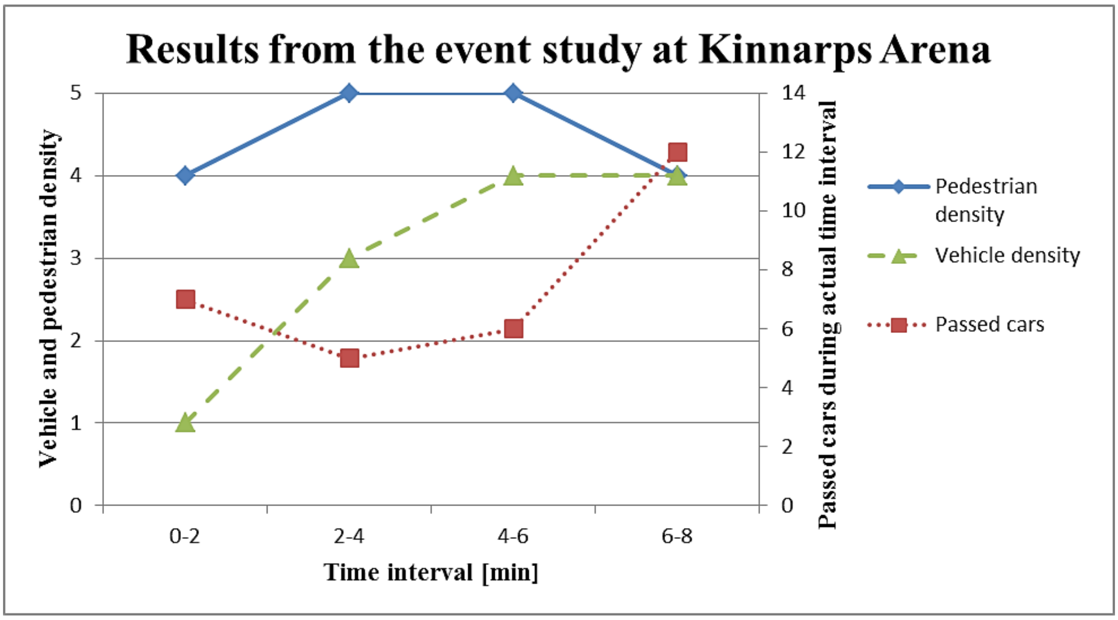

Figure 8 Chart of passing vehicles at different pedestrian and vehicle densities

Another conclusion drawn from the diagram in Figure 8 is that the distribution of pedestrian density is not constant, but rather increases the first four minutes, only to decline again after six minutes. Furthermore, the arriving vehicles are observed to follow a similar distribution, but with a small time lag compared to the pedestrians. Due to the similarities in spectator numbers at Kinnarps Arena and the planned football stadium in Falkenberg, it is assumed that the evacuation procedure of the two arenas will be similar in both time as well as pedestrian and vehicle flows. Therefore, the results from the study at Kinnarps Arena are used for calibration when constructing the model around the planned arena in this master thesis.

3.2 VISSIM Elements

PTV VISSIM provides tools to create a representative model of a traffic network. In this section, the tools used to construct the model of the traffic situation surrounding the planned football stadium will be described. The first tools to be presented are links and connectors, followed by modelling of pedestrian areas, which enables vehicle and pedestrian movements in the model. Thereafter, priority rules in non-signalised intersections, speed control measures, vehicle and pedestrian inputs, route definition and creation of PT lines are described. These tools regulate and define the traffic flow of pedestrians and vehicles. Finally, evaluation measures are presented which are used to collect simulation data.

3.2.1 Links and Connectors

A road network is described in PTV VISSIM by using *links* and *connectors* according to PTV (2013). It is further explained that a link is a representation of a road and can therefore have one or multiple lanes, depending on the studied situation, as well as a direction of movement which vehicles will follow during simulation. All links are independent of each other, why a vehicle will follow a link from start to finish, even though other links crosses the first. To connect links and make it possible for vehicles to travel from one link to another (e.g. to simulate turning motions in intersections or roundabouts) connectors are used to enable a representative depiction of a real traffic situation. Links (blue) and connectors (purple) can be seen with wireframe mode activated showing the centre line in Figure 9a and without wireframe in Figure 9 b.

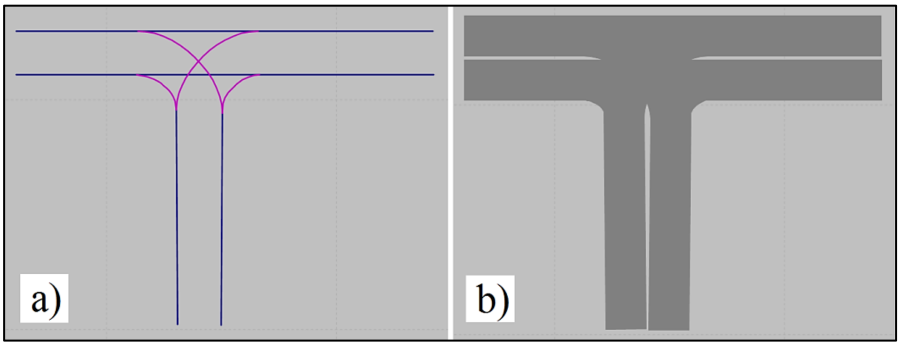

Figure 9 a) Links (blue) and Connectors (purple) in wireframe mode, b) Links and connectors without wireframe mode

Both links and connectors can be defined with different attributes to make the simulated traffic network behave as realistic as possible. Behaviour type (i.e. how vehicles can move on a certain link), gradient, width and number of lanes are some of the attributes that can be specified for links, stated by Trueblood & Dale (2003). Attributes that can be specified for connectors are gradients as well as emergency stop and lane change distances. PTV (2013) explain that the emergency stop distance determine the minimum distance before an upcoming connector located in an adjacent lane, where a vehicle needs to make a lane change to be able to enter the connector. Furthermore, the lane change distance is described as the upstream distance from a connector in an adjacent lane where a driver begins to try to change lane in order to enter the connector.

3.2.2 Pedestrian areas

Since motorised vehicles have a dominant longitudinal movement the use of links, which has a predefined direction, is appropriate. However, the movements of pedestrians are not as clear since they have the possibility to move sideways without moving longitudinally, as mentioned in Section 2.2. Therefore it is, according to Fellendorf & Vortisch (2010), important to use another element to simulate this. In PTV VISSIM, *areas* which have no predefined direction, rather than links are used to model pedestrian motion since this allows for a free movement which better represents reality.

A number of attributes can be assigned to each pedestrian area created in PTV VISSIM. These include the possibility to define thickness and height, visual appearance, pedestrian behaviour and whether it is used as a PT platform.

3.2.3 Priority in non-signalised intersections

According to PTV (2011), VISSIM uses two basic principles, *priority rules* and *conflict areas*, when dealing with the movement conflict between modes of transport at non-signalised intersections (e.g. roundabouts and T-intersections). Generally, it is recommended that conflict areas are used for modelling such intersections, stated by the Oregon Department of Transportation (2011). However, if the model does not return expected results in the interaction between modes of transport, priority rules can be used.

An example of a non-signalised merging area, modelled with the priority rule principle, is shown in Figure 10. Priority rules do, according to Fellendorf & Vortisch (2010), consist of one *stop line* and one or more *conflict markers* associated with the stop line. At the stop line the car travelling on the minor road (yellow vehicle) observes if there are any vehicles in the headway area, described in Section 2.1. Additionally, the yellow vehicle perceives if there are any vehicles within the critical gap time, explained in Section 2.4, and acts accordingly if it has to let this vehicle pass before merging into the major road.

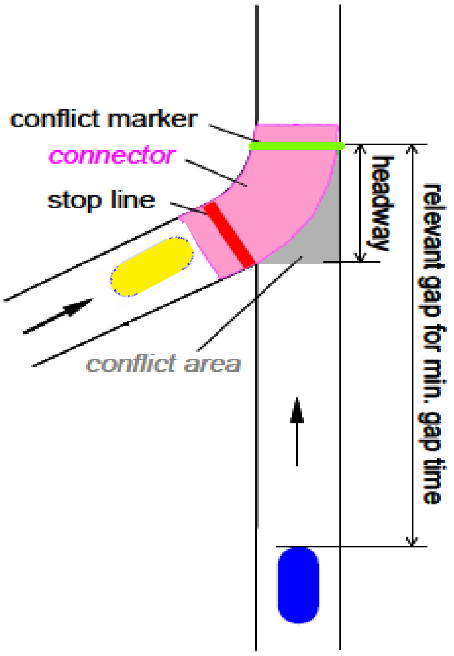

Figure 10 Priority rules in PTV VISSIM (PTV, 2011)

A conflict area can, in PTV VISSIM, be defined wherever two links or connectors in the network intersect explained by PTV (2011). In each such area, it can be specified which of the conflicting links has the right of way. In these conflict areas, drivers and pedestrians are forced to plan how to cross the area. The yielding driver observes the approaching vehicles/pedestrians in the main stream and decides which gap is the optimal one. Consequently, an acceleration profile is setup for the following seconds that will allow the vehicle to cross the area. Vehicles in the main stream will also react on the conflict area, explained by Fellendorf & Vortisch (2010). If the vehicle crossing the conflict area over anticipated its acceleration profile, the vehicle on the main road reacts by either braking or even come to a full stop.

PTV (2011), describe four different conflict area setups of intersections, which can be seen in Figure 11. The leftmost intersection, intersection A, is setup so that no vehicle has right of way before another. This is not very realistic since this allows for cars crashing into each other because of the no-yield setup. Intersection B however is arranged so the vehicles travelling in the north-south direction has priority before the vehicles travelling in the east-west direction and vice versa in intersection C. This is more realistic since in a real traffic situation one traffic direction usually has priority over the other. In intersection D all vehicles yield to approaching traffic, no direction has right of way.

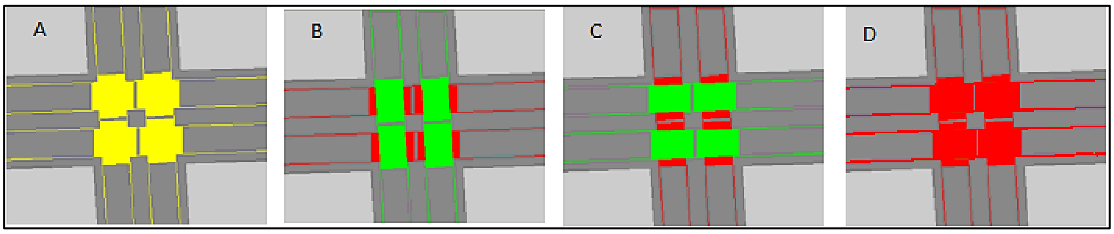

Figure 11 Conflict areas in PTV VISSIM (PTV, 2011)

The vehicle behaviour at a conflict area is influenced by a number of attributes, according to PTV (2013). These attributes have default values when a conflict area is activated, but these can be changed in order to replicate the behaviour at a specific location. PTV 2013, further explains that the *front gap* parameter describe the minimum gap time for a minor road vehicle to enter an empty conflict area after a major road vehicle has left the area, both in merging and crossings conflicts. The default value for this parameter is 0.5 seconds. The *rear gap* parameter influence the minimum time gap for minor road vehicles crossing a major road and is defined as the elapsed time from when the minor road vehicle exits a conflict area until a major road vehicle enters the same and the default value is 0.7 seconds. In Figure 12, illustrations of front and rear gap parameters can be seen.

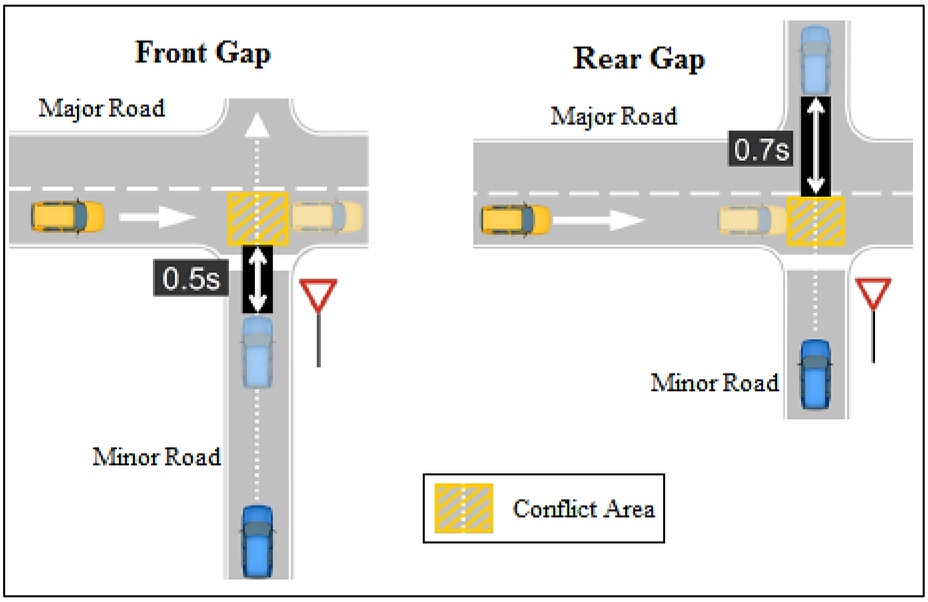

Figure 12 Illustration of front gap and rear gap parameters, (PTV, 2013)

The *safety distance factor* is described in PTV (2013), as a multiplier for the minimum desired safety distance to another vehicle. The factor influence the accepted safety distance between vehicles during merging. As default, this parameter is set to

0.5. Smaller values allows for a larger number of vehicles to merge during a time interval as the acceptable safety distance is lowered, thus enhancing the vehicle flow through the conflict area. Another attribute is the *anticipated routes* parameter, which influences the ability for minor road vehicles that approach a conflict area to anticipate the actions of approaching main road users (e.g. anticipate if an approaching major road vehicle will enter the conflict area or not), according to PTV (2013). Through this parameter the percentage of minor road vehicles that can anticipate the behaviour of major road vehicle can be defined. The default value is that no vehicle can anticipate the actions of major road vehicles.

3.2.4 Speed control

According to PTV (2013), there are two ways to reduce the vehicle speed on the modelled network, these are *reduced speed areas* and *desired speed decisions*. Each of the ways of modelling speed changes is preferable in different situations.

Reduced speed areas are often used as a temporary speed change on a limited section of the road. Trueblood & Dale, (2003) states that a vehicle approaching a reduced speed area automatically decelerates before it enter to ensure that the specified speed is reached. When the vehicle leaves the area, it once again accelerates to reach its desired speed on the road stretch. According to PTV (2013), reduced speed areas are primarily used for modelling slower movement in curves and therefore often used on connectors between two links. Furthermore, different vehicle classes (e.g. cars and buses) can be allocated different speeds in the reduced speed area. This is helpful when simulating the need for speed reduction, primarily for the heavier vehicles classes, due to limited capabilities of making sharp turns.

Desired speed decisions are used to simulate a permanent change in speeds (e.g. traffic signs on road segments with limited speed). PTV (2013) explains that a vehicle approaching a desired speed decision only reduces its speed once it reaches the starting point, after this point the vehicle starts to decelerate. Similarly as the reduced speed areas, different vehicle classes can be assigned different desired speeds.

3.2.5 Vehicles and pedestrian inputs

PTV (2013) explains that vehicles and pedestrians are introduced into a traffic model in PTV VISSIM through vehicle and pedestrian inputs. Vehicle input points can only be placed on links as opposed to pedestrian inputs which can be applied at any position on a pedestrian area designated to be a starting point. The input points can be inserted at multiple points in the model, allowing traffic and pedestrian flows to enter at different locations.

Variable traffic and pedestrian volumes can be defined in PTV VISSIM according to PTV (2013). The volumes are defined as vehicles/pedestrians per hour even if the simulation runs for another duration of time. To simulate a possible change in traffic and pedestrian volumes during a simulation run, time interval segments can be defined within the total runtime. Within separate segments specific vehicle/pedestrian volumes can be defined, enabling modelling of varying traffic volumes during the simulation. The vehicle/pedestrian volumes defined within a specific time period must be recalculated into volume per hour to ensure that the desired number of vehicles/pedestrians enter the model during a specific time segment. PTV (2013) explains that stochastic or exact volume types can be defined, where the first type allows for stochastic fluctuation of the traffic volumes (i.e. the numbers of vehicles/pedestrian that enters the model may differ from the defined volume) and the second type only allows the specified volume to be generated.

3.2.6 Routes

When simulating the behaviour of vehicle flows in different directions there are, according to PTV (2013), a tool in PTV VISSIM where static routes are used. These routes start at a *routing decision* and ends as a *destination point*. Each routing decision can have several destinations and each destination is assigned a fraction of the vehicle flow travelling along it. Seen to the left in Figure 13, a decision point (purple line) is connected with two destinations points (turquoise lines) through routes (yellow areas). The routing decision can also be configured to affect different vehicle types in order to simulate vehicle specific routes such as bus lanes. Routes may have any length, thus making it possible to represent a variety of situations from a single turning movement at an intersection to complex routing choices stretching over multiple directional changes.

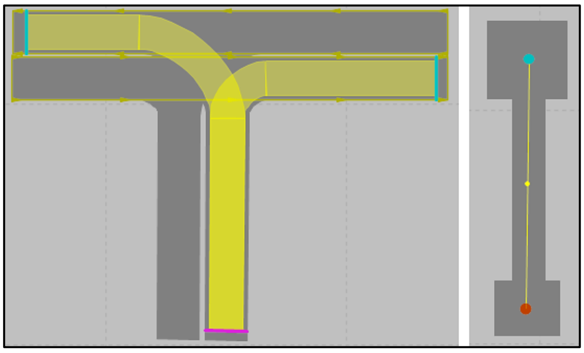

Figure 13 Vehicle (left) and Pedestrian (right) Routes

According to PTV (2013), pedestrian routing can be modelled using a similar way as vehicle routing decisions. Pedestrian routing decision starts with a decision point at a defined pedestrian area, which is connected to destination areas via pedestrian routes. Depending on the simulated situation, routes make it possible to replicate different destinations throughout a modelled network. In Figure 13, a decision point (red) is linked to a destination point (turquoise) through a pedestrian route (yellow line). Pedestrian flows can be manoeuvred by inserting intermediate points along a pedestrian route. Pedestrians following a specific route must pass the pedestrian areas that contain intermediate points connected to the route on their way to the destination point, thus making it possible to direct pedestrian flows. The difference between vehicle and pedestrian routing is that pedestrians do not follow predefined links but rather travel over areas, thereby finding the shortest way through the network.

3.2.7 Public Transport

According to PTV (2013), the modelling of PT in PTV VISSIM is done in four stages; setup of the stops, assignment of lines, setting up a timetable and defining the vehicles operating on the line.

In PTV VISSIM, public transport stops can be located according to two principles. Fellendorf & Vortisch (2010), states that buses may either stop at curb-side stops on the lane itself or as a lay-by stop parallel to the road. PTV (2013) explains that when using the lay-by stop, a separate bay where the PT vehicle can stop allowing vehicles traveling behind to pass, is created next to the road. When the PT vehicle has finished loading and unloading, it will exit the lay-by stop with the right of way over vehicles travelling on the road. In order to let the passengers board and alight the vehicle, a platform edge must be created next to the stop. Furthermore, to allow for pedestrians to board and alight from the vehicle, the length of the stop and platform edge should be greater than the longest public transport vehicle. To visualise pedestrians waiting for the bus, a waiting area has to be created next to the platform, otherwise the pedestrians disappear once they reach the platform edge.

PTV (2013) explains that the principle of routes is used to define PT systems. However in contrast to vehicle and pedestrian routes explained in section 3.2.6, PT routing defines the path of a specific PT line as well as generating the flow of PT vehicles. The flow is created by defining the interval between PT vehicles entering the network, thus enabling a recreation of actual time-tables.

In order to replicate the actual PT vehicle fleet, several options are available in PTV VISSIM to customise the setup of the fleet used on PT lines. According to PTV 2013, such options include the possibility to change occupancy and vehicle characteristics such as acceleration, desired speed and deceleration. These options allow a more realistic interpretation of reality in order to simulate PT systems in a representative way.

3.2.8 Evaluation tools

A number of evaluation tools can be used in PTV VISSIM and these are presented in detail, with descriptions obtained from PTV (2013) and PTV (2011), in this section. However, before any data collection can begin, some areas or points where the measurements will take place must be defined. Which parameters are measured can be specified at these points or areas. Furthermore, data can be presented as lists or databases as well as text files which can be imported to a spreadsheet program.

Nodes are a way of collecting data for a user-defined area in the road network. A node evaluation is intended to gather data specifically for intersections without having to manually specify all the data collection points in the cross-sections. See Table 1 for details of parameters which can be evaluated using nodes. All output parameters given in a node evaluation is presented according to the specific route of vehicles inside the node (e.g. from link A to link B).

Table 1 Node evaluation parameters

Parameter	**Definition**	**Unit**
Average queue length	An average of all the queue lengths on the specific movement	[m]
Delay time	(Actual travel time) – (optimal travel time when travelling at the desired speed)	[s]
Max queue length	The maximum length of the queue at any time during the simulation	[m]
Stopped delay	Average time spent at a standstill per vehicle	[s]
Stops	Average number of stops per vehicle	[stops]

Another way of defining measurement is the *data collection points*. Instead of using nodes which evaluates entire intersections, data collection points can be used to monitor specific locations in the network. In Table 2 a summary of parameters, which can be extracted from data collection points, is presented.

Table 2 Data collection parameters

Parameter	**Definition**	**Unit**
Vehicles	Number of vehicles that pass the collection point during one simulation	[veh]
Acceleration	Average acceleration of vehicles when the collection point is passed	[m/s^2]
Speed	Average speed of vehicles when the collection point is passed	[km/h]
Queue delay	Average time vehicles has spent in a congested state	[s]

The *vehicle travel time* tool can be used to measure total travel times for vehicles from one specific location in the traffic network to another. In addition to the vehicle travel time tool, a similar tool for measuring pedestrian travel times can be used. The procedure for collecting data for pedestrian travel times is similar to vehicle travel time in such a way that a starting point and an ending point have to be defined. The travel time is presented in seconds.

In order to measure queues in the network, *queue counters* can be set up at any point in the VISSIM network. Queues are measured from the position of the queue counter up to the last vehicle that enters the queue state. A vehicle enters the queue state if its travelling velocity is less than 5 km/h and remains in this state until the velocity surpasses 10 km/h. If queues have several ends, the queue counter only takes the longest one into account when calculating maximum length and average length. The parameters, presented in Table 3, are the possible outputs which can be evaluated using queue counters.

Table 3 Queue counter parameters

Parameter	**Definition**	**Unit**
Queue length	Average queue length upstream from the queue counter	[m]
Maximum queue length	Maximum length of the queue at any point of time in the simulation	[m]
Queue stops	Number of stops a vehicle does in a queue (i.e. number of times that a vehicle enters the “queue state” specific speed)	[stops]

In addition to defining which collection points and areas should be used for measurements, there is also the option in PTV VISSIM to evaluate individual links. This allows for, instead of measuring the individual vehicles, gathering of the simulation results based on the links without requiring pre-definition of the measurement area. The possible output from link measurements is presented in Table 4.

Table 4 Link measurement output

Parameter	**Definition**	**Unit**
Volume	Number of vehicles per hour travelling on the link	[veh/h]
Density	Number of vehicles per kilometre of road	[veh/km]
Speed	Average speed on the road link	[km/h]
Loss of time (relative)	The proportion of the average delay of vehicles on the segment relative the total travel time on the segment	[-]

PTV VISSIM also allows for an evaluation of the entire network according to several parameters that are aggregated for the whole simulation run. This evaluation tool takes into consideration both the vehicles which have already left the network and the vehicles still remaining in the network at the end of the simulation interval. In Table 5, the parameters possible to gather from the network evaluation, is presented.

Table 5 Network evaluation parameters

Parameter	**Definition**	**Unit**
Vehicles	Total number of vehicles which can be presented in terms of sums in the network at the end of the simulation, arrived vehicles and vehicles that were not able to enter the network	[veh]
Speed (average)	Average speed of all vehicles in the network	[km/h]
Stops	Number of stops that vehicles make on the network.	[stops]
Demand (latent)	Number of vehicles that could not enter the network before the simulation ended	[veh]
Travel time (total)	The total travel time of all the vehicles that are in or have left the network	[h]
Delay	The delay of vehicles that are in the network or have left it.	[s]
Delay stopped	Delay time due to standstill.	[h]
Distance	The total distance travelled of all vehicles that are in or have left the network	[km]

3.3 Simplifications

A model is only a representation of the real scenario which it is set up to study. It is impossible to create a completely accurate representation of reality, because of existing uncertainties and the amount of information needed to duplicate a real situation. Hence, simplifications are needed to be able to create a representative model of a studied situation. In this section, simplifications carried out during the creation of the traffic model will be described.

3.3.1 Vehicle and pedestrian definition

The true traffic and pedestrian compositions in a traffic situation can never be fully replicated in a simulation. PTV (2013) explain that the PTV VISSIM software provide the option to create vehicle and pedestrian compositions, so that the real scenario can be emulated as accurate as possible. The accuracy in the created composition influences the models ability to replicate the studied situation.

PTV VISSIM divides vehicles into types, classes and categories, according to PTV (2013), in order to create a representative vehicle composition, where:

- *Type*: is a group of vehicles that have similar technical properties and driving behaviour (e.g. cars, bicyclists, buses etc.).
- *Class*: is one or more vehicle types that share similar speed and general driving behaviour, but have differences in vehicle characteristics. The vehicle classes can be used to control where different types of vehicles can or cannot drive in the modelled traffic network.
- *Categories*: Pre-set, static categorisations of vehicles that have similar vehicle interactions.

For the same reason as for the vehicles, pedestrians are divided into types and classes, where:

- *Type*: is a group of people with similar physical properties and walking behaviour (e.g. man, woman, child etc.).
- *Class*: is used to group one or more pedestrian types together. A pedestrian type can belong to multiple classes or none at all. Colours can be defined to the classes which make it possible to identify a pedestrian class during simulation.

PTV (2013) explain that a new vehicle/pedestrian *composition* is defined by selecting which specific vehicle/pedestrian types will be included, what desired speed they have and how the different types will be distributed in the composition. Figure 14 show the vehicle and pedestrian compositions used during this master thesis. Two vehicle compositions are defined; background traffic and parking lot traffic. The difference between the two is that the background traffic consists of 0.1 percent HGV:s and 99.9 percent cars, whereas the parking lot traffic entirely comprises of cars. Two pedestrian compositions are also defined, one being the pedestrians in the model and the other representing bicycles. It is estimated that more men than women attend a high profile sports event, why a distribution of 80 percent men and 20 percent women are used during simulation.

Count: 2	No	Name	Count: 3	VehType	DesSpeedDistr	RelFlow
1	1	Background traffic	1	100: Car	50: 50 km/h	0.999
			2	200: HGV	50: 50 km/h	0.001
2	2	Parking lot traffic	3	100: Car	50: 50 km/h	1.000

Count: 2	No	Name	Count: 3	PedType	DesSpeedDistr	RelFlow
1	1	Pedestrians	1	100: Man	1002:IMO-F 3	80.000
			2	200: Wo	1002:IMO-F 3	20.000
2	2	Bikes	3	300: Bike	1008: Bicycle	1.000

Figure 14 Vehicle and pedestrian composition

3.3.2 Geometry

The geometry of the modelled area is carried out in a manner that tries to be as accurate as possible. However, some simplifications have to be done due to limitations in the software. According to Kjellson & Salomonsson (2013), two major parking lots are planned in the vicinity of the planned football stadium, one to the west of the arena housing 420 cars and the other to the east housing approximately 200 cars. Furthermore, another 580 vehicles need to park in the area surrounding the sport centre. PTV VISSIM provides tools to incorporate on-street parking into a simulation as explained by PTV (2013). The parking mentioned above are not on-street parking however, why the provided tools cannot be used. Therefore, another method must be applied to model the traffic flow from these areas.

Since the finished model will simulate the traffic situation after an event, instead of simulating vehicle behaviour on the parking lots, vehicles are modelled to appear at the car-park exits after a specified time delay. PTV VISSIM requires vehicles to be present in the model (i.e. a vehicle has entered the model boundaries) to be able to collect some specific data, such as vehicle travel time, according to PTV (2011). However, data is also collected for generated vehicles outside the modelled network, still waiting to pass the model boundaries. This data, the so called *latent delay*, summarise the time vehicle spend waiting to enter the model. By modelling the parking lots as exits and thereafter generating the exiting vehicles during a short time period, vehicles outside the model boundaries have to wait their turn to enter. Hence, latent delay can be used as a measure to evaluate the amount of time spent at the parking lots. To ensure that only parking lot vehicles contribute to the latent delay factor, road segments representing the major roads (i.e. roads not representing parking lot exits) must be made long enough to allow vehicles generated on these segments to enter the model without delay, even if queues are formed in the network during the simulation run.

Another simplification needed is to modify the areas which pedestrians and bicyclists use in the model. These shared-use footpaths are constructed on top of a map illustrating the planned sport centre which is inserted and scaled in PTV VISSIM. However, when saturating the footpaths with pedestrians and bicyclists, some unrealistic bottlenecks are created in the system. These bottlenecks occur, for example, when pedestrians and bicyclists have to turn sharp corners or are forced to walk through narrow passages as both pedestrians and bicycles strive to travel the shortest path possible, thereby competing for the same space and blocking each other, stated by Kretz et al. (2011). It is further explained that an alternative to the *shortest path* method to describe pedestrian motion is the *quickest path* method, where each pedestrian evaluate the least time consuming path (not always the shortest) continuously according to a specified time interval. This method demands more computational power and due to limitations in available computer power and the complexity of the modelled network, this method is not feasible and the shortest path method is used. Therefore, to simulate a more realistic flow of pedestrians and bicycle traffic, sharp corners in the footpath geometry are smoothed out and at bottlenecks (e.g. zebra crossings) the footpath is broadened in order to alleviate this problem and get a more realistic flow. So instead of being an accurate representation of the footpaths around the stadium, the emphasis of the models is to represent the flow of people in a realistic manner.

3.3.3 Bicycles

In order to simulate the interaction between pedestrians and bicyclists on the shared-use footways, a new pedestrian class acting as bicycles is created. This allows for the bikes to travel on the same areas as the pedestrians. To obtain a more realistic behaviour of the bicycles in a congested state, occurring when a lot of pedestrians move in a narrow area, the desired speed is reduced. This speed reduction represents the lower travel speed possible for a bicyclist when a lot of pedestrians have to yield to a bicycle approaching from behind, as well as adapting its speed to the surrounding crowd.

3.4 Model construction and data input

A good and representative model of a studied traffic situation is needed in order for the results gained from a simulation to be relevant. In this section, the procedure used when creating the model representing the traffic situation surrounding the planned football stadium in Falkenberg is presented. Both the actual model construction, using the elements described in Section 3.2, as well as the definition of input parameters will be described. According to PTV (2011), a range of these input parameters can be defined as distributions instead of static values in PTV VISSIM, which makes it possible to simulate stochastic traffic behaviour. Elefteriadou (2014) states that a strength with stochastic microscopic traffic simulators, such as PTV VISSIM, is this ability to simulate a range of vehicle types and driver behaviour, which is needed to represent the variability that is present in the real traffic stream.

In the document released by Falkenbergs kommun (2012), an estimation of the distribution of different communication means is presented, which is based on an evaluation tool developed by the Swedish Transport Administration. The estimation suggests that 40 percent of the people at a high profile event (i.e. an event with 6 000 spectators) travel by car, 30 percent on foot, 24 percent by bicycle and 2 percent by PT. Traffic volumes normally occurring in the traffic system at the time when a high profile ends, seen as the *background traffic*, is presented by Kjellson & Salomonsson (2013). The volumes are based on a traffic measurement conducted in 2010 by Falkenberg municipality and the estimation that 6 percent of the AADT move through the traffic network during the first hour after an event finishes. The communication mode distribution and the background traffic volumes are used to define the pedestrian and vehicle input volumes described in this section.

3.4.1 Network geometry

The first step during the construction of the model is to insert a background image, illustrating the planned football stadium and its surroundings, and scale it in PTV VISSIM. Using the illustration as a guide, the road network in the area is created with the use of links and connectors. Link elements are used to represent individual traffic lanes with a specified direction of movement, why two links with opposite directions of motion are needed to represent a two way road. Connectors are used to allow vehicles to travel between the links (e.g. to simulate turning motions). Hence, connectors are used at the different intersections and the roundabout to enable the modelled road users to move realistically through the road network. At the southern approach to the T-intersection on Kristineslättsallén, separate lanes are defined for west and east turning vehicles to represent the possibility to simultaneous turn in each direction.

Secondly, pedestrian areas are used to create the sections of the model where people and bicycles travel during a simulation. These areas include the shared-use footways, the pedestrian crossings and the PT stops as well as the plaza in front of the stadium from where spectators can enter and exit the arena. In order to cover all the essential areas where pedestrians and bicyclists travel and interact with vehicles, multiple area-segments are created and connected. Thereby forming a network of shared-use footways around the stadium where pedestrians and bicycles can move freely. An overview of the completed network geometry, containing roads (dark grey) and shared used footway areas (light grey), can be seen in Figure 15.

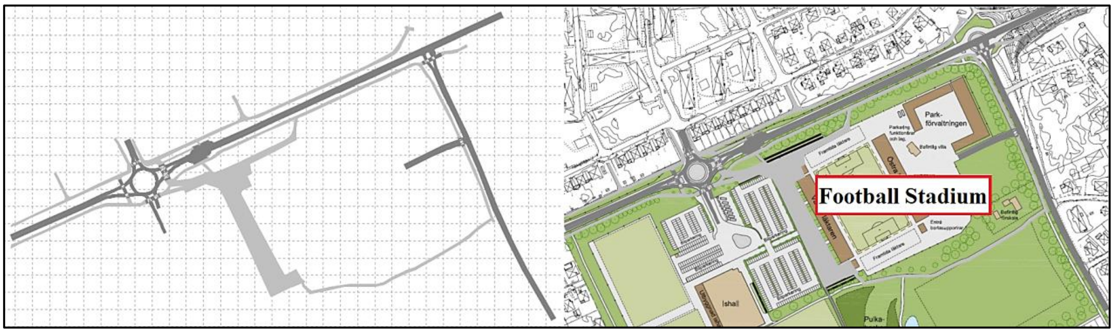

Figure 15 Overview of network geometry without and with background image

3.4.2 Priority in non-signalised intersections

Pedestrian and vehicle interactions are a crucial part of the model, which are controlled by the use of priority rules at the interaction points. In Section 3.2.3, two different setups of priorities in non-signalised intersections are presented, conflict areas and priority rules. In the model constructed in this master thesis, both these setups are used at different locations in the traffic network. At the two T-intersections east of the arena and at the roundabout, conflict areas are used to model priority amongst vehicles. Priority rules, on the other hand, are used to simulate priority between vehicles and pedestrians at the zebra crossings surrounding the T-intersections and the roundabout.

The conflict areas are setup different from each other depending on traffic regulations at the specific intersection. At the roundabout, conflict areas are configured in accordance to current Swedish traffic regulation where vehicles about to enter the roundabout must give way to vehicles which are already in the roundabout Swedish Transport Agency (2013). At the T-intersection between Kristineslättsallén and Skogsvägen, the priority is defined so that vehicles travelling on Kristineslättsallén have priority over all other vehicles since this is an arterial road. At the T-intersection between Skogsvägen and the East parking lot exit, the traffic flow on Skogsvägen has priority over vehicles exiting the parking lot due to the traffic regulation that cars exiting a parking lot have to yield to vehicles travelling on the main road. Furthermore, in the cases of crossing paths at these intersections, the right-hand rule is applied to determine which car has priority over the other. In Figure 16 the different conflict area setups for the three non-signalised intersections can be observed.

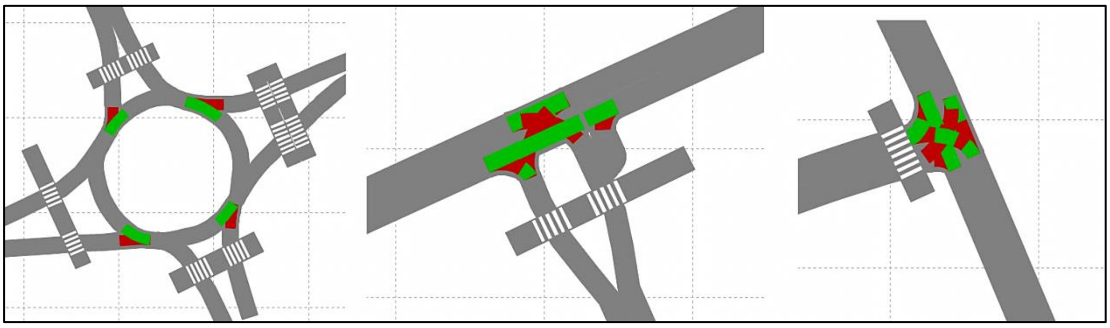

Figure 16 Conflict areas applied in the model at three different locations

The options available in PTV VISSIM to configure each conflict area are presented in Section 3.2.3. In order to simulate more aggressive driving behaviour in the roundabout, which occurs when congestion builds up, some default parameters were changed. One of the changed parameters is the *safety distance factor* which was halved from 1.0 to 0.5. This factor was even further reduced to 0.2 at the conflict area at southern entrance to the roundabout. This in order to enable more vehicles to enter the roundabout from this exit than observed during calibration runs of the model. Moreover, the parameter *anticipate route* is increased from 0 to 0.8 which means that 80 percent of the drivers can anticipate that the vehicles inside the roundabout will exit the roundabout before reaching the conflict area. The reason for increasing this parameter is that a majority of vehicles signal when they exit a roundabout, hence the vehicle entering the roundabout should be able to anticipate this exit and start to enter the roundabout earlier.

As previously mentioned, priority rules are used when the interaction between pedestrian/bicycles and vehicles are simulated. In Section 3.2.3 it is explained that priority rules are comprised of a stop line connected to one or more conflict markers. These conflict markers influence the flow of vehicles passing the stop line through the defined headway and gap time parameters. All stop lines are placed on links representing road segments with a connected conflict marker on the crossing pedestrian area. The headway and gap time parameters are adjusted to replicate the vehicle flow observed outside Kinnarps Arena during the event study, described in Section 3.1. During the study it was observed that vehicles have a tendency to slowly inch forward through high pedestrian flows, why vehicles passed the zebra-crossing even during times with high occupancy. As a result, when trying to replicate this behaviour the headway and gap time parameters are assigned low values to enhance the opportunities for vehicles to pass the modelled zebra-crossings. At the pedestrian crossing with the highest pedestrian flow, an additional method is used to promote vehicles to pass. The specific crossing is divided into two parts along its width, each with its own stop line and conflict marker, which enables vehicles to pass in stages. This further increase the opportunities for vehicles to pass as the distance to cross are shortened, thereby reducing the defined headway or gap time areas in which pedestrians can be present.

In total, 13 priority rules are used to model the vehicle and pedestrian/bicycle interactions, which are described in Table 6. They consists of one stop line

(Count: 1-13) and one connected conflict marker (PrioRule: 8-20). The different gap times (MinGapTime) and headways (MinHdwy) used in the simulation are presented in Table 6, where the first parameter is defined in seconds and the second in meters. The parameters differ due to the attempt to replicate the observed vehicle and pedestrian interactions at Kinnarps Arena. At interaction points with higher pedestrian flows lower values are assigned in order to generate an adequate vehicle flow.

Table 6 Priority rule parameters in model

Count: 13	PrioRule	MinGapTime	MinHdwy	Count: 13	PrioRule	MinGapTime	MinHdwy
1	8	2.0	2.0	8	15	1.5	1.5
2	9	2.0	2.0	9	16	1.0	1.0
3	10	2.0	2.0	10	17	1.0	1.0
4	11	1.5	1.5	11	18	1.0	1.0
5	12	1.5	1.5	12	19	1.0	1.0
6	13	1.5	1.5	13	20	1.5	1.5
7	14	1.0	1.0				

When trying to replicate the interactions between vehicles and pedestrians/bicycles based on the observations from the event study the default values have been lowered to the values in Table 6. Consequently, vehicles and pedestrians seem to collide in the model (i.e. be at the same place at the same time), see Figure 17. This is due to the low headway and gap time values together with the setting that only vehicles yield for pedestrians and not vice versa. Vehicles start to move forward as fast as the assigned headway and gap time demands are fulfilled, ignoring pedestrians that move inside the defined areas after the motion is started. Furthermore, pedestrians do not register the presence of vehicles in the model as no priority rules or conflict areas are defined for them, why it is possible for both kinds of road users to collide during simulation. Instead of interpreting these situations as actual collisions, they are viewed in this master thesis as if the pedestrians walk around the vehicle as it moves slowly forwards.

Figure 17 Vehicle and pedestrian virtual collision

3.4.3 Speed control

According to Trueblood & Dale (2003), reduced speed areas is a good tool when modelling roundabouts and turning motions in PTV VISSIM. The reduced speed zones should be placed inside the roundabout as well as at the entry points or shortly thereafter. This enables vehicles to realistically travel with speeds generally observed within roundabouts. Therefore, speed reduction areas are used in the roundabout located on Kristineslättsallén. Figure 18 is a modelled representation of this roundabout. Moreover, speed reduction areas are also implemented in the proximity of all zebra crossings in the model in order to simulate the increased caution which drivers have when passing these road segments. The basic principle for speed reductions used is that inside the roundabout, a 20 km/h limit is applied, while on the approaches to the zebra crossings, a 25 km/h limit is implemented.

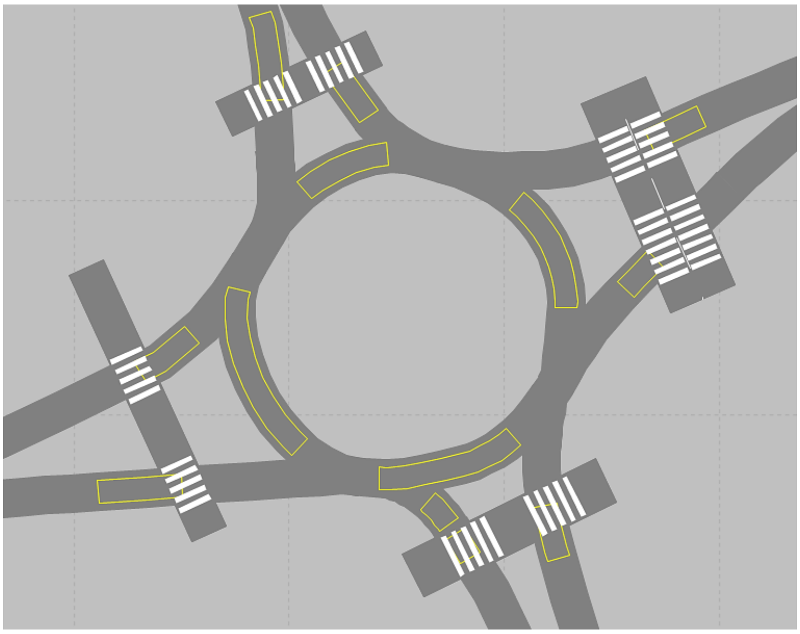

Figure 18 Reduced speed areas in the roundabout located at Kristineslättsallén

When modelling speed limits in the area, desired speed decisions are used at locations where this is applicable. The information regarding speed limits were obtained from the Swedish national road database provided by Trafikverket (2014). A total number of 14 desired speed decisions, presented in Table 7 are spread throughout the traffic network. Furthermore, vehicle class specific speed limits can be specified by changing the value in any of the three rightmost columns which represents cars, HGV:s and buses respectively. Since no such vehicle class specific speed limits exist in the studied area, there are identical inputs in each column.

Table 7 Desired speed decisions in model

Count: 14	Lane	TimeFrom	TimeTo	DesSpeedDistr(10)	DesSpeedDistr(20)	DesSpeedDistr(30)
1	1: Kristineslättsallén Eastbound - 1	0	99999	50: 50 km/h	50: 50 km/h	50: 50 km/h
2	5: Sport Centre West Exit - 1	0	99999	15: 15 km/h	15: 15 km/h	15: 15 km/h
3	2: Kristineslättsallén Westbound - 1	0	99999	60: 60 km/h	60: 60 km/h	60: 60 km/h
4	8: Skogsvägen Southbound - 1	0	99999	30: 30 km/h	30: 30 km/h	30: 30 km/h
5	7: Skogsvägen Northbound - 1	0	99999	30: 30 km/h	30: 30 km/h	30: 30 km/h
6	10: Sport Centre East Exit - 1	0	99999	15: 15 km/h	15: 15 km/h	15: 15 km/h
7	26: Kristineslättsallén Eastbound - 1	0	99999	60: 60 km/h	60: 60 km/h	60: 60 km/h
8	2: Kristineslättsallén Westbound - 1	0	99999	50: 50 km/h	50: 50 km/h	50: 50 km/h
9	3: August Bondesons väg Southbound -	0	99999	50: 50 km/h	50: 50 km/h	50: 50 km/h
10	26: Kristineslättsallén Eastbound - 1	0	99999	50: 50 km/h	50: 50 km/h	50: 50 km/h
11	2: Kristineslättsallén Westbound - 1	0	99999	50: 50 km/h	50: 50 km/h	50: 50 km/h
12	7: Skogsvägen Northbound - 1	0	99999	30: 30 km/h	30: 30 km/h	30: 30 km/h
13	8: Skogsvägen Southbound - 1	0	99999	30: 30 km/h	30: 30 km/h	30: 30 km/h
14	10: Sport Centre East Exit - 1	0	99999	15: 15 km/h	15: 15 km/h	15: 15 km/h

Since only the exits of the parking lots are modelled, stated in Section 3.3.2, desired speed decisions must also be implemented in the beginning of these roads. It is assumed that the vehicles exiting the parking lots have the same speed as the vehicles travelling inside the parking lot. Thus, an approximation of relevant speeds in a parking lot is done with an assumption that cars in parking lots have a slightly higher speed than walking speed. As stated by Bohannon (1997), a normal walking speed is about 5-10 km/h. Consequently, the desired speed limits at the parking lot exits are set to 15 km/h.

3.4.4 Vehicle and pedestrian inputs

Variable traffic and pedestrian volumes can be defined in PTV VISSIM according to PTV (2013). The volumes are defined as vehicles/pedestrians per hour even if the simulation runs for another duration of time or if the simulation is divided into time interval segments. The vehicle/pedestrian volumes defined within a specific time period must be recalculated into volume per hour, according to Equation 1, to ensure that the desired number of vehicles/pedestrians enter the model during a specific time segment.

$$V = \frac{x}{\frac{min}{60}} \qquad (1)$$

where: **V** *is the calculated input volume per hour [pedestrians/h or vehicles/h]*
x *is the desired volume of pedestrians/vehicles in a specific time interval [pedestrians or vehicles]*
min *is the specific time interval [min]*

In Table 8, a summary of the vehicle inputs specified in the model are presented. All vehicle volumes are divided into seven intervals, where the first two spans over 5 minutes (i.e. 300 seconds) each, whereas the remaining five time intervals lasts for 10 minutes (i.e. 600 seconds). The reason for this division is to simulate the distribution of vehicles departing from a sports event which was observed at Kinnarps Arena, see Section 3.1. The two vehicle compositions (i.e. background traffic and parking lot traffic) defined in Section 3.3.1 are specified in the columns VehComp. Furthermore, the traffic originating from the parking lots are delayed 5 and 10 minutes respectively. This is done in order to simulate the additional time it would take for the spectators to travel the distance on foot from the stadium to their car.

As stated in 3.2.5, stochastic or exact volume types can be defined. The background traffic is defined as stochastic, specified in column VolType in Table 8, while the parking lot traffic is defined as exact number of vehicles since the aim for the model is to simulate when the parking lots are filled to a specific capacity. A total number of seven vehicle input points are defined in the model, one at each parking lot exit and at road segments inserting background traffic into the network. All inputs are located on individual links with the exception of August Bondessons väg where two vehicle inputs are inserted. These two represent the exit for vehicles parked in the residential area as well as the background traffic. Vehicle input volume calculations are presented in Appendix 2.

Table 8 Vehicle volume, composition and distribution type used in the model

Count: 7	Name	Volume(0)	Volume(300)	Volume(600)	Volume(1200)	Volume(1800)	Volume(2400)	VehComp(0)	VolType(0)
1	Kristineslättsallén Eastbound	225.0	225.0	225.0	225.0	225.0	225.0	1: Background traffic	Stochastic
2	Kristineslättsallén Westbound	270.0	270.0	270.0	270.0	270.0	270.0	1: Background traffic	Stochastic
3	Skogsvägen Northbound	70.0	70.0	70.0	70.0	70.0	70.0	1: Background traffic	Stochastic
4	August Bondessons väg Southboun	60.0	60.0	60.0	60.0	60.0	60.0	1: Background traffic	Stochastic
5	East Parking Lot	0.0	600.0	600.0	300.0	0.0	0.0	3: Parking lot traffic	Exact
6	West Parking Lot	0.0	600.0	2100.0	120.0	0.0	0.0	3: Parking lot traffic	Exact
7	August Bondesson Parking	0.0	0.0	300.0	1200.0	240.0	0.0	3: Parking lot traffic	Exact

As described in Section 3.3.3, bicycles are modelled as pedestrians. Consequently, pedestrian input refers to both pedestrians and bicycle inputs in this thesis. Similar to the vehicle inputs, pedestrian inputs are also divided into different time intervals. However there are two main differences, the first being a shorter timespan during which the pedestrians and bicycles are inserted in the model. Secondly, finer time segments in the beginning of the simulation, 0 to 2.5 minutes for pedestrian inputs instead of 0 to 5 minutes for vehicles, are used to better represent the characteristics of pedestrian and bicycle flow distributions after an event.

Five pedestrian input points are defined, two for pedestrians located at the north and south stadium exits, and three for bicycles placed by the northern bicycle parking. The bicycle input is divided in three separate points to enhance the movement through the modelled traffic network. The flows of pedestrian and bicycle in this model are based on the flows observed at the event described in Section 3.1 and can be seen in Table 9. In the column labelled PedComp the two different types of pedestrian compositions, bikes and pedestrians, can be observed. The rightmost column named VolType, describes whether the volume distribution is stochastic or exact. Since the studied case has a precise number of spectators attending the event at the stadium, an exact volume distribution is chosen for every pedestrian input in the model. For pedestrian volume calculations, see Appendix 2.

Table 9 Pedestrian volume, composition and distribution type in the model

Count: 5	Area	Volume(0)	Volume(150)	Volume(300)	Volume(600)	Volume(900)	Volume(1200)	PedComp(0)	VolType(0)
1	3: North Exit	1848.0	7368.0	11052.0	2772.0	0.0	0.0	1: Pedestrians	Exact
2	4: South Exit	1848.0	7368.0	11052.0	2772.0	0.0	0.0	1: Pedestrians	Exact
3	18: West Bicycle parking	0.0	1728.0	2880.0	1440.0	576.0	0.0	2: Bikes	Exact
4	5: Middle bicycle parking	0.0	1728.0	2880.0	1440.0	576.0	0.0	2: Bikes	Exact
5	46: East Bicycle parking	0.0	1728.0	2880.0	1440.0	576.0	0.0	2: Bikes	Exact

3.4.5 Routes

Vehicle and pedestrian routes are defined in the model to simulate traffic and pedestrian flows through the network. A traffic volume measurement conducted in 2010 by Falkenberg municipality was used in the traffic investigation made by

Kjellson & Salomonsson (2013). Volumes from this investigation, together with estimations done by Kjellson & Salomonsson, are used to divide background traffic and vehicles leaving the West parking lot and August Bondessons väg into different vehicle routing decisions. In the previous investigation, it is assumed that an equal proportion of exiting vehicles travel east and west along Kristineslättsallén. However, routing decisions made by drivers leaving the East parking lot are estimated in this master thesis and it is assumed that 80 percent of the vehicles turn left at Skogsvägen, since this is the direction towards the major road Kristineslättsallén. Vehicles approaching the T-intersection at the major road are estimated to turn equally in both directions. To simplify the determination of vehicle routing decisions, no routes are directed to the parking lots since the number entering these are considered negligible at the time of the simulation (i.e. after a high profile event). Division into vehicle routing choices, based on above mentioned estimations, are presented in Appendix 3.

The determination of vehicle routing choices results in a total of ten decision points, with 19 separate destination points. All routes are positioned to direct vehicle flows at the two T-intersections at Kristineslättsallén-Skogsvägen and Skogsvägen-eastern parking lot as well as the roundabout. Table 10 present the decision points (i.e. VehRoutDec: 1-10), together with connected destination points (i.e. Count: 1-19) and number of vehicles directed to them during the simulation (i.e. RelFlow).

Table 10 Static Vehicle Routes

Count: 19	VehRoutDec	RelFlow(0)	Count: 19	VehRoutDec	RelFlow(0)
1	1	40.000	11	6	297.000
2	1	160.000	12	7	175.000
3	2	1.000	13	7	175.000
4	3	115.000	14	8	190.000
5	3	115.000	15	8	30.000
6	4	59.000	16	9	200.000
7	4	212.000	17	9	20.000
8	5	11.000	18	9	200.000
9	5	565.000	19	10	1.000
10	6	30.000			

The amount of vehicles travelling via the routes to the different destination points are specified in exact numbers in Table 10, with the exception of destination points 3 and 19. The purpose of these two routes is to prevent vehicles to enter the eastern parking lot during simulation. This is modelled using two routes in opposite directions with a single destination point each, where "RelFlow=1.0" means that 100 percent of the vehicles will follow the routes from decision to destination point, thus preventing entry to the parking lot.

Pedestrian routing decisions are based on estimations by Kjellson & Salomonsson (2013), as well as estimations conducted in this master thesis. Five pedestrian decision points are defined in the model (i.e. one at each pedestrian input point described in Section 3.4.4), where two distributes the pedestrian flows from the stadium exits and three control the bicycle volumes. The two decision points defined at the stadium exits share the same nine destination areas, of which seven are located at the edge of the model and two at the PT stops. The three bicycle inputs have two routing decisions each, adding up to a total of six different bicycle routes. These routes have destination points at the edge of the model, which are shared with pedestrian routes, but not with other bicycle routes. The reason for this is to promote a more effective flow through the model during simulation. The routes with destinations at the edge represent pedestrians and bicyclists with final destinations outside the modelled network.

In total 24 pedestrian and bicycle routes are defined, divided between nine destination areas, to create a plausible movement pattern during a simulation run. Destination points (Count: 1-24), initiating decision points (PedRoutDecSta) and distributed volumes (RelFlow) for the different routes are presented in Table 11, for determination of volumes see Appendix 3. Similarly to the vehicle routes, exact numbers of people using pedestrian routes (Count: 1-18) are specified. Since there is no information concerning bicycle route choices, it is assumed that the bicycle flow is evenly distributed between all bicycle routes (Count: 19-24). This is represented in the model by assigning the same probability for all bicycle routes to be used, why "RelFlow=1.0" is defined for all bicycle routes, which can be seen in Table 11.

Table 11 Static Pedestrian Routes

Count: 24	PedRoutDecSta	RelFlow(0)	Count: 24	PedRoutDecSta	RelFlow(0)
1	1	129.000	13	2	419.000
2	1	129.000	14	2	129.000
3	1	419.000	15	2	129.000
4	1	419.000	16	2	129.000
5	1	129.000	17	2	30.000
6	1	129.000	18	2	30.000
7	1	129.000	19	3	1.000
8	1	30.000	20	3	1.000
9	1	30.000	21	4	1.000
10	2	129.000	22	4	1.000
11	2	129.000	23	5	1.000
12	2	419.000	24	5	1.000

Figure 19 illustrates the defined pedestrian decision points (red points), destination areas (turquoise points), connecting pedestrian and bicycle routes (yellow lines) as well as the intermediate points along the routes (dark blue points).

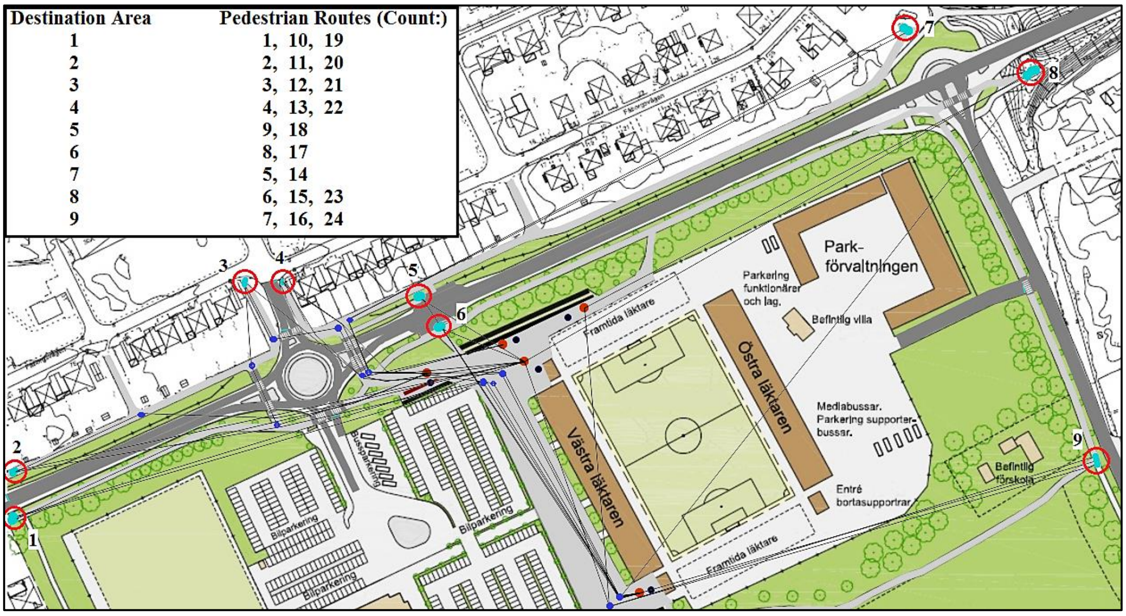

Figure 19 Pedestrian destination areas and connecting routes

To enhance the pedestrian and bicycle flow through the modelled network, intermediate points are used at different routes, illustrated in Figure 19 as dark blue points. Intermediate points help spread the flows in the model, which is important for pedestrians since all individual pedestrians strive to move the shortest distance possible from decision to destination area, mentioned in Section 3.3.2. This increases the efficiency of pedestrian motion through the simulated network, thus creating a more representative movement during simulation.

3.4.6 Public Transport

In the area of interest in this master thesis, there exist, according to Kjellson & Salomonsson (2013), two PT stops on either side of Kristineslättsallén just north of the arena. These are modelled as lay-by stops, because of the layout of the existing bus stops. This allows for vehicles passing the bus when it halts to load and unload passengers.

As stated by Kjellson & Salomonsson (2013), there are three lines that frequent the stops at Kristineslättsallén; bus lines 3, 351 and 517. According to the match schedule for Allsvenskan provided by Svenska fotbollsförbundet (2014), the majority of the games are played at 16:00 on the weekends and 19:00 on weekdays. With the assumption that a football game lasts for two hours, the games will be finished at 18:00 on weekends and 21:00 on weekdays. When studying the timetables for the previously mentioned PT lines, found in Appendix 4, there is on average one bus in each direction serving the bus stops during the first hour after a the game on weekdays. Serving busses are even fewer during weekends, so weekday schedules are used to generate a higher PT frequency. Therefore, one bus in each direction will be incorporated into the model.

As mentioned in Section 3.2.7, PT flows are generated by defining at what time PT vehicles are inserted into the model. Using the timetables in Appendix 4, it is established that the eastbound bus (i.e. the one traveling away from Falkenberg city centre) arrive at 21:08 and the westbound arrive 21:42. Travel time from the network edge, where buses are generated, to the PT stops are approximately 30 seconds for both PT lines. Hence, the defined times for PT vehicle generation during the simulation is set 30 seconds prior to the above mentioned bus arrival times. No pedestrians are modelled to alight the buses during stops and default values for bus capacity (i.e. 999 people per bus) are used as it is estimated that all waiting pedestrians can board the buses, why a more precise capacity definition is unnecessary during this particular simulation.

3.4.7 Evaluation

As stated in Section 3.2.8, there are a number of evaluation tools which can be used to assess the performance of the traffic network. The following section will explain in more detail where these evaluation tools have been placed, what purpose they serve and how they are used to measure the performance of the system.

Variable stochastic distribution of the background traffic generation is used, rendering different results with each simulation run. Therefore, results used for the evaluation are compiled as an average result obtained from 5 simulation runs. Furthermore, two different scenarios of the simulation are used, one with pedestrians and one without. This is done in order to analyse which influence pedestrians have on the performance of the traffic network.

One way of evaluating the intersections and roundabout in the system is to use the *nodes* evaluation tool. Consequently, this tool is used to evaluate the roundabout and the T-intersection on Kristineslättsallén as well as the T-intersection on Skogsvägen. All these node locations can be noticed in Figure 20 where they are used to gather intersection specific data in order to study the isolated intersections. The node data is collected in 2.5 minutes (i.e. 150 seconds) time intervals in order to study the number of vehicles able to pass each approach during different periods of the simulation.

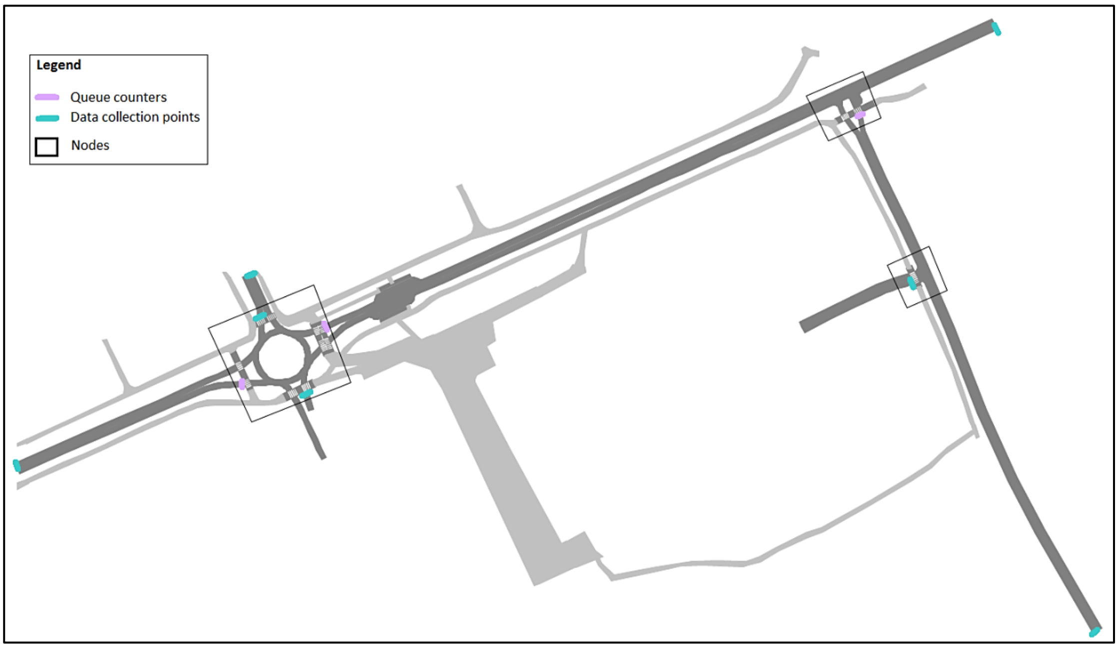

Figure 20 Placement of evaluation tools in the modelled network

Another way of evaluating the network is the *data collection measure* which is used to monitor specific points in the network. This tool is implemented at seven locations throughout the network, which can be observed in Figure 20, including one at each of the three parking lot exits and one at each of the four roads exiting at the edge of the modelled network. The main reason for implementing this evaluation tool at the parking lot exits is to be able to collect individual data of each car and thereby make it possible to evaluate at which time the last car leave each parking lot respectively.

When studying the evacuation process from the arena area in Falkenberg two parameters involving the parking lots are examined; the time it takes to empty them and the delay affecting the exiting cars. These parameters are studied with and without pedestrians in the model in order to evaluate which impact pedestrians have on the evacuation process. Furthermore, the parking lots do not begin to evacuate at simulation start but rather have a time lag (i.e. the time it takes for drivers to walk from the stadium to their vehicle), which can be subtracted from the time it takes for the last vehicle to exit in order to obtain the evacuation time.

Queue counters are placed, as seen in Figure 20, at the western and eastern entrances to the roundabout on Kristineslättsallén as well as to the south of the T-intersection between Kristineslättsallén and Skogsvägen. This adds up to a total of three queue counters in the network. The purpose of these queue counters is to measure the queue lengths that build up upstream from these non-signalised intersections. The results from queue counters will be used to measure the queue spill-back effect where queues from one intersection accumulate backwards resulting in blocking the approaches of another intersection. In order to determine when the queue originating from one intersection is long enough to cause such effect, the distance between the roundabout and the T-intersection on Kristineslättsallén is measured to 333 meters. In the same way, the distance between the T-intersection on Kristineslättsallén and the T-intersection on Skogsvägen is determined to 150 meters. If these limit values are exceeded, the intersections have an influence on each other due to the queue spill-back effect. The duration of the queue spill-back can be obtained by studying the number of time intervals when the limit values are exceeded.

The tool for *vehicle travel time* measurement is used to measure the time it takes to travel through the network at different time periods during the simulation. The collected data is used to evaluate how the traffic situation for drivers, with concern to the time spent traveling from different points in the model to desired destinations, varies during a simulation run. Background traffic are of interest in this master thesis as they use the traffic network regardless of a high profile event, thus becoming affected by the traffic situation arising after an event without taking part in it themselves. Four travel time measurements are defined in the model to enable the collection of travel time data for the background traffic, seen in Figure 21.

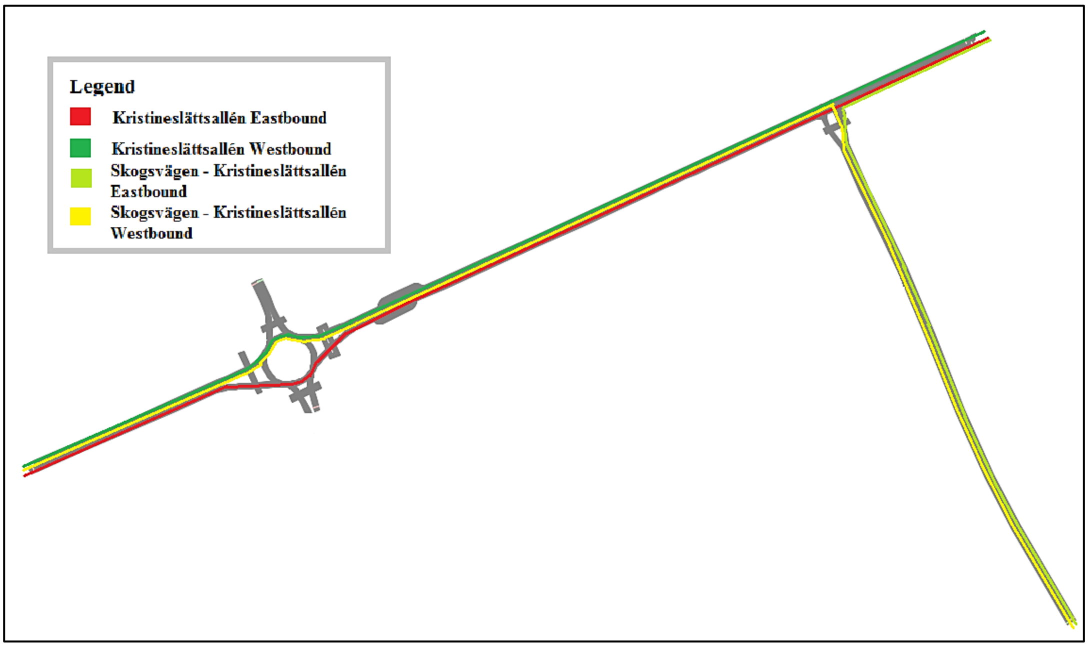

Figure 21 Background travel time measurements

Two measurements are defined at Kristineslättsallén, one in each direction containing one starting and ending point, to study the background traffic using the road. The other two measurements are placed to study the travel times for vehicles that drive along Skogsvägen and turns in either direction at the Kristineslättsallén T-intersection, with starting points at Skogsvägen and finishing points at the east and west ends of Kristineslättsallén. As for the node evaluation described above, data is collected in 2.5 minutes time segments to enable the study of the traffic network during different periods of time during the simulation.

Network evaluation provides an overall indication of how the modelled network performs. One output value of interest from the network evaluation is the latent delay which will be used to approximate the time vehicles spend on the parking lots outside the model. Other output values worth studying is the average speed and average travel times of all vehicles in the network which gives an indication of how congested the system is.

In order to evaluate and compare results from Capcal and PTV VISSIM, similar output values existing in both software need to be identified or calculated. According to Allström et al. (2008), PTV VISSIM does not give the capacity of non-signalised intersections explicitly. Hence, a method for evaluating the capacity of such intersections is developed based on the concepts introduced in Section 2.7. Elefteriadou (2014), states that there are three different time periods of interest when defining the capacity of a traffic facility; intervals prior to the breakdown of flow, the time interval directly before breakdown and the lengthy interval throughout congested condition. The method used when analysing the T-intersection in this master thesis is based on investigating which capacity is relevant during a lengthy interval of congested conditions. This means that a lengthy congested state need to be achieved in the simulation. Another method is used when analysing the roundabout where a lengthy interval of congested conditions were difficult to achieve. Therefore, an interval prior to breakdown of flow is used when calculating capacity in the roundabout. Furthermore, since the T-intersection and the roundabout in the traffic network influence each other, they have to be separated from one another to obtain representative results comparable to Capcal.

To be able to reach a congested state in the traffic facility, all the approaches leading up to the facility are gradually saturated with an increased vehicle flow. All approaches start with a vehicle flow of 500 vehicles per hour and for each 5 minute interval the flow is increased by a 100 vehicles per hour. The resulting total throughput of the facility is then studied in order to determine if the congested condition of this facility has been met. A facility is considered to be congested when the total throughput no longer increases but rather fluctuates or even decreases. A diagram, seen in Figure 22, shows the total throughput of vehicles, when using the method described above, at the T-intersection during different time intervals. It is evident that the number of vehicles able to travel through the intersection increases initially but reaches a point where it starts to fluctuate. Thereby a congested state is reached and the T-intersection is operating close to capacity.

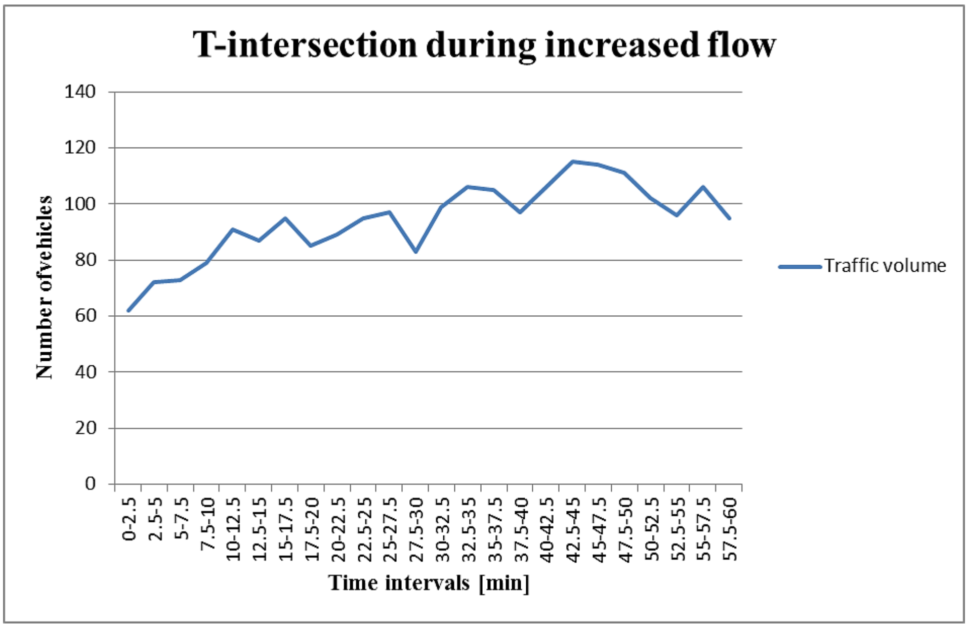

Figure 22 Capacity of the T-intersection during increased flow

When evaluating the capacity of the roundabout on Kristineslättsallén, the same method described above was used. However, when increasing the input flow from the approaches, no real decrease or levelling out of the throughput curve, the dashed curve in Figure 23, could be identified. Another simulation run was carried out with even higher flows on the approaches in order to reach this congested state. The results from this run can be observed as the continuous curve in Figure 23. During this simulation run a more distinct levelling out and fluctuation of the volume curve can be observed toward the end of the simulation period. However, when increasing the flow to between 1 300 and 2 400 vehicles per hour, a main route through the roundabout along Kristineslättsallén in both directions was created, preventing the vehicles arriving from the north and south approaches to enter. For example, in one of the runs with the higher flow, only 8 vehicles from the north and 3 vehicles from the south were able to enter from these two approaches during a 2.5 minute time interval whereas 65 and 60 vehicles that was able to enter from the approaches on Kristineslättsallén. This is not representable compared to the real situation, why the scenario with a lower vehicle flow, representing the flow prior to breakdown, is used.

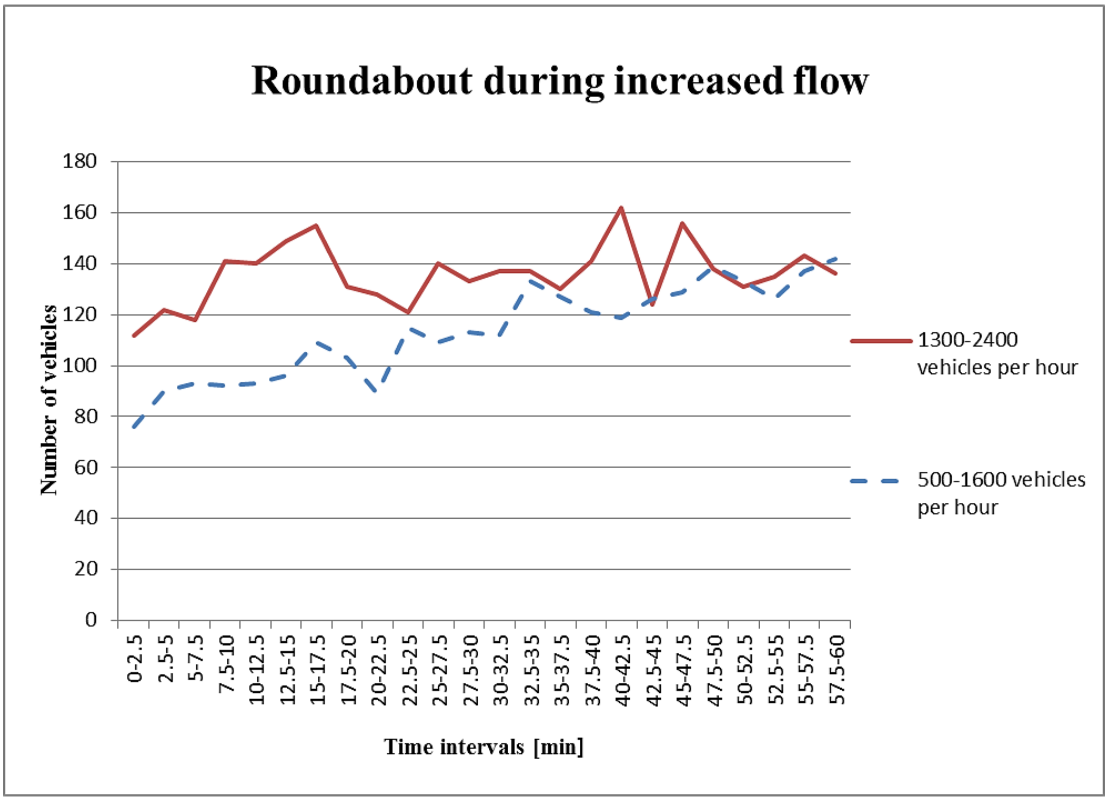

Figure 23 Capacity of the roundabout during increased flow

When the input vehicle flows for network saturation is established, 5 separate simulations are run with different stochastic variation of the traffic. The maximum number of vehicles able to enter the traffic facility from each approach at any time interval is taken out and an average between the simulation runs is calculated. The value is then recalculated into vehicles per hour using the method as presented in Section 3.4.4, representing the theoretical capacity per hour for each approach in the traffic facility.

Load rate is an indication of at which rate an approach to an intersection is operating. The load rate of a specific approach is calculated using Equation 2.

$$Load\ Rate = \frac{N_{Vehicles}}{C} \qquad (2)$$

Where: $\mathbf{N_{Vehicles}}$ *is the number of vehicles using a specific approach during a high profile event simulation [veh/h].*

C *is the calculated capacity for the specific approach [veh/h].*

3.5 Simulation parameters

Before a simulation starts, a number of parameters can be setup to define the framework of the simulation, explained by PTV (2011). Some of the options available and relevant in this master thesis are

- *Period* which defines the period of time to be simulated. In the simulation in this master thesis, a time period of 1 hour (i.e. 3 600 seconds) are simulated to allow for all vehicles, pedestrians and bicyclists to leave the area.
- *Start time* states at which time at the day the simulation starts. This time is specified to 21:00 according to assumption to when a game finishes on weekdays.
- *Simulation resolution* which describes the number of times a vehicles position will be calculated within one second of the simulation. Basically, having more calculation steps per simulated second generates a more accurate representation of the vehicles position in the model. On the other hand, having more calculation steps leads to a higher demand on computing capacity. In order to obtain accurate results while not putting too high demand on computing power, a simulation resolution of 10 time steps per simulation second is used in this simulation.
- The *Random seed* initialises the random number generator where a change in this number changes the profile of the traffic arriving and therefore the simulation result changes, even with identical input files. By using this method, a stochastic variation of the input flow of traffic arrival times can be simulated. Hence, in this simulation 5 simulations are run with different random seed to generate results with a stochastic variation. These results are in turn averaged to obtain the final results.

3.6 Capcal

In the report compiled by Kjellson & Salomonsson (2013), it is stated that the analytical modelling method Capcal is used to evaluate the roundabout and T-intersection located on Kristineslättsallén. A set of predefined intersections can be chosen in Capcal, where the intersection at the exit from the western parking lot is described as a four leg roundabout with a one lane approach from each direction. The T-intersection between Skogsvägen and Kristineslättsallén is modelled as a yield regulated intersection without a separate left-turn lane. The background traffic volume used in the analysis is 6 % of the AADT, presented in Appendix 2. Since Capcal does not enable a multi intersection evaluation, two separate studies were conducted on the roundabout and the T-intersection respectively. Moreover, the analysis was conducted on a scenario after a high profile event at the arena with 6 000 spectators. Additional input data regarding geometry, weaving length, speed limits and proportion of heavy vehicles can be found in Appendix 5.

According to Kjellson & Salomonsson (2013), a situation with cars queuing to exit the parking lot will arise when the spectators leave the arena after a game. The aim of the analysis of the intersections was to evaluate the time it takes for the last car to leave the parking lot. However, Capcal is limited to analyse an intersection during one hour time intervals. Hence, an iterative process, where the user can define the flows according to time intervals and study if the resulting capacity is realistic, has to be used in order to model a saturated flow of a known number of vehicles. To calculate the time interval specific flows, the method explained in Section 3.4.4, is used.

Kjellson & Salomonsson (2013), does not consider pedestrians or bicycles in their capacity calculations using Capcal, even though a limited possibility to incorporate non-motorised communication means exist. Allström et al. (2008) explain that Capcal only takes pedestrians crossing intersection approaches where vehicles must yield into consideration. Consequently, pedestrian crossings on major roads and intersection exits do not influence the calculations. Instead of using this possibility, Kjellson & Salomonsson (2013) assume that some delay due to crossing pedestrian and bicycle flows will occur during a limited time, but it is not specified how large this delay will be or how long it will last.

4 Results

In this chapter the results from two different simulation scenarios, one with and another without pedestrians, are presented in order to illustrate the pedestrian influence on the traffic situation. The results are presented according to specific measurements (i.e. vehicle travel time, queue length, speeds, evacuation process and capacity) as well as an overall network evaluation in the end of the chapter. Comparisons between PTV VISSIM and Capcal results are made where this is applicable.

4.1 Background traffic travel time

The average vehicle travel times for the background traffic obtained during the PTV VISSIM simulations are presented in this section. Travel times gathered from simulations with pedestrians are presented in *light* bars and without in *dark*. The travel time results are divided according to the four studied routes, presented in Section 3.4.7. Lastly, the total average travel time in the network is presented.

4.1.1 Kristineslättsallén eastbound

Vehicle travel times for background traffic driving east along Kristineslättsallén can be seen in Figure 24.

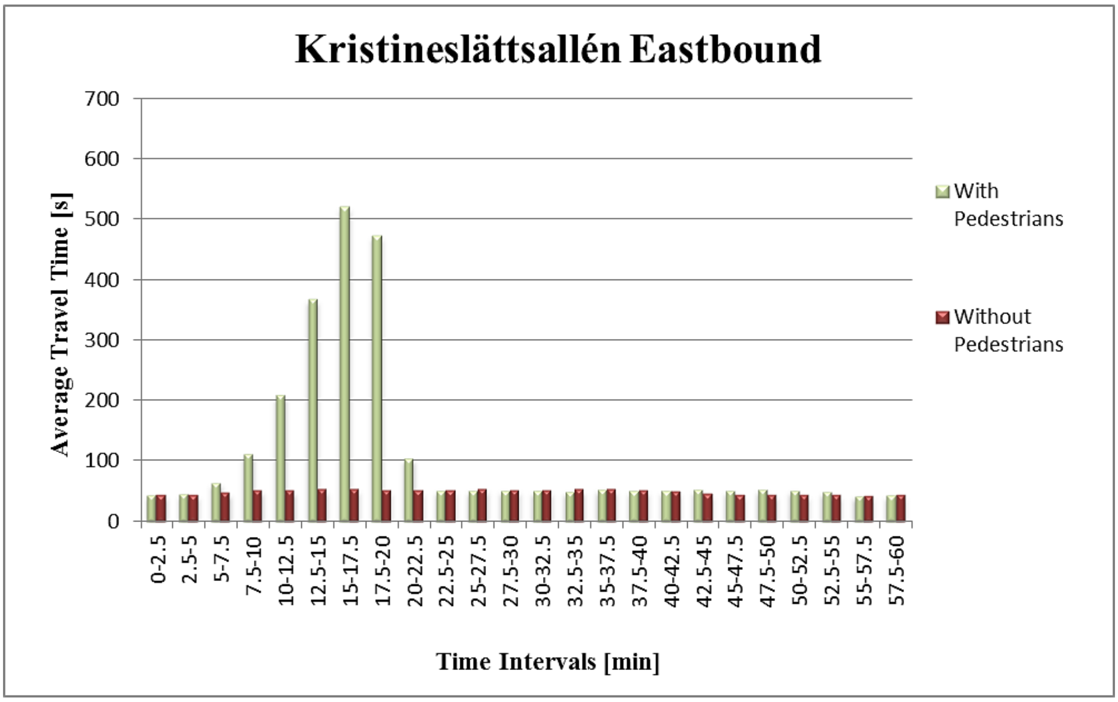

Figure 24 Chart showing the average travel times for vehicles driving east along Kristineslättsallén during different time intervals.

It can be observed that the pedestrians start to influence the average travel time after approximately 5 minutes. The influence thereafter increases until it reaches the maximum average travel time of 521 seconds (i.e. 8 minutes and 41 seconds) during the time interval 15-17.5 minutes. In the 17.5-20 minutes interval the pedestrian influence start to diminish and decreases rapidly during the next interval until it have small affect after 22.5 minutes. The average travel times for simulations without pedestrians are stable, with only a slight fluctuation between the highest value 53.5 seconds and the lowest 42.7 seconds.

4.1.2 Kristineslättsallén westbound

The average vehicle travel times obtained for the background traffic driving west on Kristineslättsallén are presented in Figure 25.

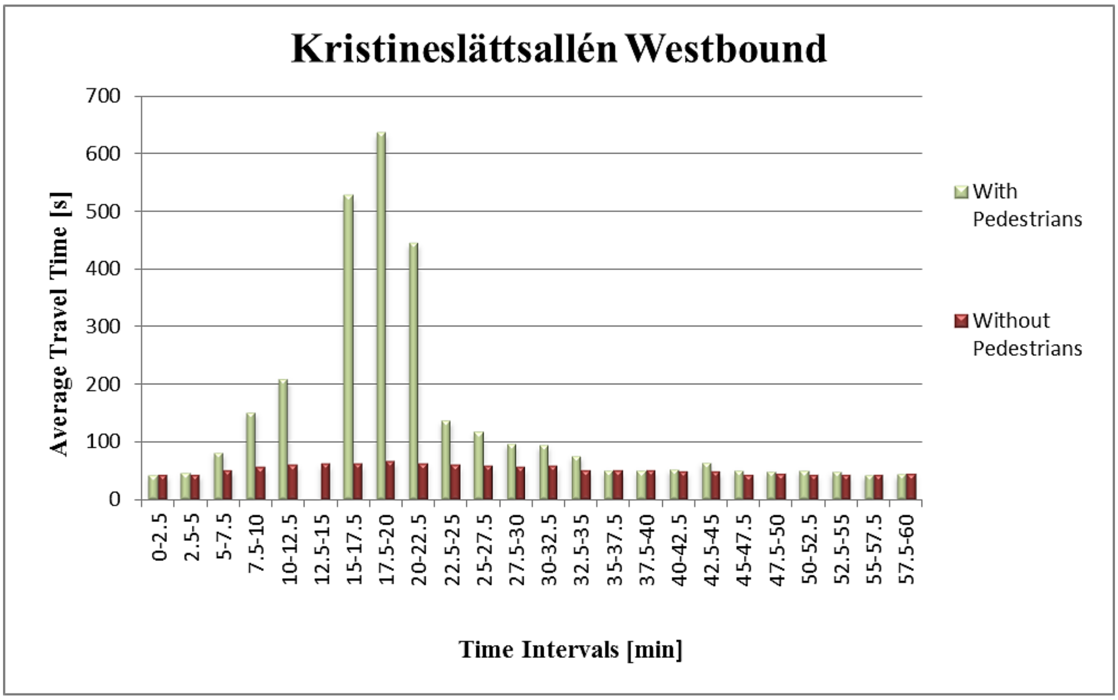

Figure 25 Chart showing the average travel times for vehicles driving west along Kristineslättsallén during different time intervals.

The pedestrians begin to affect the average travel times after 5 minutes. Thereafter, the influence increases until the maximum average travel time at 636 seconds (i.e. 10 minutes and 36 seconds) is reached in the 17.5-20 minutes interval. The pedestrian influence decreases during the following intervals and have little impact after 35 minutes. During the 12.5-15 minutes interval no vehicle passes the travel time measurement endpoint, why no data is collected during this specific time period. This explains the missing bar at this interval, since the bar chart present the average travel time data obtained during simulations. The travel time accumulates when no vehicle complete the studied travel path, why such a high increase occurs in the time intervals following the missing bar.

The travel times without pedestrians are relatively stable, with times fluctuating between 42.9 seconds and 66.5 seconds. It can be observed in Figure 25 that there is an interval with generally higher values from 5-32.5 minutes during the simulations.

4.1.3 Skogsvägen – Kristineslättsallén eastbound

The obtained results for the background traffic driving along Skogsvägen and thereafter continuing east along Kristineslättsallén can be seen in Figure 26.

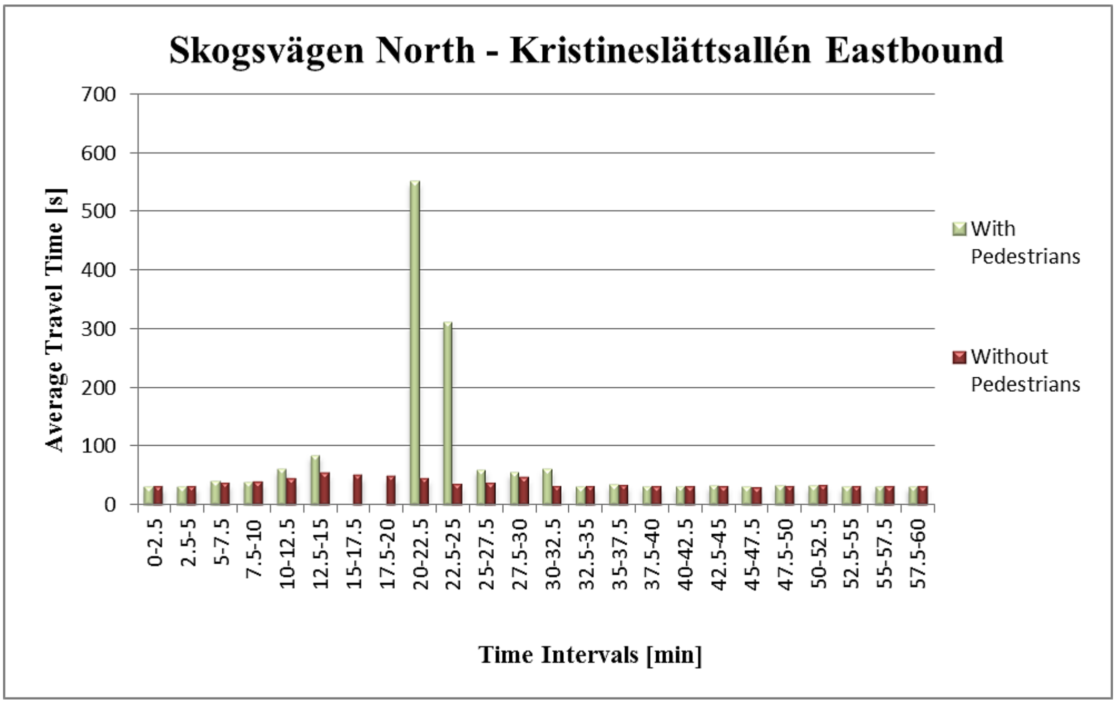

Figure 26 Chart showing the average travel times for vehicles driving from Skogsvägen and continuing east along Kristineslättsallén.

It can be observed that pedestrians begin to affect the average travel time after 5 minutes. The influence thereafter increase and in the interval 15-20 minutes, no vehicle passes the finishing travel time measurement endpoint for the specific travel path, resulting in two time intervals without collected data. Since travel time accumulates when no vehicle complete the studied travel path, the highest average travel time at 551 seconds (i.e. 9 minutes and 11 seconds) occur during the following time interval 20-22.5 minutes. The pedestrian influence reduces rapidly during the next time interval 22.5-25 minutes until it have limited effect after 32.5 minutes. The average travel times obtained from the simulations without pedestrians are generally low with values from 29.0 seconds to 53.8 seconds, with a tendency for higher travel times in the interval 5-32.5 minutes.

4.1.4 Skogsvägen – Kristineslättsallén westbound

In Figure 27, the average travel times for the background traffic vehicles starting at Skogsvägen and continuing west along Kristineslättsallén are presented.

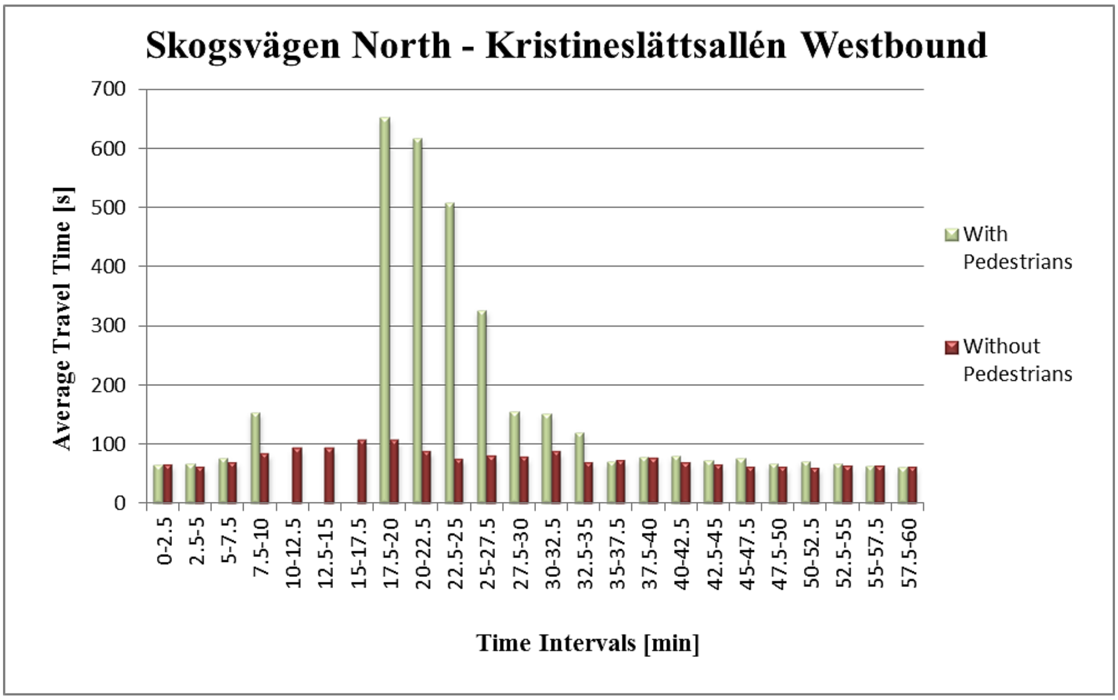

Figure 27 Chart showing the average travel times for vehicles driving from Skogsvägen and continuing west along Kristineslättsallén.

It can be seen that the pedestrian influence start to affect the average travel times after 7.5 minutes. No vehicles complete the specific travel path during the three following time intervals from 10 to 17.5 minutes and due to the travel time accumulation, the subsequent time interval 17.5-20 minutes has the highest average value at 652 seconds (i.e. 10 minutes and 52 seconds). The pedestrian influence thereafter begins to decrease, but not as rapidly as for the other measurements presented earlier in this section with influence ceasing after 35 minutes.

Results obtained during simulations of the background traffic without pedestrians, presented in Figure 27, show generally higher and more fluctuated values for the average travel times than for the previously presented results. Higher values can be observed from 5 to 40 minutes, which includes the time interval 17.5-20 minutes within which the maximum average travel time of 106.2 seconds (i.e. 1 minute and 46 seconds) occurs.

4.1.5 Total average travel time in network

The total average travel times in the traffic network obtained during simulations with and without pedestrians are presented in Figure 28.

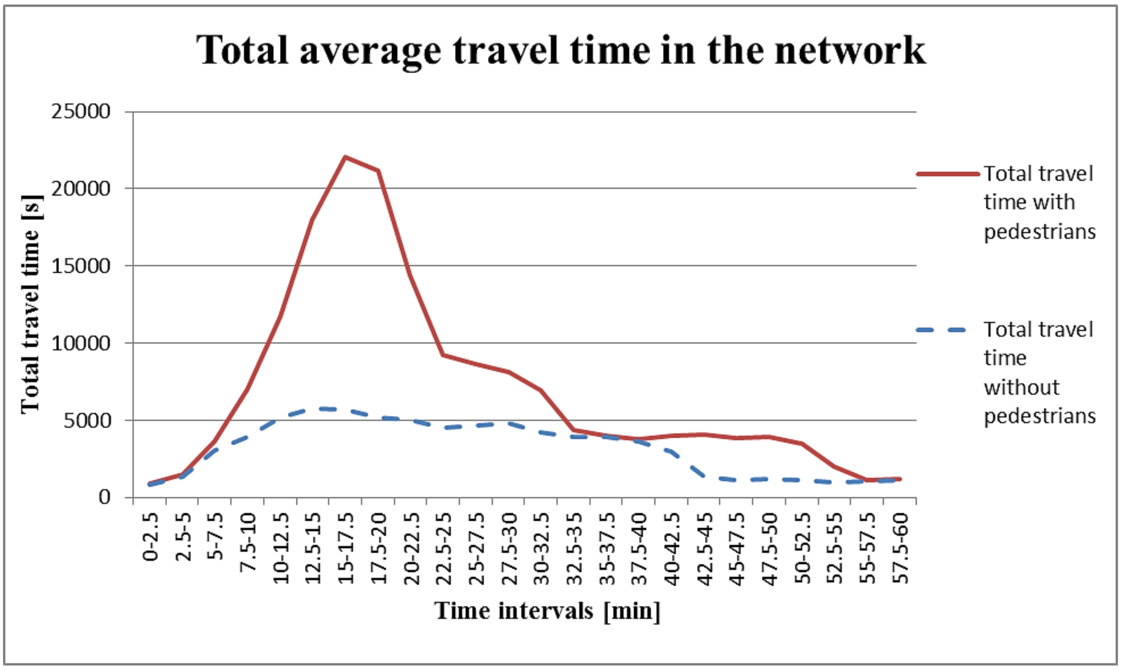

Figure 28 Total average travel time during simulations with and without pedestrians influence

It can be observed that the pedestrians start to affect the total travel time in the network during the 2.5-5 minutes time interval. Thereafter, the travel time increases steeply until the 15-17.5 minutes interval in which the maximal total travel time is obtained. After this point, the total travel time begins to decrease, with a change in decline after 25 minutes. The decrease cease after 35 minutes when the values even out and stabilise. There is a final decrease from 50 to 57.5 minutes, after which the total travel time stabilises yet again and the values coincide with the results obtained from the simulations without pedestrians.

The total average travel time without pedestrians, presented in Figure 28, steadily increase until the time interval 12.5-15 minutes, in which the maximum value occurs. The total travel time decreases evenly after this interval until it stabilises during the 42.5-45 minutes interval.

4.2 Queue

As described in Section 3.4.7, queue build up is studied in order to determine if a queue spill-back effect from one intersection causes interference in an intersection further upstream. The maximum queue lengths in each time interval at the two T-intersections are presented in Figure 29 and Figure 30 together with the limit values described in Section 3.4.7.

Figure 29 present the queue originating at the eastern approach to the roundabout on Kristineslättsallén.

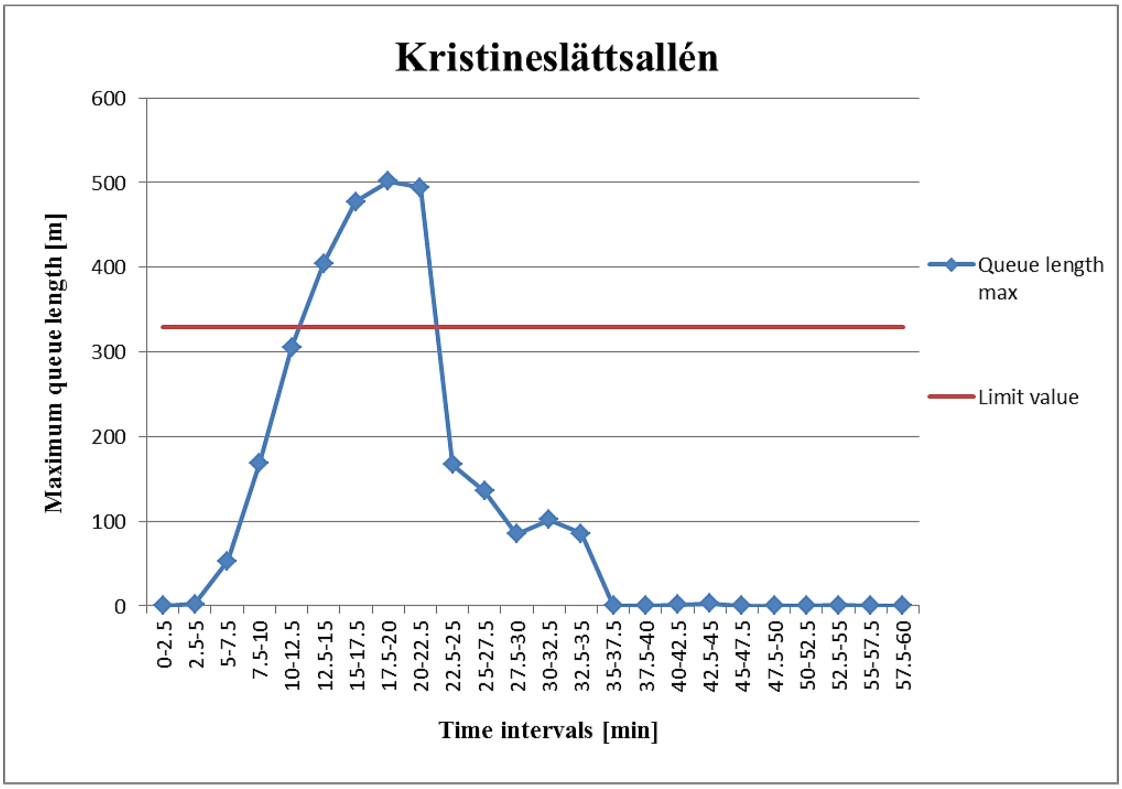

Figure 29 Maximum queue length on Kristineslättsallén

A queue starts to accumulate after 5 minutes and continues to build up until the 10-12.5 minutes interval. It can be observed that the limit value is exceeded in the time interval 12.5 minutes to 22.5 minutes during the simulated hour. Thereafter, the queue dissipates until it dissolves completely after 35 minutes.

The results from the T-intersection on Kristineslättsallén are presented in Figure 30.

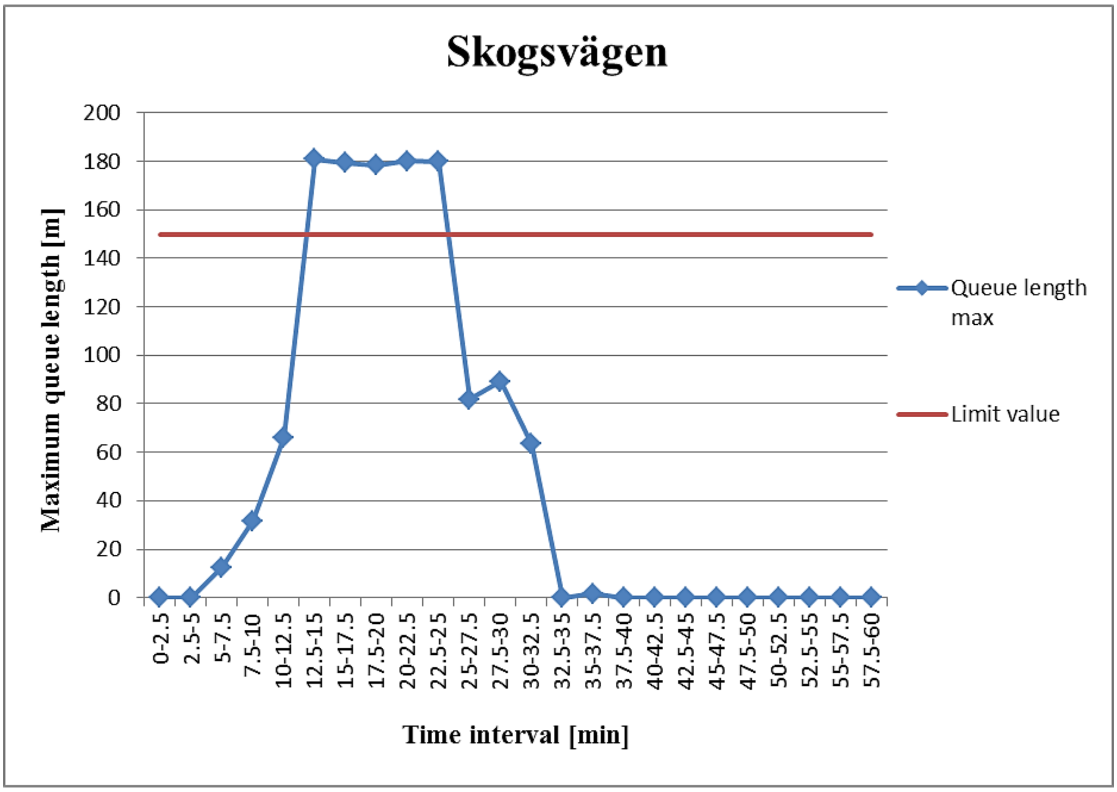

Figure 30 Maximum queue length on Skogsvägen

The queue on Skogsvägen begins to form in the 5-7.5 minutes interval and continues to accumulate until it reaches its maximum length during the 12.5-25 minutes interval. It can be observed that the limit value is exceeded during this interval and that the period when it exceeds the limit lasts for a longer duration of time than the queue on Kristineslättsallén. After 25 minutes the queue starts to dissipate until it disappears altogether after 37.5 minutes.

4.3 Speed

The average speed throughout the network with and without pedestrians in the system is presented in Figure 31.

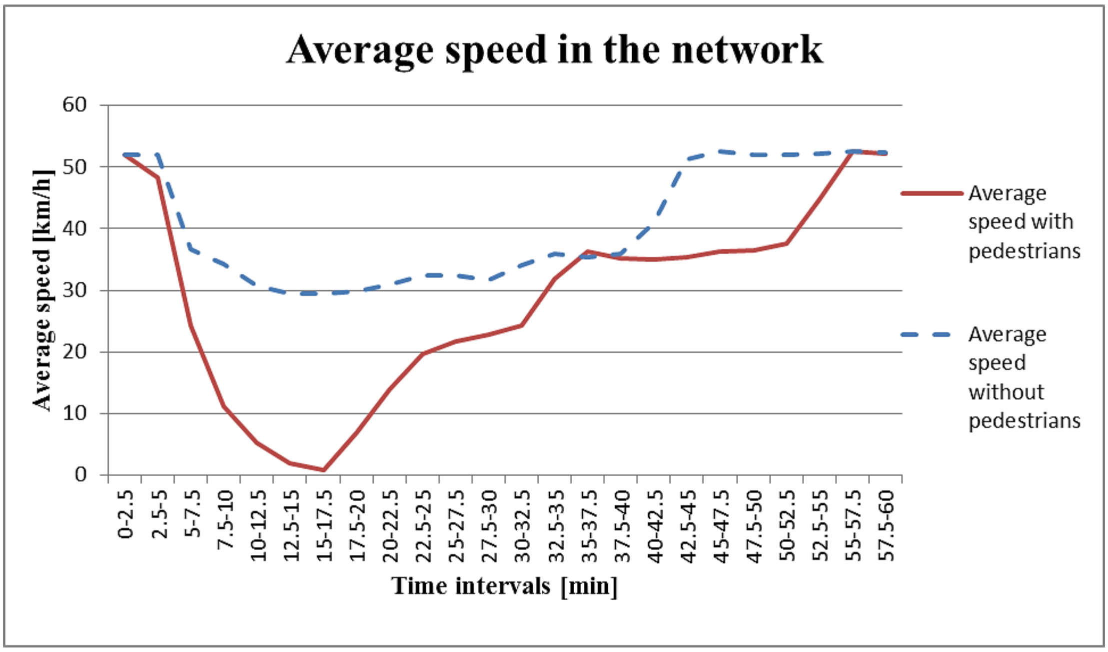

Figure 31 Average speed in the network

It is evident that the overall speed in the network is lower when pedestrians are interfering with the traffic as opposed to the higher speed observed when there are no pedestrians present. Furthermore two time intervals where the two curves coincide can be observed, one occur between 35 and 40 minutes and the other towards the end of the simulated period from 55 minutes to 60 minutes. Towards the end of the simulation, the average speed without pedestrians reaches a plateau slightly above 50 kilometres per hour which is interpreted as the average speed of free flowing traffic. Another feature to observe in Figure 31 is that in the time interval between 12.5 and 17.5 minutes, the average speed in the network with pedestrians reaches almost zero which indicates that the vehicles in the traffic network is almost at a standstill during this time period.

4.4 Evacuation process

In this section, results obtained from the Capcal and PTV VISSIM investigations regarding the evacuation process from the parking lots are presented. In the case of PTV VISSIM, results both with and without pedestrians are presented. The West parking lot is modelled to house 420 vehicles, the East parking lot 200 vehicles and August Bondessons väg 290 vehicles.

The evacuation time estimated in the Capcal investigation for the West parking lot and August Bondessons väg is 40 minutes. It is further approximated that the East parking lot is emptied in 30 minutes.

The results of the PTV VISSIM study are presented in Table 12 where pedestrians have been taken into account and in Table 13 where pedestrians have been removed from the simulation. It can be observed that the evacuation time is dependent on the number of vehicles housed in the parking lot. In Table 12, it can be observed that the last parked vehicle leaves the West parking lot and August Bondessons väg after approximately 50 minutes. However, when calculating the evacuation time which takes the time lag for the evacuation to start at each parking lot into account, it is evident that the West parking lot takes the longest time of 48.2 minutes to evacuate followed by August Bondessons väg at 41.9 minutes. The least time consuming evacuation process is the East parking lot which only takes 26.2 minutes to evacuate.

Table 12 Evacuation time from parking lots with pedestrians

	Last vehicle [s]	Last vehicle [min]	Time lag [min]	Evacuation time [min]
West parking lot	3190.7	53.2	5	48.2
August Bondesson	3115.4	51.9	10	41.9
East parking lot	1872.9	31.2	5	26.2

Table 13, showing the evacuation time without any pedestrians, demonstrates that the East parking lot takes the least amount of time to empty, 25.1 minutes, followed by August Bondessons väg at 31.7 minutes and lastly the West parking lot which takes 35.6 minutes to evacuate. When comparing the results with and without pedestrians, it can be observed that the East parking lot is emptied only approximately 1 minute faster without pedestrians while the other parking lots empty in approximately 10 and 13 minutes less time.

Table 13 Evacuation time from parking lots without pedestrians

	Last vehicle [s]	Last vehicle [min]	Time lag [min]	Evacuation time [min]
West parking lot	2433.4	40.6	5	35.6
August Bondesson	2502.4	41.7	10	31.7
East parking lot	1808.1	30.1	5	25.1

The delay time for vehicles waiting to exit the parking lots, in this thesis described with the parameter latent delay, is presented in Table 14. This result show that the total time spent on parking lots is 222.3 hours with pedestrians and 75.5 hours without pedestrians in the network. The average delay per car is 14.7 minutes with pedestrians and only 5 minutes with the pedestrians excluded.

Table 14 Latent delay with and without pedestrians

	Total latent delay [h]	Latent delay per car [min]
With pedestrians	222.3	14.7
Without pedestrians	75.5	5.0

In Figure 32, showing the total latent delay in different time intervals, it can be observed that the latent delay starts building up at around 5 minutes and increases rapidly in the following 6 time intervals before it reaches its peak in the time interval between 22.5 and 25 minutes. After this time interval the latent delay starts to decrease until it reaches zero in the time interval 52.5 to 55 minutes where all the parking lots, as stated previously, are deemed to be emptied.

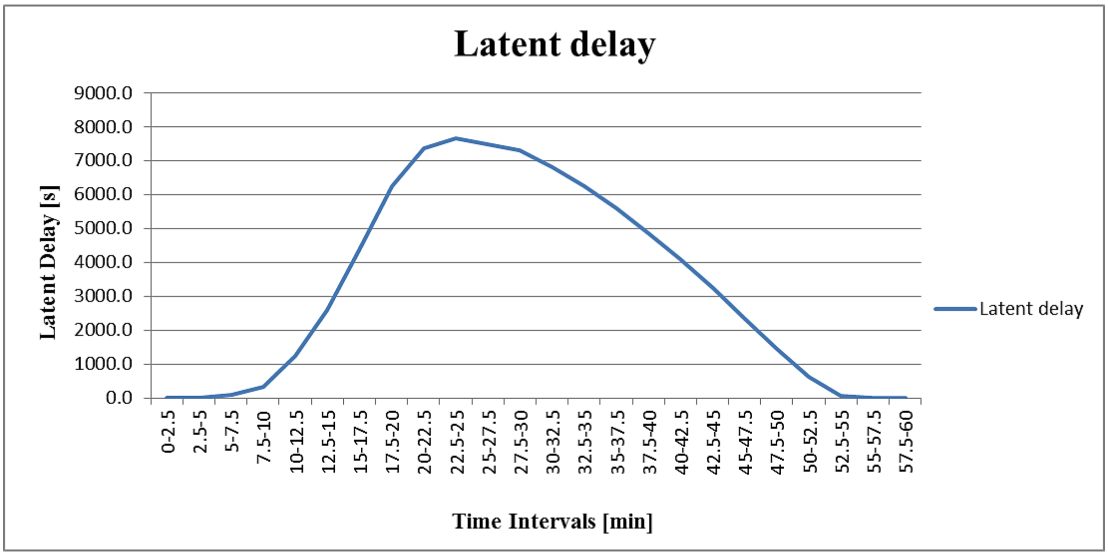

Figure 32 Latent delay in the traffic network

Based on average travel times and vehicle speed, a period of direct pedestrian influence with significantly lower average speeds and longer travel times is identified between 5 and 17.5 minutes in the simulation. In Table 15, the vehicles able to pass from each approach during the direct pedestrian influence period are presented. The average number of vehicles able to pass per minute is approximately 1 car per minute and approach.

Table 15 Vehicles able to pass each roundabout approach during a period with direct pedestrian influence

	Exiting vehicles	Average during period [Veh/min]
Kristineslättsallén Eastbound	14	1.1
Kristineslättsallén Westbound	12	1.0
August Bondessons väg	11	0.9
West parking lot	9	0.7

During the time period without direct pedestrian influence (i.e. 5 to 17.5 minutes) a significantly higher amount of cars are able to pass, between 5 and 11 cars per minute depending on the approach studied, seen in Table 16.

Table 16 Vehicles able to pass each roundabout approach during a period without direct pedestrian influence

	Exiting vehicles	Average during period [Veh/min]
Kristineslättsallén Eastbound	173	4.9
Kristineslättsallén Westbound	272	7.8
August Bondessons väg	315	9.0
West parking lot	389	11.1

4.5 Capacity and load rate

The capacities and load rates calculated in Capcal and PTV VISSIM for the roundabout and the T-intersection at Kristineslättsallén are presented in this section. To simplify the comparison between the two software, the PTV VISSIM results are calculated using identical time intervals used in the Capcal investigation (i.e. 40 minutes for the roundabout and 30 minutes for the T-intersection).

4.5.1 The roundabout on Kristineslättsallén

In Table 17, the vehicle flows used during the Capcal simulation together with the calculated capacities and load rates for the individual approaches to the roundabout can be seen. August Bondessons väg and the West parking lot approaches have higher flows and lower capacity compared to the other two approaches. Hence, the load rates are higher at these locations.

Table 17 Defined vehicle flows and obtained results from the Capcal investigation of the roundabout.

Approach	Flow [veh/h]	Capacity[veh/h]	Load rate[-]
Kristineslättsallén Eastbound	220	1169	0.19
August Bondessons väg	469	948	0.52
Kristineslättsallén Westbound	220	1045	0.21
West parking lot	630	969	0.65

In Table 18, the capacities and load rates for the roundabout calculated with PTV VISSIM are presented. The vehicle flows are calculated as the average number of vehicles using the different approaches during 40 minutes of simulation, which are recalculated as vehicles per hour. The load rates from the PTV VISSIM investigation shows similar results as the Capcal investigation with the highest load rates occurring on the August Bondessons väg and West parking lot approaches. However, the West parking lot value indicates that this approach operates at a high load rate.

Table 18 Defined vehicle flows and obtained results from the PTV VISSIM simulation of the roundabout.

Approach	Flow [veh/h]	Capacity [veh/h]	Load rate[-]
Kristineslättsallén Eastbound	226	1603	0.14
August Bondessons väg	456	869	0.52
Kristineslättsallén Westbound	360	1627	0.22
West parking lot	586	614	0.95

4.5.2 The T-intersection on Kristineslättsallén

Table 19 present the defined vehicle flows in Capcal together with the calculated capacities and load rates for the individual approaches to the T-intersection along Kristineslättsallén. It can be observed that the highest load rate in the T-intersection occurs at the Skogsvägen approach which operates at a rate of 0.74.

Table 19 Defined vehicle flows and obtained results from the Capcal investigation of the T-intersection.

Approach	Flow [veh/h]	Capacity[veh/h]	Load rate[-]
Kristineslättsallén Eastbound	223	1852	0.12
Kristineslättsallén Westbound	271	1452	0.19
Skogsvägen	470	635	0.74

In Table 20, the capacities and load rates calculated with PTV VISSIM are presented. The vehicle flows are calculated as the average number of vehicles using the different approaches in the T-intersection during 30 minutes of simulation, which are recalculated as vehicles per hour. Similar to the Capcal investigation, the approach from Skogsvägen has the highest load rate. However, the value is lower than the value presented in the Capcal investigation. In contrast, the Eastbound approach from Kristineslättsallén shows higher load rate compared to the Capcal investigation.

Table 20 Defined vehicle flows and obtained results from the PTV VISSIM simulation of the T-intersection.

Approach	Flow [veh/h]	Capacity [veh/h]	Load rate[-]
Kristineslättsallén Eastbound	643	1862	0.35
Kristineslättsallén Westbound	263	1411	0.19
Skogsvägen	389	802	0.49

4.6 Network evaluation

When evaluating and describing the overall performance of the traffic network the simulated time period are divided into segments observed to have a similar behaviour within the segment. Therefore, Figure 28 describing the average travel time in the network, presented in Section 4.1, is divided into five time segments A1-A5 resulting in Figure 33.

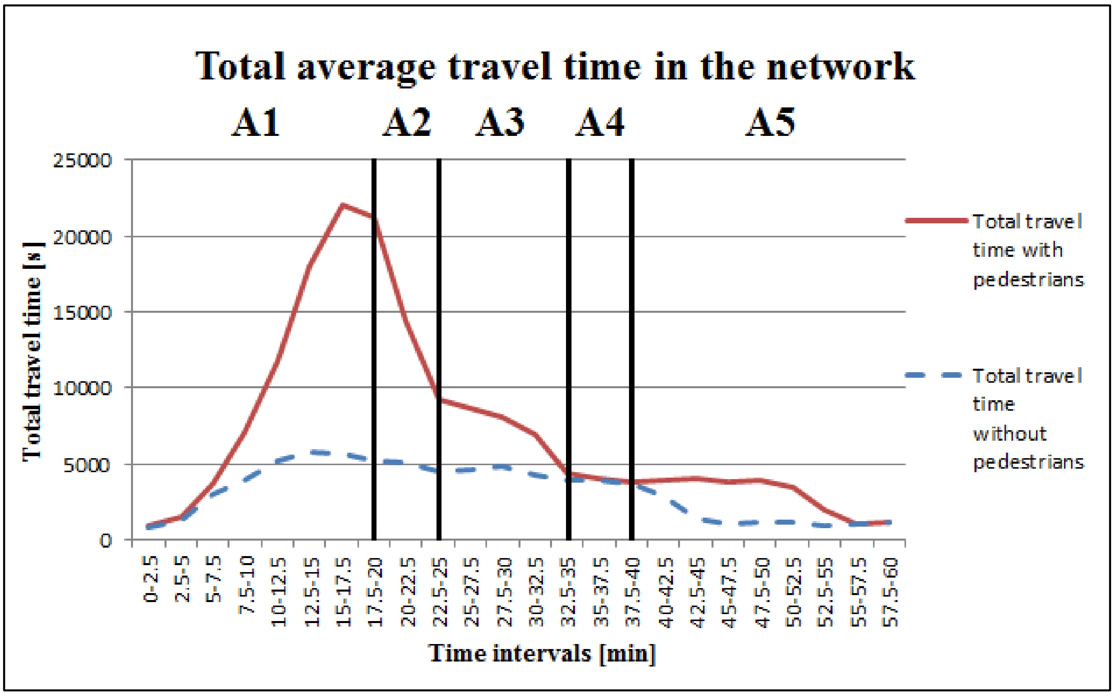

Figure 33 Simulation time divided into segments based on network performance

In segment A1, pedestrians affect the travel time directly, represented by people passing the zebra crossings, and have a large influence on the travel times. Hence, there is a noticeably higher average travel time in the network with pedestrians compared to the travel time without pedestrian influence. The large influence by pedestrians during the A1 segment contributes to a congested state in the traffic system. The low average speed during the A1 time intervals, presented in Section 4.3, is a further indication that the system is in a congested state. The direct pedestrian influence ceases in segment A2 as the modelled pedestrians exit the simulations after approximately 20 minutes. This can be observed as the rapid decrease of total travel time in the A2 segment in Figure 33.

The difference in travel time with and without pedestrians in segment A3, seen in Figure 33, is explained by the queues on Kristineslättsallén and Skogsvägen, described in Section 4.2, contributing to the total travel time. During this segment the queues begins to dissipate as the congestion decreases and are fully dissipated in the beginning of segment A4. The increase in average speed, seen in Section 4.3, during the time intervals in segment A3 further indicates that the congestion eases. The direct influence of both queues and pedestrians cease after the congestion is fully dissipated at the start of segment A4, where the total travels times with and without pedestrians coincides. This indicates that the travel times during both simulation scenarios are generated by background and parking lot traffic exclusively, without any other influences.

In segment A5, the total travel times differentiate yet again. The reason for this is that the parking lots are emptied after 41 minutes and 40 seconds in the simulations without pedestrians, presented in Section 4.4. The remaining total travel time is formed by the background traffic alone. With pedestrians in the simulation the parking lot traffic continues to affect the travel times until the parking lots are emptied in the 52.5-55 minutes interval. After this interval the results coincide once again and only the background traffic contribute to the travel time for both scenarios.

5 Discussion

This chapter is divided into three sections in order to deal with the main focuses in this master thesis. These are the uncertainties during model construction, the evaluation of the obtained results and the added values gained by using PTV VISSIM instead of Capcal.

5.1 Uncertainties

When creating and evaluating a model of a real life situation, it is impossible to avoid uncertainties. These stem from the complexity of modelling an actual situation, as the amount of information needed to represent the situation completely is very large and time consuming to collect. Therefore, to enable the creation of a sufficient representation of reality, assumptions have to be made. These assumptions take into consideration parameters which are problematic to obtain such as driver and pedestrian behaviour.

An effective way to make the uncertainties as few and non-influential as possible is to study the actual situation and calibrate the model according to identified key parameters. Since the situation studied in this master thesis does not exist, such key parameters have been impossible to gather. Instead, a similar scale event at Kinnarps Arena is studied in order to obtain parameters to use during calibration. Parameters collected in the event study are vehicle and pedestrian interaction behaviour as well as pedestrian evacuation distribution. Consequently, the results of the simulation conducted in this master thesis are influenced by the parameters obtained from the previously mentioned studied event. However, these parameters are considered to be applicable at situations with similar characteristics, why the simulation gives a good indication of how the studied situation will develop.

A number of inputs used during the simulation could not be obtained either from the event study at Kinnarps Arena or the previously conducted investigation of the area. One such input is the vehicle distributions, which are assumed to follow the pedestrian evacuation distribution pattern, presented in Section 3.1, but with a small time lag. These time lags are assumed to correspond to the time it takes for drivers to walk from the stadium to their vehicles. These time lags are not based on any conducted measurements, but are instead estimations regarding distance and walking speed. Another input is the vehicle compositions where it is assumed that a reduced number of HGV:s are simulated in the model which may enhance the performance of the traffic network, since these vehicles are less manoeuvrable and slower than regular cars. However, based on experience cars almost exclusively occupy the parking lots during an event and very few HGV:s use the traffic network at the time of day when the simulation takes place, why these assumptions are considered valid.

Vehicle and pedestrian routing choices are obtained from the previous investigation, based on traffic measurements conducted in Falkenberg, and are used in the cases where they are applicable. This previous investigation defines current background traffic as well as estimations based on experience concerning choice of path when leaving the parking lots. No alterations are made to these routes, why assumptions made in the previous investigation also apply in this master thesis. Remaining routing choices are based on estimations conducted within the scope of this master thesis. This applies for all pedestrian routing choices and the path selection for vehicles leaving the East parking lot. Due to the location of the arena, the majority of the vehicles originating from the East parking lot are assumed to drive towards the major road Kristineslättsallén. This may not be the case during queue build up situations, where drivers with local knowledge of the traffic system may use alternative roads to avoid congestion. However, no knowledge of such behaviour exists why this situation has not been incorporated in the model.

Regarding pedestrian route choices, the number of people travelling to each car as well as public transport users has been taken into consideration when determining these routes. The remaining pedestrians are divided equally between the remaining routes since no information could be obtained regarding pedestrian movement patterns. Furthermore, the majority of the defined destination points are located north of the arena, towards the city centre, resulting in a large pedestrian flow in this direction. This flow may be overestimated, as more people may travel south, but this configuration makes the simulation conservative as the northern flows have the largest impact on the traffic system. Therefore, due to the limitations of information regarding pedestrian movement, this conservative approach is considered more appropriate than reducing the pedestrian impact on the traffic system by a more south oriented routing pattern.

The behaviour of pedestrians in the model is based on the shortest path methodology, where an individual pedestrian always strive to travel the shortest distance from origin to destination, since the alternative and more realistic quickest path method, proved to be to computationally demanding. A consequence when using the shortest path method is that all modelled pedestrians strive to take the shortest path around corners, resulting in queues forming at these locations. To alleviate this problem, sharp corners are smoothened out and waypoints for pedestrians are inserted into the model, thereby promoting an increased pedestrian flow. This method is considered to simulate pedestrian movements adequately, since the more representative way of modelling pedestrian behaviour (i.e. quickest path method) is unavailable.

To enable the comparison of results from the software Capcal and PTV VISSIM, a way to define the capacity parameter in PTV VISSIM has to be developed since no such output is provided by the software itself. Furthermore, as there is no specific methodology for calculating capacity in PTV VISSIM, the methodology presented in Section 3.4.7, is developed in this master thesis according to theory considering the capacity concept. The method is based on the ability to determine when the traffic system is entering a congested state, why the method is dependent on the subjective opinion of the observer when this state occurs. By performing multiple simulation runs with different traffic flows, studying the times when the congested states are reached, it is considered that the defined capacities for the facilities are representative.

The default time for a simulation run spans over 3 600 seconds and since all pedestrians and vehicles originating from the event are observed to exit the modelled network during this time, the default time interval is not prolonged. A shorter time span is not considered necessary either, since the parking lots are emptied before the simulation ends, leaving a time interval during which a normalisation of the traffic system, containing only background traffic, can occur. A number of evaluation outputs are presented in 2.5 minutes time intervals. Shorter time segments can be defined, collecting more time specific data which demands a greater effort to compile and evaluate results. The 2.5 minutes time interval is considered suitable, in terms of effort versus accuracy of results, in order to obtain a representative evaluation of the traffic system.

5.2 Results

Modelling a realistic pedestrian and vehicle interaction is one of the most challenging parts of this master thesis. The interaction is based on observations conducted during the event study at Kinnarps Arena and are implemented in the PTV VISSIM model using priority rules. The priority rule parameters are modified to allow a certain number of vehicles to pass through high pedestrian flows, observed during the event study. Furthermore, vehicles have a tendency to inch forward through the pedestrian flow, a tendency that increases with higher pedestrian flows. An exact replication of this behaviour could not be achieved due to limitations in PTV VISSIM. The desired number of vehicles to pass through a high pedestrian flow could not be met as the modifications to the priority rules would allow too many vehicles to pass during a low pedestrian flow. Instead, priority rule parameters are defined to create a more representative general flow throughout the direct pedestrian influence period, with fewer vehicles passing through both high and low pedestrian flows. This approach generates more conservative results, with approximately one vehicle able to pass per minute at a high pedestrian flow during simulation compared to two vehicles per minute observed at the event study. Consequently, an underestimation of the number of vehicles able to exit the parking lots occurs during the direct pedestrian influence period, prolonging the evacuation process.

The interaction between vehicles is modelled using conflict areas. The emphasis when modifying the conflict areas has been to create an effective flow without formations of main routes through the traffic network facilities. Since the traffic situation does not exist and therefore cannot be used as a comparison, the governing parameters are altered to achieve a driving behaviour considered to be suitable in the situation occurring in this master thesis. The final setup of the conflict areas may be seen as overaggressive during normal circumstances, but in a situation like the one occurring in the simulation with long queues forming, drivers may be more alert to openings in the traffic stream resulting in a more aggressive driving style. When comparing the results for the time it takes to empty the parking lots without pedestrians in PTV VISSIM with the Capcal output, these correspond rather well indicating similar driver behaviours in the two models.

The results obtained from the background traffic travel times indicate that they are affected in a large extent after a high profile event. The direct pedestrian influence has the largest impact on the travel times, which can be seen in the charts in Section 4.1 as the height difference of the dark and light bars in the direct pedestrian influence period from 5 minutes to 17.5 minutes. In some time intervals, the height difference is 10 to 15 times higher when comparing the two bars to one another. Furthermore, the traffic originating from the parking lots seems to have a minor impact on the travel times for the background traffic. This conclusion can be drawn by comparing the maximum average travel times generated before and after the parking lots have been emptied at 42.5 minutes in simulations without pedestrians, where the difference in travel times never exceeds a twofold increase.

When studying the east and westbound background traffic travel time along Kristineslättsallén presented in Figure 24 and Figure 25 in Section 4.1, different patterns of accumulation and decline of travel time can be observed. In the eastbound direction, a steady increase of travel time until the maximum value is reached can be observed followed by a rapid decline which is explained by the existence of only one conflict point (i.e. the roundabout entry point) after the direct pedestrian influence period. This allows for a relatively unhindered traffic flow along this route which enables a rapid decrease in background traffic travel times. The westbound direction indicates a similar travel time increase pattern to the eastbound direction, with a steady accumulation during direct pedestrian influence. The exception is the missing bar in the 12.5 to 15 minutes time interval. This absence of data, explained by no vehicles able to complete the defined path, results in that the peak in travel time occurs at a later time interval for the eastbound traffic, thus prolonging the effect caused by the direct pedestrian influence. Moreover, the slower decrease of the travel time, in the westbound direction compared to the eastbound, is explained by the dissipation of the queue formed during the direct pedestrian influence period as well as the existence of two conflict points along this route. These conflict points are the entry point to the roundabout and the requirement to yield for left turning vehicles at the T-intersection, thereby disturbing the traffic traveling westbound along Kristineslättsallén.

Different patterns of increase and decline concerning background traffic travel time can also be observed when studying the results obtained from vehicles driving along Skogsvägen turning east and west in the T-intersection onto Kristineslättsallén. These results are presented in Figure 26 and Figure 27 in Section 4.1. The background traffic travel times for the vehicles turning east starts to be influenced by pedestrians after 10 minutes rather than 5 minutes for the other three travel time measurements. This time difference may be explained by it being the only route which does not travel through the roundabout where the pedestrian flows are highest. The peak travel time for vehicles turning east occur after two time intervals without any vehicles completing the route due to queue spill-back along Kristineslättsallén explained in Section 4.2. The built up queue prevent vehicles from turning west and consequently, vehicles with the desire to turn east, are held up in queue further upstream. During the dissipation of the queue, the travel times decline rapidly due to the possibility in the T-intersection to turn in either direction onto Kristineslättsallén. This indicates that the largest influence on background traffic travel time for the vehicles turning east is the queue spill-back effect. Studying the west turning traffic, the pedestrians in the model have a greater impact over a longer time period with a relatively slow decline of the background traffic travel time. Additionally, the number of time intervals without data collection is the highest among the four studied routes. This can be explained as a result of the above mentioned queue spill-back in combination with two conflict points arising at the T-intersection and roundabout hindering vehicles to complete their desired path.

The latent delay indicates that, during a simulation with pedestrians, approximately 15 minutes is spent by each car waiting to exit the parking lots. The individual time spent on the parking lots depend on the time interval a driver arrives to his or her car and at which parking lot the car is parked. However, an interpretation of the average latent delay can be that the time a driver can expect to be spending on a parking before being able to exit is 15 minutes. This value can be compared to the average latent delay without pedestrians which is 5 minutes, indicating a significant influence by the pedestrians on the waiting time at the parking lots.

As mentioned previously, the background traffic travel times and the latent delay indicate that pedestrians influence these performance measures. Additionally, the total average speed, presented in Section 4.3, and total average travel time also indicates a substantial pedestrian influence on the overall performance of the traffic network. The largest pedestrian influence occurs during the time period when the pedestrians interact directly with the vehicles. After the direct pedestrian influence ceases, the effects declines but still lingers on in the system as a delay of the evacuation process. This delay can be illustrated by the increased evacuation times from the parking lots with pedestrians present in the model. The West parking lot and August Bondessons väg takes respectively 13 and 10 minutes longer time to empty, which correlates rather well with the direct pedestrian influence period determined to last for 12.5 minutes. The evacuation time difference of only 1 minute with and without pedestrians from the East parking lot indicates that the pedestrians has less influence on this traffic facility. This may be explained by a relatively low flow of pedestrians at the T-intersection on Kristineslättsallén making the primary contributor to the increased evacuation time the queue spill-back effect along Kristineslättsallén.

Formation of main routes through the traffic network facilities influence the capacity and load rate results in PTV VISSIM. This behaviour is especially evident in the roundabout where a combination of approaching speed and turning motions contribute to the formation of these main routes. The approaching speed determines the time gap between vehicles, why a higher approaching speed reduces the time gap available for vehicles trying to enter the traffic stream. Due to higher speed limits on Kristineslättsallén, the available opportunities for vehicles coming from August Bondessons väg and the West parking lot to enter the traffic stream at the roundabout are reduced. The predefined routing choice distribution also influences the creation of main routes. As an example, no vehicles will exit the roundabout towards the West parking lot, thereby reducing the available time gaps for vehicles approaching from the West parking lot to enter the circulating traffic stream. The capacities for the main routes are higher than for other roads, a characteristic which can be observed in the roundabout where the east and west approaches have approximately twice as high capacities compared to the other two. The same pattern can be seen at the T-intersection on Kristineslättsallén, but the formation of main routes at this location is dependent on the yield requirements for vehicles on the minor road Skogsvägen, rather than current speed limits or turning motions.

The evacuation times as well as the capacity and load rate of the roundabout and T-intersection are ways of comparing the results from PTV VISSIM with Capcal. According to the PTV VISSIM simulations without pedestrians the West parking lot is emptied in approximately 36 minutes. This corresponds fairly well with the Capcal evaluation which estimates the same procedure to take around 40 minutes. The difference between the two results are small and may depend on the more aggressive driving style modelled at the roundabout. Comparing the results from the T-intersection, PTV VISSIM indicates that the evacuation time is approximately 25 minutes whereas Capcal suggests a 30 minute evacuation time. The difference in results may be explained by the possibility for two vehicles to turn in either direction simultaneously in the PTV VISSIM simulation, thereby speeding up the evacuation process.

The other ways of comparing results is the load rate and capacities calculated by the two software, presented in Section 4.5. The capacities for the different approaches at the roundabout do not correspond very well, with significantly higher capacities calculated in PTV VISSIM at the approaches along Kristineslättsallén and lower capacities at the others. This is due to the previously explained main route formation, also present in the Capcal calculation, but with a much smaller influence on the capacities. In contrast to the capacities, all load rates except the West parking lot approach matches rather well. The exception is explained by the low capacity at the

West parking lot approach, as a result of the formation of the main routes, together with a high vehicle flow exiting the parking lot. In the case of the T-intersection, the capacities at the approaches along Kristineslättsallén are almost identical between the two software. The capacity at the Skogsvägen approach is higher in PTV VISSIM due to the implementation on the right turn specific lane. The eastbound traffic flow is approximately three times higher in PTV VISSIM, which can be explained by the T-intersection being connected to the roundabout, enabling event specific traffic originating from the roundabout to influence the flow. In contrast, the T-intersection in Capcal is isolated, why only the background traffic travelling along Kristineslättsallén is taken into consideration. Another traffic flow that differs is the one at Skogsvägen, which is slightly lower in PTV VISSIM due to another setup of the routing choices at the eastern parking lot exit. In Capcal, all vehicles turn north thereby entering the T-intersection, whereas only 80 percent use this route in the PTV VISSM setup, thus reducing the amount of vehicles passing the intersection. Consequently, the difference in traffic flows affects these two load rates, why these do not correlate between the two software. However, the westbound approach indicates correlating values between the two software regarding actual flow, capacity and load rate. This can be explained by the similarities of the situation in PTV VISSIM and Capcal, where the traffic flow at this approach is unaffected by other traffic facilities and the only input being the background traffic.

5.3 Added value when using PTV VISSIM

The benefits when using PTV VISSIM compared to Capcal are many, enabling a more comprehensive analysis of a studied traffic network. The specific benefits when modelling the traffic situation surrounding the planned football stadium in Falkenberg are discussed in this section.

Capcal is limited in the study of a traffic network since it only evaluates isolated intersections. In order to study a more complex traffic system, as the one in this master thesis, individual studies of each intersection in the network must be carried out and assembled to evaluate the performance of the whole system. The capability to recreate a traffic network in PTV VISSIM, described in Chapter 3, enables the study of the whole traffic network as well as isolated sections within the network described above. This ability to construct whole traffic networks allows for the study of how intersections influence one another as well as how modes of communications interact with each other. PTV VISSIM is a multi-modal software, which allows for multiple communication means to be incorporated into a simulation. The ability to model pedestrian and bicycle movement in PTV VISSIM is very suitable in this master thesis due to the high share of spectators walking and cycling to and from the arena. This enables representative behaviour and movement modelling of the non-motorised modes of transport in the traffic systems. Capcal also has the ability to implement non-motorised means of transport, but in a more limited way compared to PTV VISSIM. The ability in Capcal to only register crossing pedestrians on the approaches to an intersection and not the exits could lead to an overestimation of vehicles able to pass through, since vehicles yielding for pedestrians at the exits may hinder the flow through the facility thereby reducing the capacity.

By creating models of complex traffic situations in PTV VISSIM it is possible to evaluate overall network performance parameters as well as parameters for specific situations of interest occurring along routes and in intersections. In this master thesis, results regarding latent delay, average travel time and average speed in system are used as an indication of how the system performs during specific time intervals. This form of evaluation cannot be achieved using Capcal since only isolated traffic facilities can be studied. Furthermore, the evacuation time for the parking lots can be determined precisely by using PTV VISSIM, compared to Capcal which only enables estimations of the evacuation time.

Due to the ability to replicate complex traffic situations in PTV VISSIM, together with the possibility to carry out more in depth analyses, it is a more time consuming and computational demanding tool to use than Capcal. It is therefore important to consider the scope of the project when deciding which software most suitable to use.

6 Conclusion

The purpose of this master thesis is to evaluate the traffic situation after a high profile event at a planned football stadium in Falkenberg. The results indicate that the overall performance of the traffic system varies during the hour following the end of the event. Using performance measures, the traffic situation is evaluated and trends in the network performance are identified. Consequently, the traffic system performance is divided into five time segments with different characteristics. In the beginning of the hour, the direct pedestrian influence affects the traffic performance most noticeably, indicated by multiple performance measures. A rapid improvement of the performance is observed when pedestrians no longer are present in the model. Thereafter, the queues, accumulated during the direct pedestrian influence, hinder free vehicle movements thus affecting the overall performance in the system. In the last identified time segment, the performance is not affected by any external influence, but are instead limited by the ability for the traffic facilities to process traffic utilising the network.

Studying the traffic performance measures, there is an apparent influence on the traffic network performance caused by the presence of pedestrians in the system. The total average travel time in the network and background traffic travel times increases significantly during the direct pedestrian influence. The pedestrian influence is also evident when comparing evacuation times from the parking lots with and without pedestrians present in the model. The West parking lot and August Bondessons väg are considerably affected, where the increase in evacuation time corresponds well with the duration of direct pedestrian influence. However, the East parking lot is only influenced marginally, indicating a smaller impact by pedestrians at this location.

As stated in the purpose, possible differences in result between PTV VISSIM and Capcal are studied. Regarding the evacuation times without pedestrians, PTV VISSIM calculates a five minutes lower evacuation time compared to Capcal. This is a result of a more aggressive driving style applied at the roundabout in PTV VISSIM as well as the possibility for two vehicles to turn in either direction simultaneously at the southern approach of the T-intersection. The capacities calculated in PTV VISSIM and Capcal have a better correlation for the roundabout than the T-intersection. In contrast, the load rates correlates better for the T-intersection. This is explained by two situations occurring in the PTV VISSIM simulation; the formation of main routes in the roundabout influencing the capacity and the increased flow in the T-intersection as a result of being connected to the roundabout.

PTV VISSIM provides the ability to recreate and analyse complex traffic systems and enables for an overall network performance analysis as well as the study of specific situations of interest occurring in the network. In this master thesis, the average travel time and speed as well as latent delay have been used to evaluate the overall network performance, which cannot be done using Capcal. Furthermore, outputs from PTV VISSIM can be used to determine precise evacuation times for the different parking lots, whereas Capcal only can estimate evacuation times. However, PTV VISSIM is a more time consuming and computationally demanding tool than Capcal, why it is important to consider the scope of the project before deciding which software to use.

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Appendix 1 Event Study Protocol

Time interval [min]	Pedestrian density	Passed cars	passed cars tot	Vehicle density
0-2	4	7	3	1
2-4	5	5	8	3
4-6	5	6	14	4
6-8	4	12	26	4
8-10	3	5	31	5
10-12	1			Not reliable results after this due to vehicle queues and low pedestrian flows

Appendix 2 Input Volume Calculations

Vehicle and pedestrian input values and distributions are based on the previously conducted investigation, the estimation of communication means presented in Falkenbergs Kommun, (2012) and the event study described in Section 3.1

Communication mean distribution

Assumed spectator number at a high profile event is 6000 people. The estimated use of different communication means is: 40 % travel by car, 30 % on foot, 24 % by bicycle, 2 % by PT and another 4 % using other transportation not specified in the report. The distribution of the different communication means used by the spectators are:

Mode of transport	Fraction of spectators	Number of spetators
Car	6000*0,4	2400
Foot	6000*0,3	1800
Bicycle	6000*0,24	1440
PT	6000*0,02	120

Vehicle input distribution

It is estimated that two people travel in each car, resulting in a total number of $\frac{2400}{2} = 1200$ cars. The amount of cars modelled to use the different parking lots are; 420 cars at West parking lot, 200 at the East parking lot and 290 of the cars parking north of Kristineslättsallén exiting via August Bondessons väg during the simulation.

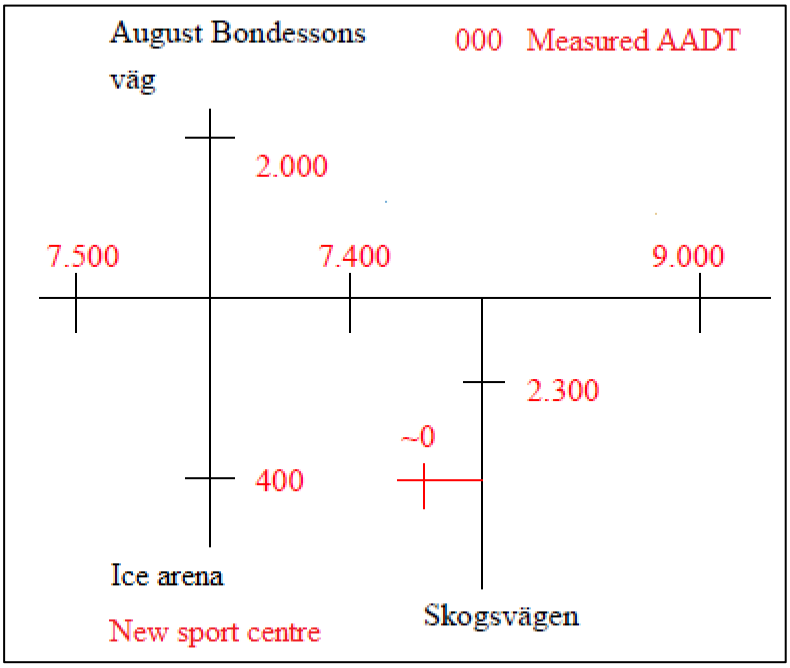
Different vehicle flow distributions are used for the parking lots to simulate the situation arising after an event, when the amount of drivers wanting to exit varies during different time intervals. The numbers of vehicles modelled to exit the parking lots at different time intervals are;

	Vehicle number[veh/interval]					
Parking lot	0-5 min	5-10 min	10-20 min	20-30 min	30-40 min	40-60 min
East parking lot	0	50	100	50	0	0
Wast parking lot	0	50	350	20	0	0
August Bondessons väg	0	0	50	200	40	0

Since input volumes must be specified in vehicles per hour in PTV VISSIM, the desired number of vehicles are recalculated using Equation 1, presented in Section3.4.4. Vehicle numbers during 5-minute intervals are multiplied by a factor $\frac{1}{\left(\frac{5}{60}\right)} = 12$ and 10-minute intervals by$\frac{1}{\left(\frac{10}{60}\right)} = 6$. The inserted vehicle volumes during different time intervals are:

	Input vehicle volumes [veh/h]					
Input point	0-5 min	5-10 min	10-20 min	20-30 min	30-40 min	40-60 min
East parking lot	0	600	600	300	0	0
Wast parking lot	0	600	2100	120	0	0
August Bondessons väg	0	0	300	1200	240	0

The background traffic during the time of the simulation is defined as 6 % of the AADT, determined from a traffic measurement in conducted in Falkenberg in 2010. The results obtained in the measurement are presented below.



Resulting background vehicle flows are:

Road	AADT [veh/day]	Background traffic [veh/h]
Kristineslättsallén Eastbound	3750	225
Kristineslättsallén Eastbound	4500	270
August Bondessons Väg Southbound	1000	60
Skogsvägen Northbound	1150	69

Using the vehicle flow distribution for the parking lots and the background traffic volume during the time of the simulation, the defined vehicle inputs used during simulation are:

Input point	Input vehicle volumes [veh/h]					
	0-5 min	5-10 min	10-20 min	20-30 min	30-40 min	40-60 min
Kristineslättsallén Eastbound	225	225	225	225	225	225
Kristineslättsallén Westbound	270	270	270	270	270	270
Skogsvägen Northbound	70	70	70	70	70	70
August Bondessons väg Southbound	60	60	60	60	60	60
East parking lot	0	600	600	300	0	0
Wast parking lot	0	600	2100	120	0	0
August Bondessons väg	0	0	300	1200	240	0

Pedestrian and bicycle input distribution

Pedestrian and bicycle inputs are distributed in order to reproduce pedestrian behaviour observed during the event study. Spectators walking on foot, using PT or have parked north of Kristineslättsallén as well as travelling by bicycle are introduced into the model. The number of pedestrians and bicycles entered into the model are:

Mode of transport	Number introduced in model
Foot	1800
PT	120
Vehicle parked north of Kristineslättallén	580*2 = 1160
In total	3080
Bike	1440

The distribution of the number of bicycles and pedestrians simulated to leave the arena at different input points during the specific time intervals are:

	Pedestrian and bicycle input [number/interval]					
Input point	0-2.5 min	2.5-5 min	5-10 min	10-15 min	15-20 min	20-60 min
North Exit	77	307	921	231	0	0
South Exit	77	307	921	231	0	0
West Bicycle parking	0	72	240	120	48	0
Middle Bicycle parking	0	72	240	120	48	0
East Bicycle parking	0	72	240	120	48	0

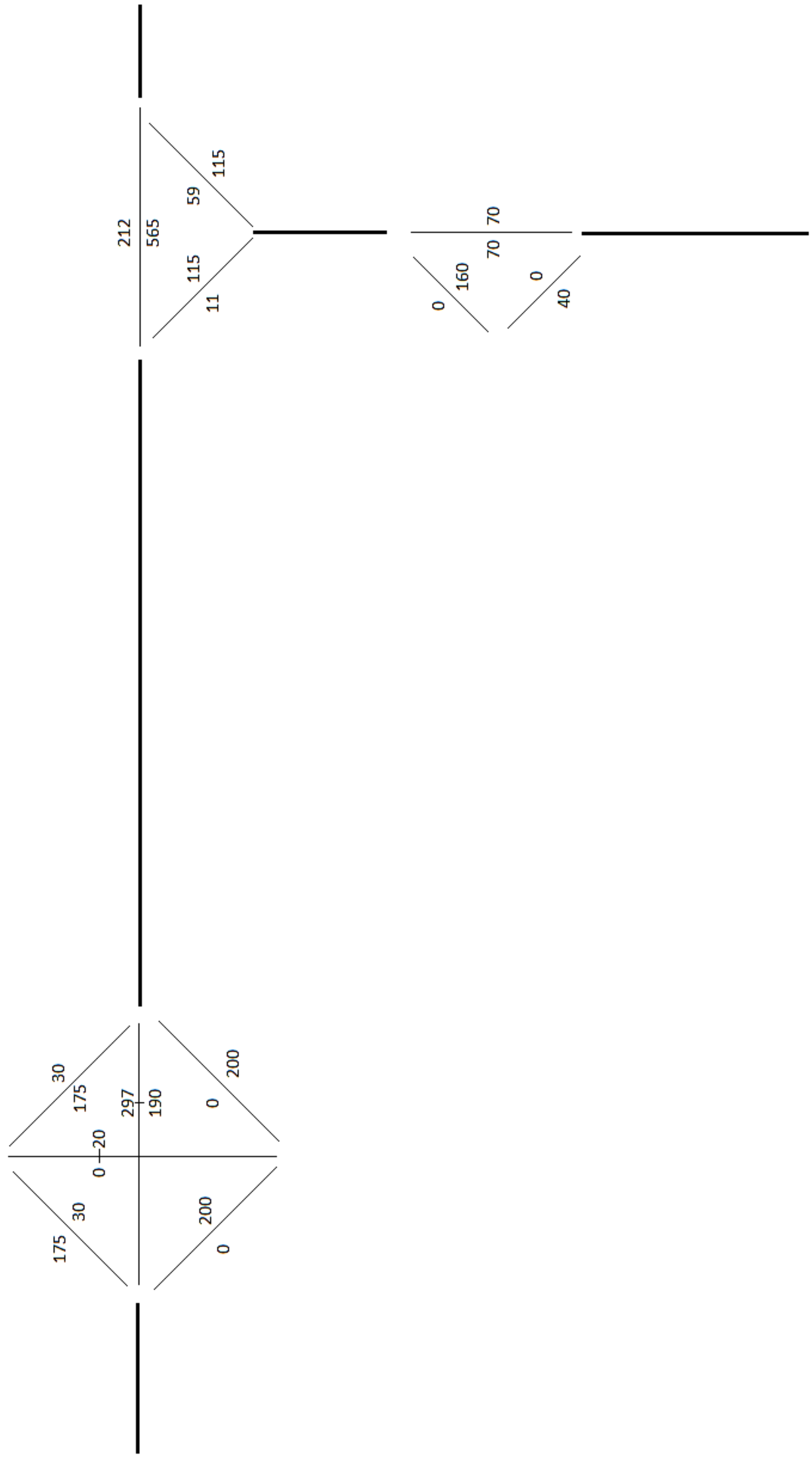
As for vehicle inputs, pedestrian and bicycle inputs must be defined in pedestrians/bicycles per hour. Therefore, the numbers of pedestrians/bicycles per interval are recalculated to input volumes using the same equation as is for the vehicle volumes. Pedestrian/bicycle numbers during 2.5-minute intervals are multiplied by a factor $\frac{1}{\left(\frac{2.5}{60}\right)} = 24$ and 5-minute intervals by $\frac{1}{\left(\frac{5}{60}\right)} = 12.$

The calculated pedestrian/bicycle volumes used in the simulation during different time intervals are:

	Pedestrian and bicycle input [number/h]					
Input point	0-2.5 min	2.5-5 min	5-10 min	10-15 min	15-20 min	20-60 min
North Exit	1848	7368	11052	2772	0	0
South Exit	1848	7368	11052	2772	0	0
West Bicycle parking	0	1728	2880	1440	576	0
Middle Bicycle parking	0	1728	2880	1440	576	0
East Bicycle parking	0	1728	2880	1440	576	0

Appendix 3 Routing Decisions

<u>Vehicle routing decisions</u>



Above, a schematic overview of the studied network is presented. The numbers represents the division in amounts per vehicles turning in each direction in the T-intersections and the roundabout.

Pedestrian routing decisions

Count: 24	PedRoutDecSta	RelFlow(0)	Count: 24	PedRoutDecSta	RelFlow(0)
1	1	129.000	13	2	419.000
2	1	129.000	14	2	129.000
3	1	419.000	15	2	129.000
4	1	419.000	16	2	129.000
5	1	129.000	17	2	30.000
6	1	129.000	18	2	30.000
7	1	129.000	19	3	1.000
8	1	30.000	20	3	1.000
9	1	30.000	21	4	1.000
10	2	129.000	22	4	1.000
11	2	129.000	23	5	1.000
12	2	419.000	24	5	1.000

The table above shows the pedestrian and bicycle routing choices applied in PTV VISSIM. Count 1-18 are pedestrian route choices and Count 19-24 are bicycle route choices. All bicycle routes are equally distributed, why all these rows all have the same number. The pedestrian routes are described by a number which represents the actual number of pedestrians choosing each route respectively. The counts 8, 9, 17 and 18 represent the PT-passengers which are a total of 120 people evacuating the arena. These pedestrians are divided equally to both exits of the arena as well as the two PT stops of which they desire to travel to. This results in $\frac{120}{4} = 30$ pedestrians at each PT routing decision. The remaining 14 pedestrian routing decisions (i.e. 1-7 and 10-16) comprises of two components; the equally distributed pedestrians originating from the arena travelling by foot and the pedestrians travelling through the network on the way to their car. The pedestrians originating from the arena, a total of 1 800 people, are equally divided on all 14 pedestrian routes resulting in $\frac{1\,800}{14} = 129$ pedestrians on each route. Four of the routes (i.e. 3, 4, 12 and 13) also have the number of pedestrians travelling through the network on the way to their car included. In order to calculate how many pedestrians to be added to these routes the total number of vehicles parked north of the arena is multiplied by the occupancy in each car, $580 \times 2 = 1160$ pedestrians. These pedestrians will use the four routes and are divided equally on each route, $\frac{1\,160}{4} = 290$ pedestrians. These are added to the pedestrians travelling by foot resulting in $290 + 129 = 419$ pedestrians using routes 3, 4, 12 and 13.

Appendix 4 Bus Timetable

Bus 3

3 Stortorget - Bussterminalen - Slätten - Hjortsberg
Från hållplats: Stortorget

	Måndag-Fredag	Lördag	Sön/Helgdag
tim	min	min	min
7	05		
8	05		
9	03	03	
10	03	03	
11	03	03	
12	03	03	
13	03[a]	03	Ingen trafik
14	14	03	
15	14		
16	14		
17	20		
18	20		
19	20		

a = Går via Hertingsskolan. Går ej Halmstadvägen.

3 Hjortsberg - Slätten - Bussterminalen - Stortorget
Från hållplats: Hjortsberg

	Måndag-Fredag	Lördag	Sön/Helgdag
tim	min	min	min
5	44		
6	44		
7	24[b]		
8	24		
9	24[a]	24[a]	
10	24[a]	24[a]	
11	24[a]	24[a]	
12	24[a]	24[a]	Ingen trafik
13	28[a]	24[a]	
14	34[a]	24	
15	34[a]		
16	34[a]		
17	39		
18	39		
19	39		

a = Fortsätter efter Stortorget som linje 6.
b = Går via Hertingsskolan. Går ej via Halmstadvägen. Ankommer Stortorget ca 07.50

Bus 351

Giltig 2013-12-15–2014-12-13, Uppdaterad 2013-12-13

351 Halmstad - Kvibille - Getinge - Falkenberg

	Måndag till fredag															
ANMÄRKNING			b,e		e											
Halmstad Regionbussterm.	**05.22**	**05.42**	**06.22**	**06.42**	**07.42**	**08.42**	**09.42**	**11.12**	**12.12**	**13.42**	**14.42**	**15.10**	**15.40**	**16.10**	**16.40**	**17.10**
Halmstad Västerbro (Karl XI:s väg)	05.26	05.46	06.26	06.46	07.47	08.47	09.47	11.17	12.17	13.47	14.47	15.15	15.45	16.15	16.45	17.15
Halmstad Regementet	05.32	05.52	06.32	06.52	07.54	08.54	09.54	11.24	12.24	13.54	14.55	15.23	15.53	16.24	16.54	17.23
Halmstad Stenstorpsskolan	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Holm	05.37	06.00	06.40	07.01	08.03	09.02	10.02	11.32	12.32	14.02	15.03	15.31	16.01	16.32	17.02	17.31
Kvibille	05.45	06.08	06.48	07.09	08.11	09.11	10.11	11.41	12.43	14.13	15.14	15.42	16.12	16.43	17.13	17.42
Getinge Motell	05.57	06.20	07.04	07.18	08.26	09.25	10.25	11.55	12.57	14.27	15.28	15.56	16.26	16.57	17.27	17.56
Getinge Vårdcentral	X	X	06.56	|	X	X	X	X	X	X	X	X	X	X	X	X
Getinge	**05.55**	**06.18**	**07.01b**	**07.21**	**08.23**	**09.22**	**10.22**	**11.52**	**12.54**	**14.24**	**15.25**	**15.53**	**16.23**	**16.54**	**17.24**	**17.53**
Slöinge Göteborgsvägen	06.02	06.25	07.11		08.31	09.30	10.30	12.00	13.02	14.32	15.33	16.01	16.31	17.02	17.32	18.01
Slöinge Björkgatan	06.05	06.28	07.14		08.34	09.34	10.34	12.04	13.06	14.36	15.37	16.05	16.35	17.06	17.36	18.04
Heberg station	06.10	06.33	07.20		08.39	09.39	10.39	12.09	13.11	14.41	15.42	16.10	16.40	17.11	17.41	18.09
Hebergs skola	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X
Skrea korsväg	06.15	06.38	07.27		08.45	09.44	10.44	12.14	13.16	14.46	15.48	16.16	16.46	17.16	17.46	18.14
Falkenberg Hjortsbergsvägen	|	|	|		|	|	|	|	|	|	|	|	|	|	|	|
Falkenberg Slättenvägen	06.20	06.42	07.31e		08.49e	09.48	10.48	12.18	13.20	14.50	15.52	16.20	16.50	17.20	17.50	18.18
Falkenbergs bussterminal	**06.29**	**06.50**	**07.39**		**08.57**	**09.56**	**10.56**	**12.26**	**13.28**	**14.58**	**15.59**	**16.29**	**16.59**	**17.28**	**17.59**	**18.25**

Bus 517

Giltig 2013-12-15–2014-12-13, Uppdaterad 2013-12-13

517 Falkenberg - Årstad - Bjärnared

	M,O,F			Måndag till fredag						
ANMÄRKNING	E,S	E,S	E,S	a,E,V	E,V	E,V	E,V	E,V	E,V	E,V
Falkenbergs bussterminal	**10.55**	**12.45**	**14.20**	**07.50**	**08.50**	**10.55**	**12.45**	**14.20**	**15.20**	**16.20**
Falkenberg Stortorget	X	X	X	|	X	X	X	X	X	X
Falkenberg Vårdcentralen	10.58	12.48	14.23	|	08.53	10.58	12.48	14.23	15.23	16.23
Falkenberg Östra gärdet	X	X	X	|	X	X	X	X	X	X
Falkenberg Hjortsbergsvägen	|	|	|	X	|	|	|	|	|	|
Heberg	|	|	|	08.18	|	|	|	|	|	|
Hebergs skola	|	|	|	X	|	|	|	|	|	|
Gödastorp	11.05	12.55	14.30	|	09.00	11.05	12.55	14.30	15.30	16.30
Årstad	**11.10**	**13.00**	**14.35**	|	**09.05**	**11.10**	**13.00**	**14.35**	**15.35**	**16.35**
Årstad kyrka	11.11	13.01	14.36	08.30	09.06	11.11	13.01	14.36	15.36	16.36
Asige			14.45					14.45	15.45	16.45
Abild			14.53					14.53	15.53	16.53A
Mosilt										17.00A
Bjärnared										**17.05A**

Appendix 5 Capcal Inputs and Results

Capcal inputs and results for the roundabout

Capcal 3.9.0.2 - 55. K-allén-IP, 2015, 6000, 40 min

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55. K-allén-IP, 2015, 6000, 40 min
Korsningstyp: Cirkulationsplats

Körfältsuppgifter

Tillfart	Körfält	Riktning	Kort körfält (m)	Bredd (m)
A	1	HRV		3.5
B	1	HRV		3.5
C	1	HRV		3.5
D	1	HRV		3.5

Växlingssträckor

Tillfart	Längd (m)	Körfält i cpl
A	16	1
B	16	1
C	16	1
D	16	1

Hastigheter

Tillfart	Led	Lokal
A	70	70
B	30	30
C	70	70
D	30	30

Flöden per riktning

Tillfart	Höger	Rakt fram	Vänster
A	0	190	30
B	248	0	248
C	30	190	0
D	300	30	300

Flöden per fordonstyp

Tillfart	Tunga fordon (%)	Cyklar/h	Fotgängare/h
A	8	0	0
B	3	0	0
C	8	0	0
D	3	0	0

Flöden per körfält

Samtliga tillfarter har beräknade körfältsflöden.

Flöden per tillfart

Tillfart	Flöde
A	220
B	496
C	220
D	630
Summa	1566

Sida 1 av 3 Utskrivet 2013-11-29 12:12:45

Capcal 3.9.0.2 - 55. K-allén-IP, 2015, 6000, 40 min

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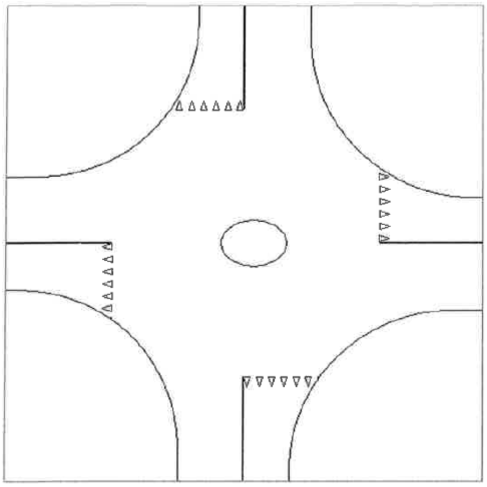
Korsningsbild



Resultat, en timme.

Kapacitet och kölängder per körfält

Tillfart	Körfält	Riktning	Flöde (f/t)	Kapacitet (f/t)	Belastningsgrad	Kölängd (antal fordon) Medel	90-percentil
A	1	HRV	220	1169	0.19	0.1	0.1
B	1	HRV	496	948	0.52	0.6	1.2
C	1	HRV	220	1045	0.21	0.1	0.1
D	1	HRV	630	969	0.65	0.9	2.1

Fördröjning och andel stopp per körfält

Tillfart	Körfält	Fördröjning s/f Konflikt	Geom.	Totalt	Andel fördröjda % Konflikt	Geom.	Totalt	Andel som stannar
A	1	1	10	10	37	63	100	1
B	1	5	7	10	67	33	100	21
C	1	2	10	10	47	53	100	3
D	1	6	7	12	73	27	100	23
Alla fordon		4	8	11	62	38	100	17

Sida 2 av 3 Utskrivet 2013-11-29 12:12:45

Capcal inputs and results for the T-intersection

Capcal 3.9.0.2 - 45. K-allén-Skogsv, 2015, 6000, väjn, 30 min

N:\103\12\1031216\U\Beräkningar\Ka-Sk,6000-10.isc   Licensägare: Norconsult AB, Väg och Bana / Trafik, Göteborg,

45. K-allén-Skogsv, 2015, 6000, väjn, 30 min
Korsningstyp: Väjningsplikt

Körfältsuppgifter

Tillfart	Körfält	Riktning	Kort körfält (m)	Bredd (m)
A	1	HR		3.5
C	1	RV		3.5
D	1	HV		3.5

Geometri

Tillfart	Stopplinje	Radie hsv	Vinkel	Lutning %
A		12	90	0
C		12	90	0
D		12	90	0

Frånfarter och refuger

Tillfart	Frånfartsbredd (m)	Vägrensbredd (m)
A	5.0	0.0
C	5.0	0.0
D	5.0	

Hastigheter

Tillfart	Led	Lokal
A	70	70
C	70	70
D	30	30

Flöden per riktning

Tillfart	Höger	Rakt fram	Vänster
A	11	212	
C		212	59
D	259		211

Flöden per fordonstyp

Tillfart	Tunga fordon (%)	Cyklar/h	Fotgängare/h
A	8	0	0
C	8	0	0
D	3	0	0

Flöden per körfält
Samtliga tillfarter har beräknade körfältsflöden.

Flöden per tillfart

Tillfart	Flöde
A	223
C	271
D	470
Summa	964

Sida 1 av 2   Utskrivet 2013-11-29 11:30:43

Capcal 3.9.0.2 - 45. K-allén-Skogsv, 2015, 6000, väjn, 30 min

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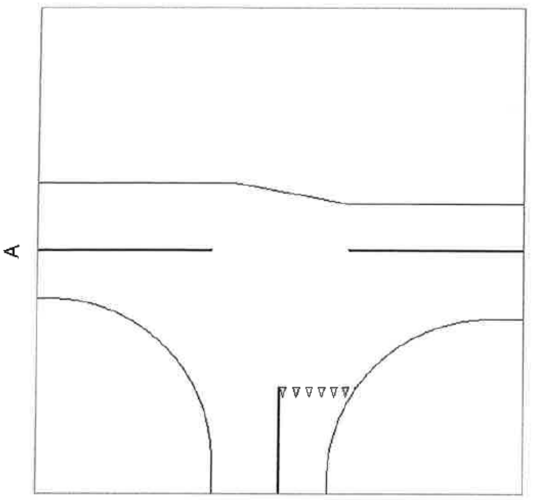
Korsningsbild



Resultat, en timme.

Kapacitet och kölängder per körfält

Tillfart	Körfält	Riktning	Flöde (f/t)	Kapacitet (f/t)	Belastningsgrad	Kölängd (antal fordon) Medel	Kölängd (antal fordon) 90-percentil
A	1	HR	223	1852	0.12	0.0	0.0
C	1	RV	271	1452	0.19	0.1	0.1
D	1	HV	470	635	0.74	1.8	4.2

Fördröjning och andel stopp per körfält

Tillfart	Körfält	Fördröjning s/f Konflikt	Geom.	Totalt	Andel fördröjda % Konflikt	Geom.	Totalt	Andel som stannar
A	1	0	0	0	0	6	6	0
C	1	1	2	2	11	21	32	2
D	1	14	6	19	79	21	100	34
Alla fordon		7	3	10	42	17	59	17

Fördröjning och andel stopp per riktning

Tillfart	Riktning	Fördröjning s/f Konflikt	Geom.	Totalt	Andel fördröjda % Konflikt	Geom.	Totalt	Andel som stannar
A	Hsv	0	4	4	0	100	100	0
	Rfr	0	0	0	0	1	1	0
	Alla	0	0	0	0	6	6	0
C	Rfr	0	1	1	6	7	12	0
	Vsv	4	6	6	30	70	100	8
	Alla	1	2	2	11	21	32	2
D	Hsv	14	5	18	75	25	100	36
	Vsv	15	6	19	85	15	100	33
	Alla	14	6	19	79	21	100	34
Total fördröjning (timmar)		2.6						

Sida 2 av 2 Utskrivet 2013-11-29 11:30:43