Thesis 194

Analysis of gap acceptance in a saturated two-lane roundabout and implementation of critical gaps in VISSIM

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Keywords:
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Abstract:
This thesis overview the gap acceptance behaviour in a saturated two-lane roundabout and the implementation of local measured critical gap times into microscopic simulation. The purpose is to measure the critical gaps in a saturated two-lane roundabout to investigate how gap acceptance differs between entering vehicles depending on desired direction and position of circulating vehicles. An additional purpose is to implement the measured critical gap times into the traffic simulation software VISSIM and compare the simulated results with results given by VISSIM default values. The thesis includes a literature study on subjects related to micro simulation and gap acceptance of two-lane roundabouts. The used data was collected in a field study of the saturated two-lane roundabout Spillepengen in Malmoe, Sweden. VISSIM was used to build and run two microscopic simulation models to test different values of critical gaps. Conclusion is that there is a significant difference in gap acceptance depending on desired direction and position of circulating vehicles. Another conclusion is that the default values for minimum gap in VISSIM generate the same result as the implemented measured values from the field study. The results also show that the headway distribution of the circulating flow is of great importance to simulate a correct entry capacity.

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Preface

This thesis was done at the Department of Technology and Society at Lund Institute of Technology, Lund University. The work was mostly carried out during the autumn of 2009 and completed in January 2010.

The authors would like to thank Jonas Andersson at Tyréns AB for initiating the thesis and for the heads up in VISSIM simulation. Thank also to the Tyréns AB office in Helsingborg for supplying workplace and VISSIM software. An additional thank to Thomas Jonsson at the Department of Technology and Society who provided necessary help with the camera equipment used in the field study.

Last but not least the authors would like to thank their supervisor at the Department of Technology and Society Zsuzsanna Toth-Szabo for your advices, necessary help and everlasting good mood.

Lund, January 2010

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Summary

When traffic in Swedish conurbation areas becomes more and more saturated there is a demand for more accurate traffic simulation results. Some nodes in the traffic network have already reached saturation flow at peak hour. To increase the reliability of microscopic simulation data about local road user behaviour at current traffic situation needs to be implemented in the software. This thesis look at gap acceptance and how well the default values for minimum gap in the microscopic simulation software package VISSIM works in a saturated two-lane roundabout compared to measured values.

The method used in the thesis consists of three larger elements: literature study, data collection and data analysis. The data collection contains a field study, video analysis, model building and data processing. In the data analysis all results were compared and different hypotheses were tested. The literature study was carried out through the project alongside the other elements. The literature study concentrates on roundabouts, gap acceptance, headway distribution, microscopic simulation and VISSIM. This to cover all the necessary information needed to understand and complete this thesis.

Roundabouts are a type of intersection and they are usually unsignalised. Some key element for roundabouts are that only two traffic streams interacts and they provide greater safety benefits compared to other intersections. The two major factors that influence the capacity of a roundabout is the geometry of the different components and the flow in the circulatory roadway. When a driver is waiting to enter into the circulation he must wait until an acceptable gap occurs. The waiting time depends on the headway distribution and which critical gap the driver can accept. Microscopic simulation models describe the system entities with its activities and interactions at a high level of detail, which makes it possible to follow individual vehicles through the network. The selected simulation software VISSIM uses a discrete, stochastic, time-step based microscopic model. The model uses a psycho-physical car following model and a rule based algorithm for lateral movements.

The two-lane roundabout of Spillepengen, Malmoe was selected as study object in the thesis. Spillepengen is saturated at some legs both during morning and afternoon rush hour traffic. The videos captured during the field study were analysed and accepted and rejected gaps were noted in different categories depending on which type of vehicle entering and the lane of the two vehicles that produced the gap. Simulation models of Spillepengen were created in VISISM to be able to compare measured data with simulated data.

The result shows that there is a significant difference in gap acceptance depending on which lane the first vehicle of a gap is situated inside the roundabout. Drivers that desire to turn right have longer accepted mean gap times than those who desire to move straight trough the roundabout. The result also indicates that the default values for minimum gap in VISSIM generate the same result as the implemented critical gap values calculated from the field study. The VISSIM comparison moreover show that follow-up times in VISSIM are lower than the measured ones from the field study and that minimum gap time in VISSIM has no influence on the generated follow-up times. At last in the result a test was made to investigate the accuracy in using conflict areas to model a two-lane roundabout. According to the result conflict areas should not be used when simulating two-lane roundabouts, instead priority rules is to be preferred.

Despite the fact that VISSIM generates higher accepted mean gap times and follow-up times than those measured in Spillepengen, there is no major difference in entry capacity between them. This might have something to do with the inconsequent behaviour of drivers while vehicles in VISSIM are more consequent.

Furthermore it is concluded that the headway distribution of the circulating flow is of great importance to simulate a correct entry capacity. This indicates that modelling the correct headway distribution is the key feature in VISSIM simulation of two-lane roundabouts. It is most likely more important than to obtain the correct critical gap time due to the fact that the VISSIM default values for minimum gap time seems to correspond well to the real situation.

Sammanfattning

När trafiken i svenska storstadsregioner närmar sig mättnadsflöde uppstår ett behov av noggrannare trafiksimuleringsmodeller för dessa omständigheter. Vissa punkter i trafiknätet har redan uppnått mättnadsflöde vid rusningstrafik. För att öka pålitligheten i mikrosimulering måste det lokala trafikantbeteendet vid rådande trafiksituation implementeras i simuleringsprogrammen. Det här examensarbetet tittar på acceptans av tidsluckor för att undersöka hur väl VISSIMs förinställda fungerar i tvåfältig cirkulationsplats med mättnadsflöde för att sedan även jämföra om uppmätta värden fungerar bättre.

Metoden för examensarbetet består av tre större delar: datainsamling, analys samt litteraturstudie. Datainsamlingen innehåller en fältstudie, videoanalys, modellkonstruktion och databehandling. I analysen jämförs alla resultat och olika hypoteser testas. Den sista delen har genomförts genom hela projektet vid sidan av de andra delarna och fokuserar på funktionen av en cirkulationsplats, minsta kritiska tidsavstånd, tidsavståndsfördelning, mikrosimulering och VISSIM. Detta för att inkludera all nödvändig kunskap för att förstå samt utföra denna studie.

Cirkulationsplatser är en typ av trafikkorsning som normalt sett är osignalerade. Då endast två trafikströmmar möts i en cirkulationsplats bibehålls en högre trafiksäkerhet än i konventionella korsningar. De två främsta faktorerna i en cirkulationsplats som påverkar kapaciteten är geometrin samt flödet i cirkulationen. När en förare vill komma in i cirkulationen måste han eller hon vänta tills en acceptabel lucka uppstår. Denna väntetid beror på tidsavståndsfördelningen och vilket kritiskt tidsavstånd som föraren kan tänka sig att acceptera.

Mikrosimuleringsmodeller beskriver ett trafiksystems enheter med dess aktiviteter och interaktioner på en högdetaljerad nivå vilket gör det möjligt att följa enskilda fordon genom trafiknätet. Det utvalda simuleringsprogrammet VISSIM använder en diskret, stokastisk, tidstegsbaserad mikroskopisk modell.

Den tvåfältiga cirkulationsplatsen vid Spillepengen i Malmö valdes till studieobjekt i examensarbetet. Spillepengen når mättnadsflöde under en tid i ett par av benen vid rusningstrafik både morgon och eftermiddag. De under fältstudien inspelade videofilmerna analyserades och accepterade samt förkastade tidsluckor noterades i olika kategorier beroende på vilken typ av fordon det gällde samt vilket körfält de två fordon som producerar luckan befinner sig i. Simuleringsmodeller av Spillepengen byggdes upp i VISSIM för att kunna jämföra de uppmätta värdena med de simulerade värdena.

Resultatet visar att det finns en signifikant skillnad i tidsluckaacceptans beroende på vilket körfält som fordonet före luckan befinner sig inuti cirkulationen. Förare som svänger höger har högre medelvärde på tidsluckaacceptansen än de som väljer att köra rakt fram i cirkulationen. Resultatet indikerar också att de förinställda värdena på kritisk tidslucka i VISSIM genererar samma resultat som de implementerade uppmätta värdena från fältstudien. Jämförelsen med VISSIM visar även att följtiderna i VISSIM är lägre än de uppmätta följtiderna i Spillepengen och att minsta kritiska tidslucka i VISSIM inte har något inflytande över de genererade följtiderna. Till sist i resultatet redovisas ett test där noggrannheten i användandet av konfliktareor i VISSIM vid simulering av tvåfältiga cirkulationsplatser undersöks. Enligt resultatet av denna undersökning bör konfliktareor

inte användas vid simulering av tvåfältiga cirkulationsplatser, istället är prioriteringsregler att föredra.

Trots det faktum att VISSIM genererar högre medelvärden på accepterade tidsluckor och följtider än the uppmätta värdena i Spillepengen så blir det i simuleringen ingen större skillnad mellan de två. Detta kan ha något att göra med det inkonsekventa beteende som förare har i verkligheten medans de simulerade förarna i VISSIM är mer konsekventa.

Detta examensarbete fastlår även att tidsavståndsfördelningen i det cirkulerande flödet är mycket viktigt för att kunna simulera korrekt entrékapacitet. Detta indikerar att en korrekt tidsavståndsfördelning är av stor vikt i VISSIM vid simulering av tvåfältiga cirkulationsplatser. Högst sannolikt viktigare än att erhålla rätt kritiskt tidsavstånd. Detta då de förinställda värdena för kritiska tidsavstånd i VISSIM verkar stämma bra överrens med den verkliga situationen.

Contents

1 Introduction

Road user behaviours differ between geographical regions, not only between countries but also within country borders. A number of aspects affect the driving behaviour such as road geometry, flow rate, level of congestion, weather, driving skills, driving culture and much more. These are all parameters that are different for each situation and network. Some of them can be used in traffic simulations and some of them not.

When doing microscopic traffic simulations road user behaviour is of high importance. Simulation software at this level has default values of road user behaviour that could be used when simulating. The question is how accurate these values are for the investigated network?

This thesis investigates the importance of implementing the correct values of gap acceptance into micro simulation models. The study object is a saturated two-lane roundabout. The thesis also show how gap acceptance diverse between desired direction and the dependency of in which circulating lane the gap is situated.

1.1 Background

The United Kingdom adopted mandatory give-way rule at circular intersections in the 1960's. This required the entering traffic to give way or yield to circulating traffic. By this, roundabouts were prevented from locking up and entering vehicles had to wait before entering until a sufficient gap occurred in the circulating traffic. (FHWA 2000, p 2)

In Sweden there has been built a lot of roundabouts in recent years. The roundabouts have replaced signalised intersections in order to increase traffic safety and capacity. The interaction between entering and circulating vehicles in roundabouts is strongly a matter of gap acceptance (Hagring 1998, p 25). Furthermore the gap acceptance is also strongly affecting the total capacity of the roundabout which makes it a very important parameter in traffic simulation.

When traffic in Swedish conurbation areas becomes more and more saturated there is a demand of more accurate traffic simulation models for these conditions. Some nodes in the traffic network have already reached saturation flow at peak hour. This makes simulation of these situations more sensitive and complex due to the important effect the road user behaviour has on the model. To increase the reliability of microscopic simulations data of local road user behaviour at current traffic situation needs to be implemented in the software.

1.2 Purpose

The purpose of this study is to measure the critical gaps in a saturated two-lane roundabout and implement the measured critical gap times into the traffic simulation software VISSIM and compare the simulated results with results given by VISSIM default values. An additional purpose is to investigate how gap acceptance diverse between desired directions and the dependency of in which circulating lane the first vehicle of a gap is situated.

1.3 Limitations

This study has been limited, due to time and equipment, to only study gap acceptance. For other parameters such as acceleration, speed, stand still distance, safety distance et cetera, the default values of VISSIM are used. Furthermore the question of why gaps are accepted or rejected is not dealt with in this thesis.

The investigated object Spillepengen is also limited to only the roundabout. The effect that nearby intersections may have on the traffic entering the roundabout has been excluded. The study only involves the south and north entrance and only during saturation flow.

1.4 Hypotheses

Hypothesis H6 was the base for this thesis and the other hypotheses were developed during the literature study, field study and VISSIM model building. The hypotheses are sorted by their appearance in the result chapter.

H1 – Car drivers accept shorter gaps than lorry drivers.

H2 – Drivers accept larger gaps when a lorry is approaching in the roundabout.

Hypotheses H1 and H2 were founded as the circulation of Spillepengen was said to hold a lot of lorry traffic. The two hypotheses are intended to investigate how the lorry traffic affects the behaviour of normal vehicles and if there is any difference in entering behaviour of lorries and normal vehicles.

H3 – Drivers accept shorter gaps when the first vehicle of the gap is in the far lane.

The H3 hypothesis was to see the difference in gap acceptance depending on in which lane the circulating vehicles are situated.

H4 – Drivers in the right entering lane have the same gap acceptance regardless if they desire to turn right or go straight.

Hypothesis H4 is a result of a discovery during the field study. At first thought the obvious would be that right turning vehicles have shorter gap acceptance than those desiring to go straight ahead. This since they are not affected by the vehicles in the far lane. But when observing the traffic at the circulation of Spillepengen it seemed like the opposite. As no measurements were made at the first visit of the site it was impossible to know how desired direction affected the gap acceptance in the right entering lane. Hypothesis H4 was then founded and included in the thesis from that time to see if the first thought or the indications at the site would be the correct answer to the question.

H5 – Floating cars accept shorter gaps than static cars.

The belief that vehicles that do not have to stop before entering the roundabout would accept a shorter gap formulated thesis H5.

H6 – VISSIM default critical gap times generates a lower entry capacity in VISSIM than implementation of measured critical gap times from a saturated roundabout.

As mentioned above hypothesis H6 is the base of this thesis and was formulated during the initiation of the study.

H7 – Simulation of a saturated roundabout in VISSIM at default values of priority rules generates higher mean gaps than mean gaps measured from field studies.

Since there is a need of parameters that can be compared when calibrating and validating a model in VISSIM the hypothesis H7 was founded. H7 investigates if mean gap would be a suitable parameter to compare during calibration and validation.

H8 – Roundabouts at saturation flow have lower follow-up times than follow-up times generated by VISSIM.

H9 – Minimum gap time in VISSIM has no influence on follow-up times in VISSIM.

During the VISSIM modelling there were some difficulties to obtain the measured capacity from Spillepengen. A thought was that it had something to do with the follow-up times and therefore those were investigated further by founding hypotheses H8 and H9.

H10 – The use of conflict areas in VISSIM when simulating two-lane roundabouts gives inaccurate results.

Since conflict areas provides a bit less ability to fine tune entry behaviour it was suspected that conflict areas would not cope with the complex traffic situation of a two lane roundabout. Hypothesis H10 was formulated just before the VISSIM modelling phase of the thesis started.

2 Method

A literature study was carried out through the thesis alongside the other elements and studies. Focus of the literature study has been on subjects related to gap acceptance, headway distribution, capacity and saturation flow of two-lane roundabouts. The high importance of micro simulation modelling in this thesis required that the proper function of a two-lane roundabout was investigated and how the selected software, VISSIM, handles the above named parameters. To make any conclusions on how the gap acceptance affects simulations at micro level the basic theory behind micro simulations is also included in the study.

To collect the demanded data for this thesis a field study was made. Video recording of a two-lane roundabout at saturation flow was done at peak hour both morning and afternoon for three days. The field study also included learning how to use the equipment in terms of handling the software and to set up the camera system.

Playback software was used for the manual video analysis of the most saturated half hour each day, both morning and afternoon. For entering vehicles, sorted by lane, the rejected and accepted gaps were noted in a number of categories. The circulating and entering flows were also measured at each filmed leg of the roundabout.

Two VISSIM models were built, one for the morning and one for the afternoon. The models were calibrated by using measured circulating flows inside the roundabout. Measured gaps and recommended gaps from the literature study were implemented in VISSIM and a number of different simulation tests were run.

All data, both from field study and VISSIM, was compiled and statistical analysis was carried out in order to test and analyse the different hypotheses. In the end a discussion and conclusions of the thesis was fulfilled and a written report was completed.

3 Literature study

The literature study aims to assure the necessary competence to this thesis. First some general information about roundabouts that will initiate the literature study. One of the key elements in this thesis is gap acceptance. Headway distribution is another important component due to its influence on entry capacity at unsignalised intersections. Traffic simulation has an important role in this thesis and creates a demand for some theory behind traffic simulation models. Traffic simulation is presented in general and at last there is a presentation of the selected software VISSIM.

3.1 Roundabouts

General

Roundabouts are a type of circular intersections that have some specific features to control the traffic. The approaching traffic is channelized and all entering traffic must yield for the circulating vehicles (FHWA 2000, p 5). In a roundabout there are no minor or major stream as in a conventional intersection, the entering vehicles are all minor while those in the circulatory roadway are major, minor streams have lower priority than major streams. Usually unsignalised intersections have more than two traffic streams. Roundabouts are example of intersections where only two traffic streams interacts (FHWA 2009, p 8-1). The geometry of roundabouts makes entering vehicles and those in the circulation meet in a sharp angled conflict area that gives greater safety benefits compared to other intersection types (VGU 2004, p 7-116). See figure 3.1 and 3.2 for the key features and dimensions for roundabouts.

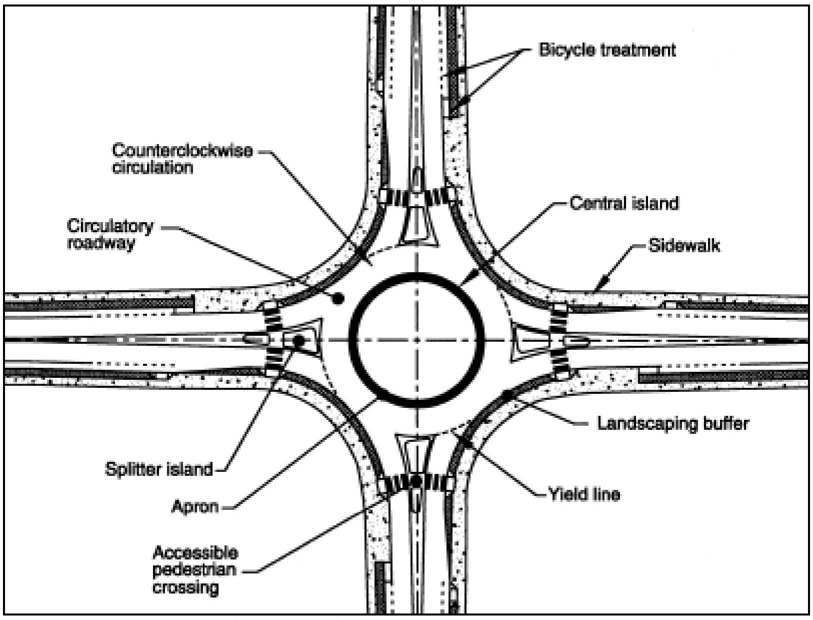

Figure 3.1 Key features for roundabouts. (FHWA 2000, p 6)

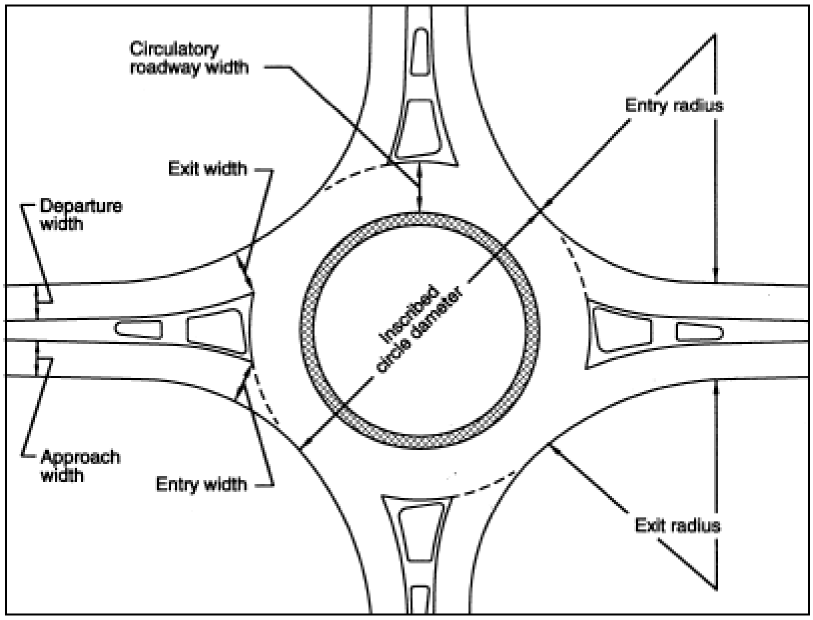

Figure 3.2 Key dimensions for roundabouts. (FHWA 2000, p 7)

Capacity

The capacity of roundabouts depends on two major factors, the geometry of the different components in the roundabout and the circulating flow which prevents vehicles to enter. The most important factors of the geometry in a roundabout, that affects capacity, are the width of the lanes at the entry and the circulatory roadway and the number of lanes at the entry, see figure 3.2. The wider the lane in the circulatory is the more effective vehicles can bunch up or travel side by side which will increase the capacity. The reason for this is that it creates bigger gaps between the bunches of vehicles, platoon flow. The higher the circulating flow is the lower the entry capacity is, for example if the circulating flow increases it will result in a lower entry capacity due to the size of the gaps decreases and vice-versa. Two-lane entry almost doubles capacity compared with one-lane entry. The entry angle and the inscribed diameter have less effect on capacity. (FHWA 2000, p 86)

3.2 Gap acceptance

General

At unsignalised intersections drivers have to decide when it is safe to cross or merge into conflicting traffic streams. They need to look for gaps between vehicles that they are willing to accept and they also need to take other drivers in consideration that have higher priority, this procedure is defined as gap acceptance. A gap between two vehicles is the distance between the rear bumper of the first vehicle and the front bumper of the second vehicle and is usually measured in seconds, see figure 3.3. (FHWA 2009, p 8-1) It is optional for a driver to utilize a gap at a yield or stop line; this is not always the case in merging situations when an acceleration lane ends. If a driver uses a gap then the gap is accepted if not accepted it is referred to as a rejected gap. If a vehicle in the conflicting stream has to reduce its speed or change lane it is a forced gap otherwise it is an ideal gap. A gap can also be used by more than one vehicle, the first vehicle uses the gap and the following vehicles use the lag. Lag is the distance in time between the entering vehicle and the successive vehicle in the major stream, see figure 3.4. (Drew 1968, p 177)

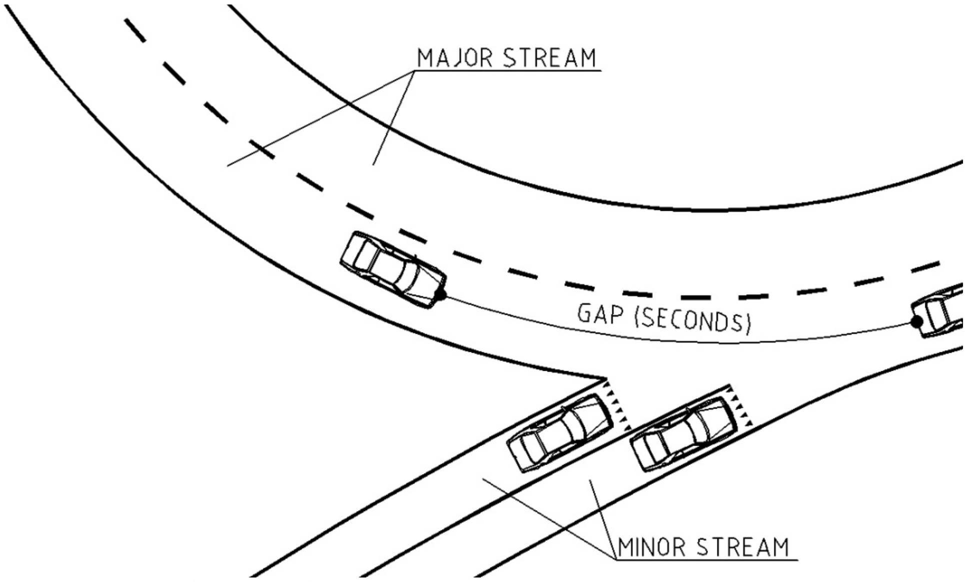

Figure 3.3 Definition of gap.

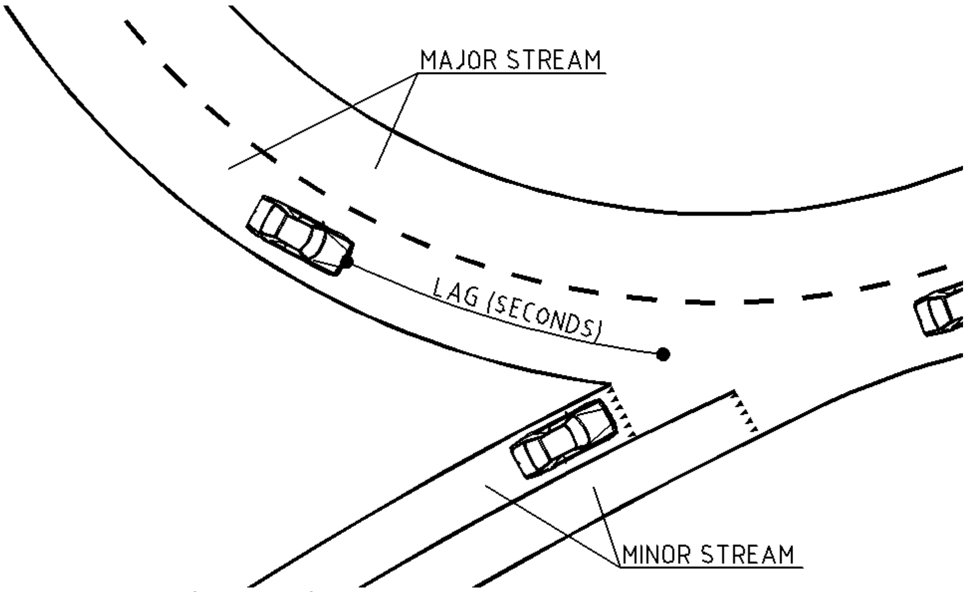

Figure 3.4 Definition of lag.

Critical gap

When a driver is waiting for a gap that can be accepted the driver will usually also reject some gaps. The size of the accepted gap and the rejected gaps for different drivers do not provide information about what the smallest gap they would accept or the biggest gap they would reject. Therefore it is necessary to calculate a critical gap. (Ashton 1971, p 131) The critical gap is the smallest gap that a driver can accept when they are crossing or merging into a conflicting traffic stream. All gaps less than the critical gap would be rejected and all gaps greater than or equal to the critical gap would be accepted. (HCM 1994, p 10-6)

Follow-up

If more than one vehicle from a minor stream uses a gap then the succeeding vehicles are referred to as follow-ups. The follow-up time is the headway between the vehicles entering, see figure 3.5. The follow-up time can only be measured when there is a queue situation. (FHWA 2009, p 8-4)

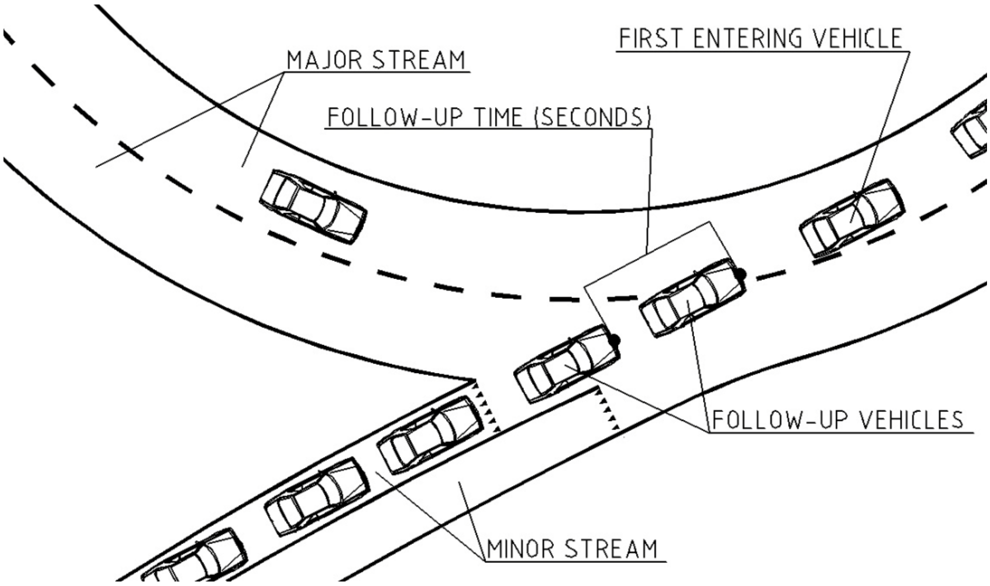

Figure 3.5 Definition of follow-up time.

3.3 Headway distribution

Headway is the time between two following vehicles and is measured from the first vehicle's front bumper to the following vehicle's front bumper, see figure 3.6. As mentioned above it is the gap drivers accept but headway distribution is used to describe the flow in the different traffic streams. This is usually described as a negative exponential distribution. The distribution of gap sizes in a major stream has a great impact on capacity at unsignalised intersections. (FHWA 2009, p 8-6 8-7) The difference in capacity between a random flow and a platoon flow can be as much as 25-30 percentages higher for the latter (McShane & Roess 1990, p 372). If the traffic inside a roundabout comes in platoons it will increase the capacity because the follow-up time is usually lower than the critical gap time (FHWA 2000, p 224). Figure 3.7 shows how different the gaps can be distributed for intersections with the same major flow.

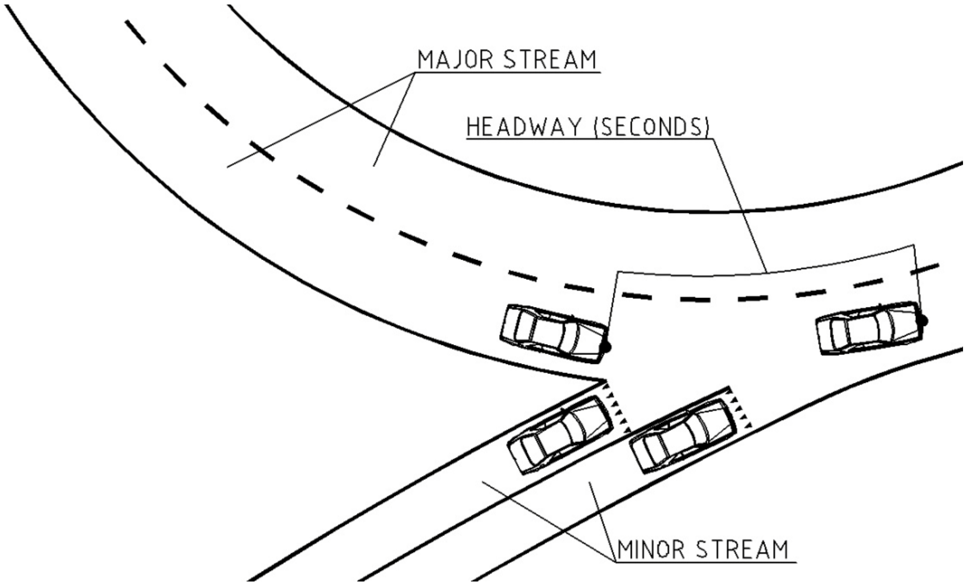

Figure 3.6 Definition of headway.

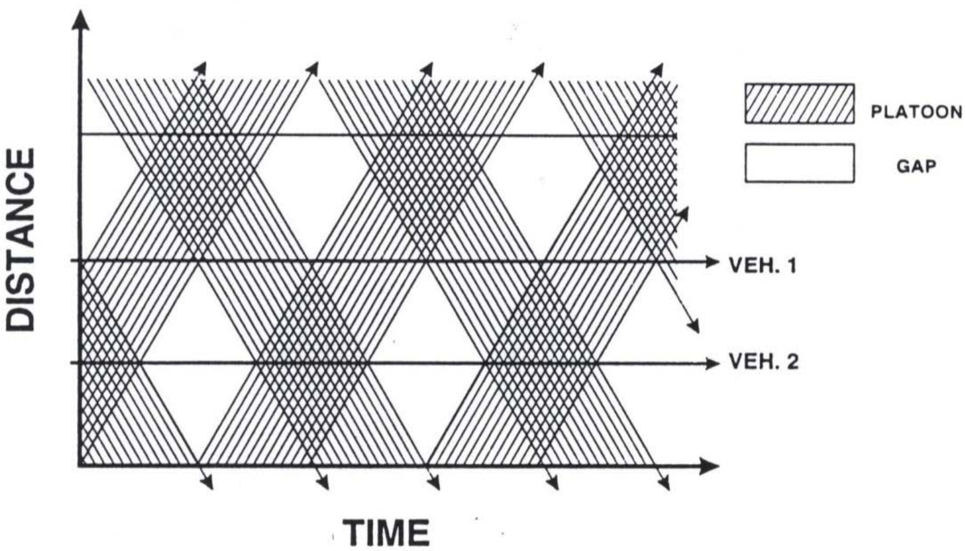

Figure 3.7 Platoon flow impacts on gaps. (HCM 1994, p 10-5)

Figure 3.7 illustrates two traffic streams with platoon flow going in different directions and how it can differ for vehicles to cross those streams. Vehicle 1 in figure 3.7 is at an intersection where the traffic arrives randomly, random flow, and vehicle 2 is at an intersection where the traffic in the different directions passes at the same time, platoon flow, this makes it easier for vehicle 2 to cross due to the bigger gaps given. Vehicle 1 is at the worst position to cross in regard to the gap sizes.

3.4 Traffic simulation

General

Simulation can be described as a depiction of reality, a model, mostly within a limited range. The model is considered as a system with elements, objects and components that are affected by the environment and each other. These entities could alone or in limited interactions be described and understood with acceptable confidence by mathematical or logical analyses. But when it comes to larger and more complex systems with interactions of many entities and components the simulation model is needed. Simulation models are also useful when there is no other means to study a dynamical problem or when the cost is too high to make the study in reality. (Strömgren 2002, p 18; FHWA 2009, p 10-1)

Roundabouts are often used to solve some of the current existing traffic problems. This has produced a number of traffic simulation models that are able to estimate and predict capacity, delays, queues and much more. These models are used by a number of different software packages for traffic simulation that provide roundabout analysis tools. These packages can be divided into two categories: deterministic and stochastic simulation models. Deterministic simulation models use series of equations to correlate capacity, delays, queues et cetera, with a set of variables. Stochastic simulation models use an interval-based simulation to describe the traffic activity. (Gallelli & Vaiano 2008, p 3) Traffic simulations models are divided into three levels, macro-, meso- and microscopic models. These three levels refer to the detail of the simulation and depending on the level the simulation is stochastic or deterministic.

Deterministic relationships of the flow, speed and density of the traffic stream defines a macroscopic simulation model. The entities and activities are described at a low level of detail and above named data presented in more or less aggregate manner. This lead to a section by section based model that does not follow individual vehicles. Macroscopic models demand less computer strength and are less costly to develop, execute and maintain but might also be less accurate than a more detailed model. (FHWA 2009, p 10-6; FHWA 2004a, p 8; Austroads 2006, p 3)

A mesoscopic simulation model describes most entities at a high level of detail such as the unit of traffic flow which like the microscopic model is the individual vehicles (FHWA 2009, p 10-6; FHWA 2004a, p 8). The interactions and activities among the vehicles are described on a much lower level of detail similar to the macroscopic model (Austroads 2006, p4). Dynamic relationships are not included and much of the travel movement are on aggregated basis (FHWA 2004a, p 8).

Microscopic simulation models describe the system entities with its activities and interactions at a high level of detail (FHWA 2009, p 10-6). This makes it possible to follow individual vehicles through the network over very small time intervals, seconds or fraction of a second (FHWA 2004a, p 8; Austroads 2006, p 3). Each vehicle is assigned a destination, vehicle type and driver upon network entry which decides the behaviour of that vehicle inside the system (FHWA 2004a, p 8). Simulation model at this level require great computer capacity and is costly to develop, maintain and use which normally limit the network size within the model (FHWA 2009, p 10-6; FHWA 2004a, p 8). The microscopic models possess the ability to be more accurate than meso and macro models if calibrated correctly (FHWA 2009, p 10-6). This is however not easily done, due to the complexity of the model and its large number of parameters to define and data that needs to be collected and implemented into the model (FHWA 2009, p 10-6).

Working process

To do a correct study using simulation tools it is recommended to follow some steps during the work to make sure nothing is left out.

1. Identification of study, purpose and scope
2. Data collection and preparation
3. Base model development
4. Error checking
5. Calibration and validation
6. Alternatives analysis
7. Final report

(FHWA 2004c, p4)

The first step is primary to make sure that everyone involved knows what needs to be achieved (Austroads 2006, p 9). Study limits and size of the simulation is decided together with software selection (Strömgren 2002, p 19; Austroads 2006, p 9) (FHWA 2004c, p 6). It is important to know what task the model needs to solve in order to select the appropriate software and model for the study. Data collection and preparation is mainly used to understand the system that will be modelled, used as input in the simulation and finally to calibrate and validate the model. (Strömgren 2002, p 19) Data used as input could be geometry, travel demands, turning ratio, desired destinations, transit and bicycle/pedestrian data, speeds and flows (FHWA 2004c, p 6). Calibrating and validating data are usually flows, capacity, saturation, queues, delays and travel times (FHWA 2004c, p 6). Some of the collected data for this step is used to calibrate the model while the rest is saved to the validation (Austroads 2006, p20).

Base model development is basically to build the model based on the input from the data collection. This could be time consuming and has more or less complex steps specific to the chosen software that needs to be exercised. The error checking procedure is to make sure there are no errors within the model such as cars crashing into each other or breaking red light rule. Error checking could also consist of multiple tests of the network and demand data to identify incorrect input data in the model. (FHWA 2004c, p 7; Austroads 2006, p 13)

Calibration step is to change the parameter values in the model to achieve similarity between the simulated results and measured data from reality. The object is to reproduce the real system in the model. The key issue is to identify what parameters to select for the calibration and how they affect the output in the model. Calibration continues until the model is validated which occur when the output data correspond to the independent observed data of reality. (FHWA 2004c, p 7-8; Austroads 2006, p 14-19)

The validated model is at last used to test all different scenarios that were decided in the first step of the project. Normally there is a baseline scenario that corresponds to the current situation at the site. This scenario is then often compared to various future scenarios to determine future traffic network demands or behaviours. At last a report is compiled to summarise the analysis and conclusions made in the study. It should provide future analysts with enough technical input to be able to do similar studies. The report also has to be understandable for decision makers to ensure they know what assumptions and inputs the study is based on. (FHWA 2004c, p 8-9)

Simulation model or analytical model

Prior to the growing use of simulation models, when calculating future traffic condition, analytical models were used instead. One reason for this is of course the lack of good simulation models but also that traffic models tends to have some weaknesses at certain situations. (Allström et al. 2008, p 10) But the now increasing use of simulation models must be a result of more advantages than weaknesses compared to traditional analytical models. For example, in the United States the Highway Capacity Manual (HCM) is the most widely accepted traffic analysis technique with its set of traditional analytical tools. The HCM, like other analytical tools, is perfect for evaluation of limited facilities with moderate congestion problems but has not got the ability to evaluate system effects. This is easily described as one operation at a road segment is not adversely affected by the events on the adjacent roadway when using HCM. (FHWA 2004b, p 9) This creates large errors when queues arise nearby the investigated segment or when other events interfere in reality that cannot be inserted into the analysis.

Simulation model strengths are that they do take into account what happens nearby the investigated sections such as nearby intersections and adjacent lanes. They also have the capability to simulate the dynamic evolution of congestions and queues. Simulation also makes it possible to have a variety of driver, vehicle and network characteristics and the ability to visualise the result gives simulation a leading edge towards the analytical models. However there are still some disadvantages with simulation models at present time. They are much more time-consuming not just in building, calibrating and validating but also in running and analysing stages. This is an effect of the large amount of input data, calibration parameters and error checking opportunities. The investment and using cost is higher and there is a higher requirement on expertise of the user than for normal analytical tools, when it comes to creating the model and interpreting the result. (Allström et al. 2008, p 10-11; FHWA 2004b, p 10)

To summarise the differences between analytical tools and simulation, one could conclude that simulation is to prefer if time, competence and monetary resources are available. But most importantly is that the searched solution is possible to simulate. If not there is no reason to build a model at all. At last there are still some things that may improve the simulation models in the future. Simulation models still misses the ability to take into account what happens beside the road such as distractions, obstruction of visibility or stalled vehicles. Simulation also assume that there is a perfect safe driving which means changes that may or may not influence the likeliness of a collision will not affect driving behaviour. (FHWA 2004b, p 10) There is a number of different software in the simulation business and everyone has more or less all the above named advantages or disadvantages. Therefore it is of high significance that the user knows the software plus or minus to do the study in the best way possible.

3.5 VISSIM

VISSIM (Verkher In Staedten SIMulation) was developed at the University of Karlsruhe, Germany, during the early 1970s (Park et al. 2005, p 114; PTV 2009, p 3). In 1994 PTV, Planung Transport Verkher, AG started to commercially distribute VISSIM (PTV 2009, p 3; Trueblood & Dale 2003, p 3). PTV AG and Innovative Transportation Concepts Inc. in North America are today working together to develop, distribute and maintain VISSIM (Trueblood & Dale 2003, p 3).

The VISSIM package consists of two different parts, the traffic simulator and the signal state generator. The simulation generates an online visualization of traffic operations and offline it generates an output of desired statistical data such as travel times, speed, delays, queue lengths and much more. The signal state generator is signal control software polling detector information from the simulation on a discrete time step basis. It then determines the following signal status for next time step and returns the information to the simulation. (PTV 2009, p 25)

Theory

VISSIM uses a discrete, stochastic, time-step based microscopic model with the driver-vehicle units as single entities. The model uses a psycho-physical car following model and a rule based algorithm for lateral movements, the Wiedeman model. The model is based on the assumption that a driver can be in one of four driving modes: (PTV 2009, p 26; Trueblood & Dale 2003, p 4)

Free driving where the vehicle is not affected by preceding vehicles and the driver is trying to reach and maintain his individually desired speed. In reality this mode cannot be held constant due to the imperfect throttle control of the drivers. (Trueblood & Dale 2003, p 4)

Approaching is when a vehicle is closing in on a slower preceding vehicle and the driver adapts his speed to that vehicle. The driver decelerates in order to reach zero speed differentials between the two vehicles in the same moment as the driver reaches his desired safety distance. (Trueblood & Dale 2003, p 4)

Following is the mode where a vehicle follows a preceding vehicle and the driver keeps the desired safety distance more or less constant. As in free driving this is not possible in reality for the same reasons but the speed difference could be assumed to oscillate around zero. (Trueblood & Dale 2003, p 4)

Braking occur when the distance to preceding vehicle drops below desired safety distance and the driver needs to apply medium or high deceleration. This normally happen when vehicles change lanes in front of each other or if preceding vehicle changes speed abruptly. (Trueblood & Dale 2003, p 4)

It is not only the preceding vehicles that are taken into account in VISSIM, also neighbouring vehicles on the adjacent travel lanes are considered. Furthermore drivers will gain a higher alertness when approaching traffic signals or priority coded intersections. (PTV 2009, p 26)

In every mode the acceleration is described as a result of speed, speed difference, distance and driver-vehicle characteristics. As soon as a driver reaches a certain threshold the driving mode is changed which is displayed as speed and distance differences. Among the driving population the ability to apprehend speed differences and estimate distance varies as well as desired speed and safety distance. This together with different vehicle features creates the individual driving behaviours in the model. The combination of psychological and physiological aspects and restrictions of driver’s perception and vehicle features is why the model is referred to as a psycho-physical car following model. (Trueblood & Dale 2003, p 5)

Features

When simulating roundabouts in VISSIM the most important features in VISSIM are:

- Links and connectors to build the geometry.
- Vehicle distribution and entering flow.
- Routing decisions to give the vehicles a path through the network.
- Reduced speed zones to secure the right speed around exits and entries.
- Priority rules to code the yielding at entries and exits.

(Trueblood & Dale 2003, p 11)

The geometry coding in VISSIM is very flexible and allows the user to control vehicle paths and the interaction of vehicles within intersections. Instead of a link node structure VISSIM uses a link connector structure to complete the geometry, which makes the geometry accurate and uncomplicated. The links are the normal road segments and are coded with number of lanes, lane width, driving behaviour and lane restrictions such as allowing lane change or not and much more. The connectors are the connection between links and are used a lot when modelling intersections and roundabouts. The property of a connector is very similar to a link but also contains a lane-change distance and an emergency stop distance. The lane change distance is the distance back on the preceding link where the vehicles might start to attempt a lane change when approaching the connector. The emergency stop distance sets the last possible position where a lane change could be made. In addition to the link connector structure the developers have also made it possible to import CAD drawings, which brings more accuracy into the geometry. The ability to model intersections or networks of several intersections with such precision gives VISSIM an extra edge compared to other micro simulation packages. (Gallelli & Vaiano 2008, p 4; PTV 2009, p 174-187; Trueblood & Dale 2003, p 4,6)

Vehicle distribution is set by the user and the vehicles are set to enter the network on one or several locations. The distribution and vehicle flow is individual for each entry position. The vehicles are assigned routes upon entry in which it is decided how the vehicles will desire to travel through the network. The routes may end anywhere in the network and other routes may start at those ends. If a route is not decided, vehicles will follow the current link until the end. (PTV 2009, p 203-219; Trueblood & Dale 2003, p 8)

Speed is of high importance in VISSIM and each vehicle is assigned its own individual speed upon entry of the network. The speeds are based on an empirical curve that can be defined by the user to match studies or field data. The posted speed limit can also be an option. Each individual vehicle oscillates around its desired speed until speed zones or roadway geometry forces the vehicle to change its speed. VISSIM uses reduced speed zones where the user defines what speed a vehicle will oscillate around in that area. This creates behaviour similar to reality where the user may force vehicles to slow down before making a turn or move slower in other areas were the speed is lower in reality. The vehicles decelerate in order to have the right speed when entering a reduced speed zone, very similar to reality. All speed distributions in VISSIM are vehicle-type dependent which as an example allows the user to set a different distribution for cars compared to lorries. (PTV 2009, p 190-194; Trueblood & Dale 2003, p 5-10)

Priority rules are used when building unsignalised intersections and roundabouts in VISSIM. It is a tool in which enables the user to specify rules for vehicles on conflicting paths. This is normally used in intersections and roundabouts where the entering vehicles from a link or connector is given a set of rules to follow. Coding priority rules in VISSIM provides a high flexibility and allows traffic to be simulated closely to what might be expected in reality. Priority rules consist of a stop line and one or more conflict markers associated with the stop line. The stop line controls the entry of a vehicle by enable the vehicle to cross the line or not. In order to allow the vehicle to cross the line two conditions on the conflict marker must be satisfied: minimum headway distance and minimum gap time. The user can choose to use one condition or both. A combination of the two conditions on several conflict markers depending on the complexity of the intersection or roundabout is highly recommended. As a rule of thumb, for free flow traffic on the main road the minimum gap time is the relevant condition. For slow moving or queuing traffic on the main road the min headway becomes the most relevant condition. (Gallelli & Vaiano 2008, p 6; PTV 2009, p 242-253; Trueblood & Dale 2003, p 9)

The minimum headway is defined as the length of the conflict area. During the simulation the current headway is determined by the distance between the conflict marker and the first approaching vehicle on the main road. Whenever the current headway is less than the custom minimum headway the entering vehicle is unable to cross the stop lane. The current gap time is the time in every time step that an approaching vehicle has left before reaching the conflict marker assuming continued travelling at current speed. If current gap time is less than defined minimum entry gap time the entering vehicles are stopped at the stop line. Stop lines and conflict markers can be defined by lane as well as for certain vehicle classes. Figure 3.8 below displays the min headway and minimum gap time of the priority rules function. (PTV 2009, p 242)

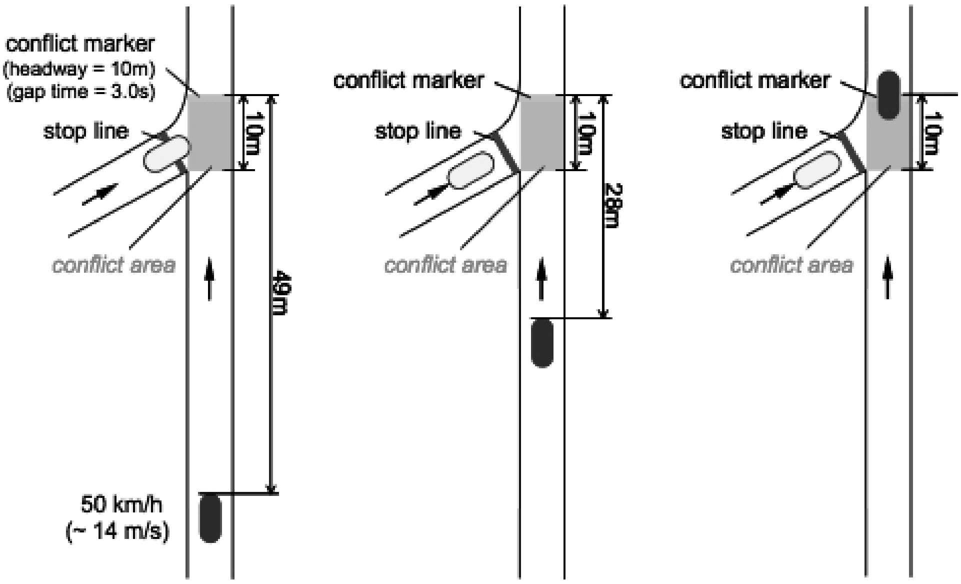

Figure 3.8 Min headway and minimum gap time in VISSIM (PTV 2009, p 243)

Unsignalised intersections can also be coded by using conflict areas, which is a function very similar to priority rules. Conflict areas are a newer approach in VISSIM and is said to be easier to define and produces more intelligent vehicle behaviour. Conflict areas can be defined at locations where links and or connectors overlap. For each conflict area the user can define which one of the links that has right of way or if none of the links has right of way, se figure 3.9. Entering vehicles approaches the main road in a manner that allows the vehicle to yield onto the main road. The entering vehicle takes vehicles on the main road into account and adapts speed and acceleration to fit into a suitable gap. The entering vehicle also take the traffic situation beyond the conflict area into account and calculates more time to cross the area if there is a stop behind the area. There might also be situations when the entering vehicle decides not to go at all if there is too much congestion beyond the conflict area. (PTV 2009, p 253-259)

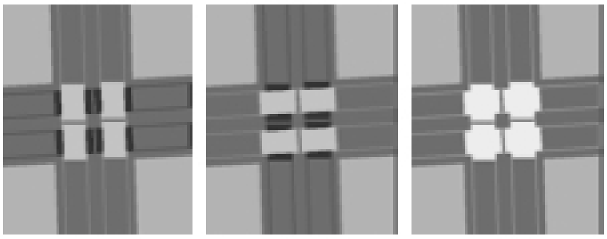

Figure 3.9 Conflict areas (PTV 2009, p 254)

There are two properties related to gap acceptance in the conflict area feature in VISSIM. Front gap is the minimum gap in seconds between rear of a vehicle on the main road and the front of a vehicle on the minor road, see figure 3.10. Rear gap is the gap in seconds between rear of a vehicle on the minor road that has crossed the main road and the front of a vehicle on the main road, see figure 3.11. (PTV 2009, p 256-257)

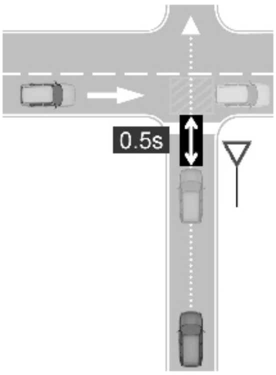

Figure 3.10 Front gap in VISSIM (PTV 2009, p 256)

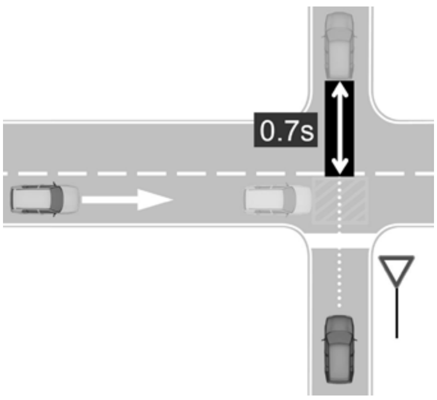

Figure 3.11 Rear gap in VISSIM (PTV 2009, p 257)

All vehicles will be affected by the conflict area not just the entering vehicles. All vehicles calculate if there is enough space behind the area before entering, if there is not enough space the vehicles will choose not to enter. This meaning that if a vehicle on the minor road enters the conflict area and for some reason are unable to leave before a vehicle on major road approaches, the major road vehicle will slow down or even stop before the conflict area. Conflict areas makes vehicles more aware of other vehicles at conflict points in the network and adopts a more intelligent behaviour in the interaction between them. (PTV 2009, p 253-259)

3.6 Definitions

In this thesis there are a number of expressions and terms that might not be well known to the general public. There might also be some things that are defined differently in this thesis than in other publications. This chapter main purpose is to explain and define some important expressions and terms used in the thesis. The definitions without reference are the authors own definitions in this thesis.

Driving behaviour

In this thesis the behaviour of the vehicle drivers is addressed as the vehicle's desires. For example, vehicles desire to move right, left or straight and vehicles take or do not take other vehicles into account in certain situations. All these examples are actually driving behaviour. But due to the use of VISSIM where vehicles are more seen as only vehicles than vehicles with a driver it has been decided to use the above explained definition. However there are still situations where drivers and driving behaviour occur in the thesis which is not seen as different behaviour than above explained.

The AM and PM model

The two VISSIM models used in this thesis are similar in geometry but different in other aspects. They are named the AM and the PM model and are built to represent the morning respectively the afternoon situation in the Spillepengen roundabout. In the AM model the north entrance is the studied leg and in the PM model it is the south leg. The flow rates from each leg differ between the models. This is to obtain the right flow in the circulation at the specific studied leg in the intersection. The flow has also been set to a very high value for the specific entrance to obtain a constant entering queue during the simulation.

Measured

The thesis contains a lot of measured values from the field study such as flows, gaps, follow-ups, turning ratio et cetera. When a value or unit is addressed as measured it has its origin in the field study.

Conflict zone

A conflict zone is the area where two vehicles have to interact with each other and a conflict might appear. This leads to a situation where one or both vehicles have to give way, stop or somehow merge to get through the zone. In VISSIM rules for this kind of behaviour at intersections and roundabouts can be modelled by two similar functions, priority rules or conflict areas.

Gap definition

This study includes four different types of gaps between circulating vehicles in the roundabout. These are near to near gap (N-N), near to far gap (N-F), far to far (F-F) and far to near gap (F-N). The gaps are showed in figure 3.12.

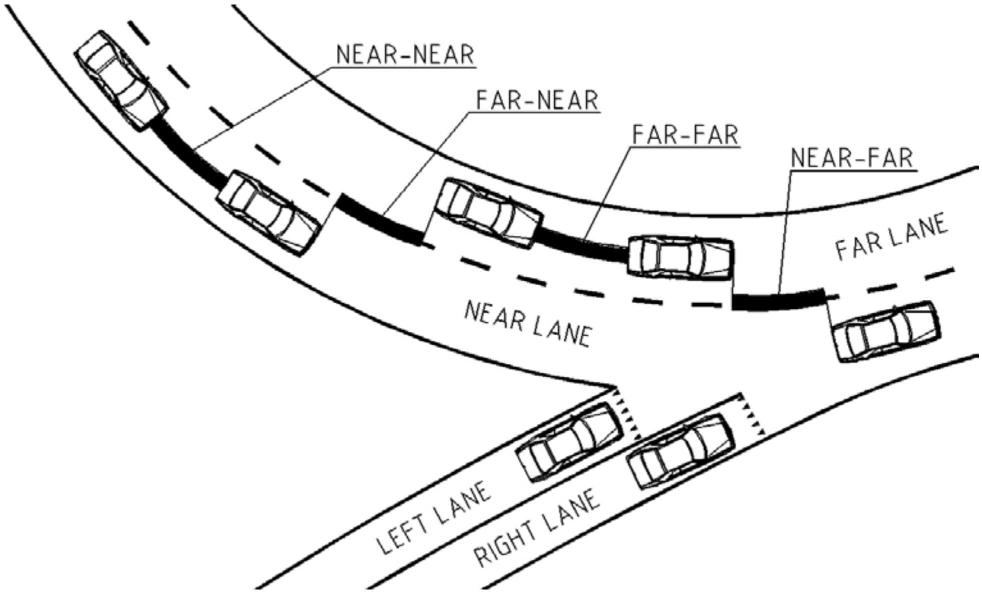

Figure 3.12 Definition of gaps.

Forced gap

A forced gap occur when a vehicle enter the roundabout without taking enough consideration of the circulating traffic. The entering vehicles force themselves into the roundabout and circulating vehicles have to slow down or even stop to not crash into the entering vehicle. Forced gaps are mainly used by lorries that have trouble entering the roundabout due to the lack of sufficient gaps.

Static entrance

If a vehicle has to stop at the yield sign and wait for a sufficient gap to occur before entering the roundabout it is marked as a static entrance.

Floating entrance

If the driver finds a gap and does not have to stop at the yield sign the vehicle is defined as floating. It is only the first vehicle entering a gap that is a floating vehicle, the succeeding vehicles are follow-ups.

Critical gap

The method used to calculate the critical gap in this thesis is known as Raff's method. The cumulative distributions of accepted and rejected gaps are plotted in the same graph. The intersection point for the two curves is the critical gap.

Follow-up

In the literature review follow-up are defined as the headway between the cars using the same gap. The definition used in this thesis is the critical gap subtracted from the gap divided with the number of follow-up vehicles.

4 Data collection

4.1 Study object

The first step of the data collection was to locate roundabouts that met the criteria's:

- Two-lane geometry.
- At least one leg saturated.
- Possible to get good camera position.
- Located in Scania (Swedish region).

It is hard to find roundabouts in Scania that are saturated at some point during the day. This made the options fewer. After finding roundabouts that met the criteria the choice fell on the Spillepengen roundabout located in Malmoe, see figure 4.1. Spillepengen belongs to the category of big two-lane roundabouts and is situated close to the harbour area in Malmoe, see figure 4.2. The target destinations in the area are industries and the harbour ferries it is therefore the roundabout holds a lot of heavy traffic.

Figure 4.1 Aerial photo of Spillepengen. (© Lantmäteriet Gävle 2009. Consent I 2008/1951)

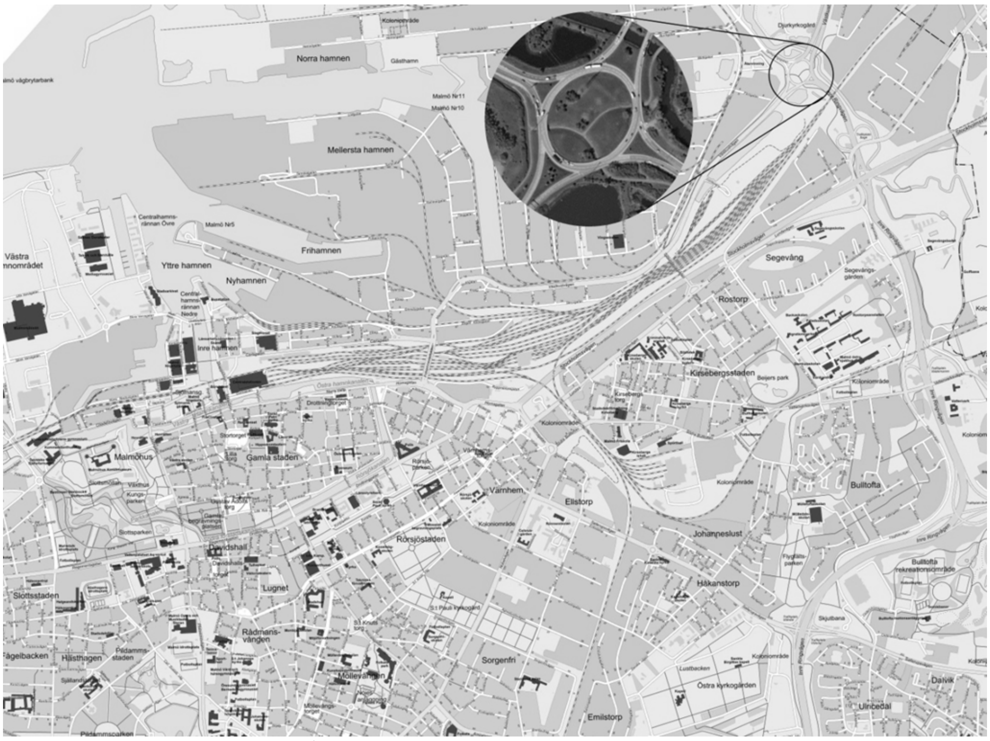

Figure 4.2 Location of Spillepengen in Malmoe. (© Lantmäteriet Gävle 2009. Consent I 2008/1951)

4.2 Field study

The period that was interesting for the study was when a leg was at saturation flow. This means that there would be a queue into the roundabout during the study. After a short visit to Spillepengen in the morning and afternoon of a normal weekday it was ascertained that the roundabout is saturated at the north and south leg in the morning respectively afternoon. The possibility to get a good placement of the camera was also examined.

The traffic was recorded 8-10th September 2009 during the morning and afternoon for two to three hours. The weather was mainly fair and the surface was dry. The camera was mounted on a road sign about four meters up in front of the relevant leg in order to record the entering traffic and make it possible to observe the gaps, see figure 4.3. The camera position could have been better; preferably it should have been mounted at a higher position to include more of the traffic in sight which would make the gaps more accurate due to the better angle. The equipment that was used to film the roundabout consisted of a small computer system with a network camera from Axis Systems. The camera was mounted together with a hard drive that the film was saved to. The system was operated by a laptop and the power supply was provided from a car battery, see figure 4.4.

Figure 4.3 Camera position.

Figure 4.4 Camera system.

The strength of the system is that the film is stored in digital format directly and that it has been equipped with a live view system. The live view system enables easy tuning of zoom and focus before recording. Current system weaknesses are the power supply of a car battery which is heavy and difficult to transport and requires a good bit of space at the site. Another side of it is that it would be difficult to mount the system high up on a pole when the battery has to be on the ground due to its immobility. Another weakness could be the fact that a laptop is needed to start, stop and calibrate the camera which reduces the ability to control the camera on a high pole. The immobility of the battery and laptop could also require long cables for connection and power. The camera is finally a bit difficult to rig but when rigged it will not move easily.

4.3 Video analysis

The video files that the system produced were transferred to a computer and re-encoded to a more user friendly format. The films are divided automatically by the system in to half hour files. The video playback software VirtualDub was then used to review the film. The gaps were manually measured with the software by the inbuilt counter and a function that enables the viewer to play one frame at the time.

Before the data was collected from the films a data sheet was created with different categories, see figure 4.5. The different categories were created with aim so that as much information as possible would be collected from the recordings.

Static (Left lane)

	Car																Lorry																			
	Car								Lorry								Car									Lorry									C = Car	
	Accepted				Rejected				Accepted				Rejected				Accepted					Rejected				Accepted					Rejected				L = Lorry	M = Motorcycle
	N-N	N-F	F-F	F-N	N-N	N-F	F-F	F-N	N-N	N-F	F-F	F-N	N-N	N-F	F-F	F-N	N-N	N-F	F-F	F-N	Forc.	N-N	N-F	F-F	F-N	N-N	N-F	F-F	F-N	Forc.	N-N	N-F	F-F	F-N	Follow-up	Type order
463						1,59																														
464																1,56																				
465							2,47																													
466																2,49																				
467					3,78																															
468					1,45																															
469				3,95																															2	CCC
470						1,56																														
471			4,99																																	
472																		12,2																	3	LLCC
473			5,15																																2	CCM
474			3,39																																1	CC
475	5,4																																			
476							1,04																													
477									4,02																											
478	4,81																																		1	CC
479																						1,42														
480																								1,13												
481																							3,77													
482																											5,37									
483							1,11																													
484							1,56																													
485			7,2																																2	CCC
486							2,84																													
487			5,44																																2	CCC
488						1,25																														
489							1,49																													
490		5,37																																	1	CC

Summary | Static (Left lane) | Static (Right lane) | Static (Right Turn) | Floating (Left lane) | Floating (Right lane) | Floating (Right Turn)

Figure 4.5 Overview of the table used for data collection

This resulted in six different data sheets. The main categories for the sheets was created after entering lane, desired direction and if the vehicle was entering the roundabout from stand still position or floating. In the left lane all vehicles move straight and in the right lane the vehicles move straight or turn right, see figure 4.6.

Static (Left lane) | Static (Right lane) | Static (Right Turn) | Floating (Left lane) | Floating (Right lane) | Floating (Right Turn)

Figure 4.6 Category sheets

The next step in the hierarchy is whether it was a car or a lorry entering and what kind of vehicle they are entering in front of. This was the same for all sheets, see figure 4.7.

Static (Left lane)	
Car	Lorry

Figure 4.7 Vehicle categories.

The next category was if they are either accepting or rejecting a gap. In case of floating vehicles only accepted gaps were measured because it is hard to tell which gaps they are actually rejecting. And the last category was what kind of gap they are accepting or rejecting, see figure 4.8. For example if the gap is between vehicles in the near lane or the gap is between a vehicle in the far and near lane. For the right turning vehicles the only gap that was taking into account was near to near because that is the only gap they are in conflict with when entering the roundabout.

Static (Left lane)																																	
Car																Lorry																	
Car								Lorry								Car									Lorry								
Accepted				Rejected				Accepted				Rejected				Accepted					Rejected				Accepted					Rejected			
N-N	N-F	F-F	F-N	N-N	N-F	F-F	F-N	N-N	N-F	F-F	F-N	N-N	N-F	F-F	F-N	N-N	N-F	F-F	F-N	Forc.	N-N	N-F	F-F	F-N	N-N	N-F	F-F	F-N	Forc.	N-N	N-F	F-F	F-N

Figure 4.8 Gap categories.

As a last approach to the data sheets three columns were added. One column was marked if a lorry used a forced gap, see figure 4.8. And the last two columns hold information about follow-ups. The first of the two follow-up columns is for amount of follow-ups in each gap and the second for which kind of vehicle in correct order, see figure 4.9.

C = Car	
L = Lorry	M = Motorcycle
Follow-up	Type order

Figure 4.9 Number of follow-ups and order.

From the films a half hour was selected from the morning and a half hour from the afternoon, 07.40-08.10 and 16.10-16.40. The criteria for the period were that the entrance must be saturated. The same time was used for all three days that made a total of 1.5 hour each leg to be analysed. The limitation of 1.5 hour was due to the time consuming process of measuring the gaps in correlation to the short amount of time to do the thesis. A plastic film was used on the monitor and a line was drawn where left lane entering and circulating vehicles conflict area begins, the gaps were measured at this line, see figure 4.10.

Figure 4.10 Line where the gaps were measured from.

Viewing the table in figure 4.11 one can follow specific drivers. For each time a gap is filled in it is done on a new row. When there was one or more follow-ups it was marked in one column how many vehicles that used the gap, the first vehicle is not included. In the next column type of vehicle was noted and in which order they entered. Here the first vehicle is included. When a lorry entered the roundabout in a too small gap and the vehicles in the circulation had to brake that was marked with an x in the column forced gaps.

Static (Left lane)

	Car															
	Car								Lorry							
	Accepted				Rejected				Accepted				Rejected			
	N-N	N-F	F-F	F-N	N-N	N-F	F-F	F-N	N-N	N-F	F-F	F-N	N-N	N-F	F-F	F-N
55				2,7												
56								0,8								
57	11															
58					2,5											
59		9,2														
60																
61																
62																
63					1,1											
64		5,1														
65		6,1														
66					1,9											
67						1,4										
68				4												
69								1,1								
70							2,1									
71						2,2										
72			3,3													
73							1,2									
74				2,5												

	Lorry																			C = Car
	Car									Lorry										L = Lorry
	Accepted					Rejected				Accepted					Rejected					M = Motorcycle
	N-N	N-F	F-F	F-N	Forc.	N-N	N-F	F-F	F-N	N-N	N-F	F-F	F-N	Forc.	N-N	N-F	F-F	F-N	Follow-up	Type order
55																				
56																				
57																			3	CCCC
58																				
59																			1	CC
60						0,8														
61							2,3													
62		8,2			X														1	LC
63																				
64																				
65																			1	CC
66																				
67																				
68																				
69																				
70																				
71																				
72																			1	CC
73																				
74																				

Figure 4.11 Example of noted gaps in Static left lane.

Every gap was noted twice, one time for the left lane and one time for the right lane when both entering vehicles desired to move straight into the roundabout. If the vehicle in the right lane desired to move right the gaps in the near lane was noted in the right turn category. Rejected gaps were noted until entering vehicle accepted a gap, which was also noted, and then it started all over with the next entering vehicle in turn.

4.4 Model building

At first a base model was created. An aerial photo was used to build the geometry of the roundabout. The different flows and route choice came from municipality of Malmoe and the recorded film at the site. Two different legs were studied north leg in the morning and south leg in the afternoon due to this two models were created one for the morning named AM and one for the afternoon named PM.

The priority rules for the entering vehicles were placed as the VISSIM manual advised as a starting point (PTV 2009, p 250). They were adjusted so the vehicles entered the gaps as similar as possible to reality, see figure 4.12 and 4.13. This means that they enter very close up the rear of the circulating vehicles. If the priority rules were too close to the conflict area the vehicles went out too slow and too fast if they were placed too far away. The priority rules were setup for left lane and the right lane. For the right lane it was divided into two categories one for those moving straight and one for right turning. The split was done with the help of a connector. In the left lane all vehicles moves straight and a split was not needed. To avoid vehicles crashing into HGV (heavy goods vehicle) the priority rules were supplemented with a one meter headway distance rule. The headway distance rule is normally only used at bumper to bumper traffic (PTV 2009, p 251).

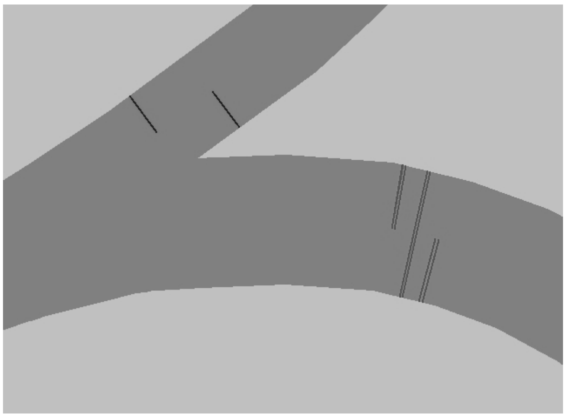

Figure 4.12 Priority rules AM.

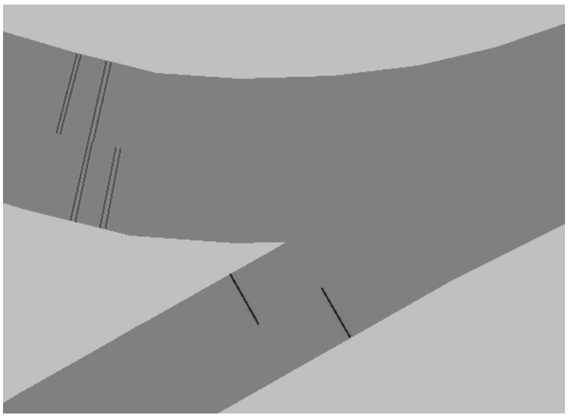

Figure 4.13 Priority rules PM.

After the error checking of the models calibration was made by using measured flows from the field study. The aim in the calibration was to obtain the same circulating flow in the near and far lane of the model as in the real roundabout. This was accomplished by modifying the flows at each leg. The studied leg was at saturation flow which means that there always was a queue. The flows in the afternoon needed rather big changes to get the right circulating flows in the roundabout. This means that flows from the municipality of Malmoe as input did not generate the flow rate measured in the field study and the values had to be raised.

When the model was calibrated the different tests were done. The first nine tests (test 1-9) was a sensitivity test to see how minimum gap time, input of priority rules, affected the entry capacity. The recommended values from the VISSIM manual (PTV 2009, p 249-253) were used as default values. The next four tests (test 10-13) were the measured values of Spillepengen roundabout and the last two tests (test 14-15) were to see how well conflict areas in VISSIM operates in two-lane roundabouts.

4.5 Data processing

The statistical data of gaps that was collected from the films were first divided into two different sheets. The first one was for one vehicle only in a gap and the second sheet was the gaps with more than one vehicle using the gap, known as the follow-ups. The follow-up sheet was also sorted; all gaps where only cars were represented ended up in their own sheet and the gaps with different type of vehicles in another. This was done with Excel.

In the output from VISSIM the gaps are not sorted differently if the accepted gap is in front of a car or a lorry. To be able to compare VISSIM values with the measured values from Spillepengen the two categories, in front of car, and, in front of lorry had to be merge together.

The output data from VISSIM was generated in two different files. One file with flows and one file with raw data. The raw data file had to be processed with the help of MATLAB to be able to calculate mean gap acceptance, critical gaps and follow-ups.

Microsoft Excel was used to calculate the different statistical data from the sheets while MATLAB was used for the statistic analyses, to calculate critical gaps and to create diagrams and graphs. MATLAB was also used to do Student’s t-tests in order to test and prove the different hypotheses in the thesis. When Student’s t-test was used it was first assured that the data set was normal distributed.

5 Result

In the result chapter the hypotheses will be tested and the required data in each case will be presented. The result order follows the numbering of the hypotheses. Terms and categories are previously presented in the definition chapter or explained in their context in this chapter.

The measured gaps from the video recording analysis are compiled and sorted in the near-near, near-far, far-far and far-near gap categories. All gaps are also divided into accepted gaps and rejected gaps. Accepted gaps are all measured gaps were one vehicle, no more or less, entered the roundabout and rejected gaps are all gaps that were rejected. As concluded in the limitations the thesis does not handle the question of why or why not gaps are accepted or rejected.

5.1 Static entrance

Hypotheses H1-H4 relate to the static entrance were vehicles are entering the roundabout from a stand still position. This is because these hypotheses are aiming to compare behaviour of the drivers and to do that the vehicles must have the same condition. Vehicles entering in motion might have a difference in speed and cannot be used in this comparison. The hypotheses are:

H1 – Car drivers accept shorter gaps than lorry drivers.

H2 – Drivers accept larger gaps when a lorry is approaching in the roundabout.

H3 – Drivers accept shorter gaps when the first vehicle of the gap is in the far lane.

H4 – Drivers in the right entering lane have the same gap acceptance regardless if they desire to turn right or go straight.

The required data to test the hypotheses H1 and H2 is presented in the tables below. To test hypothesis H2 the gaps are also categorised into two groups, in front of car and in front of lorry. This meaning that the second vehicle of the gap is either a car or a lorry.

All gaps of static entering cars are presented by lane and direction in table 5.1-5.3 and static entering lorries in table 5.4-5.6, see appendix A for extended tables.

Table 5.1 Gaps for cars in the left lane, static entering cars. (seconds)

	In front of car							
	Accepted				Rejected			
	N-N	N-F	F-F	F-N	N-N	N-F	F-F	F-N
Sample	61	40	48	43	291	222	171	90
Mean	**3,99**	**4,45**	**3,06**	**2,99**	**1,73**	**2,03**	**1,74**	**1,61**
	In front of lorry							
	Accepted				Rejected			
	N-N	N-F	F-F	F-N	N-N	N-F	F-F	F-N
Sample	9	6	4	8	18	25	10	29
Mean	**4,08**	**4,59**	**4,25**	**3,61**	**2,58**	**2,73**	**2,44**	**2,01**

Table 5.2 Gaps for cars in the right lane going straight, static entering cars. (seconds)

	In front of car							
	Accepted				Rejected			
	N-N	N-F	F-F	F-N	N-N	N-F	F-F	F-N
Sample	16	32	25	17	105	93	74	43
Mean	**3,82**	**4,84**	**3,24**	**2,72**	**1,79**	**1,96**	**1,75**	**1,63**
	In front of lorry							
	Accepted				Rejected			
	N-N	N-F	F-F	F-N	N-N	N-F	F-F	F-N
Sample	5	2	1	6	7	13	7	7
Mean	**4,30**	**5,43**	**6,1**	**2,75**	**2,67**	**2,83**	**2,33**	**1,77**

Table 5.3 Gaps for cars in the right lane turning right, static entering cars. (seconds)

	In front of car							
	Accepted				Rejected			
	N-N	N-F	F-F	F-N	N-N	N-F	F-F	F-N
Sample	91				341			
Mean	**4,81**				**2,08**			
	In front of lorry							
	Accepted				Rejected			
	N-N	N-F	F-F	F-N	N-N	N-F	F-F	F-N
Sample	18				33			
Mean	**5,87**				**3,25**			

The result from the gap collection of static entering cars in the roundabout shows that there is an almost even distribution of cars between the two entering lanes. But in the right lane there is a bit more than half of the fleet that decides to turn right. The total sample of accepted and rejected gaps in the roundabout depends on the flow rate and distribution of the cars within the circulation. Since there are much fewer observations of cars entering in front of lorries than in front of cars the two categories will from now on be joined together.

Table 5.4 Gaps for lorries in the left lane, static entering lorries. (seconds)

	In front of car							
	Accepted				Rejected			
	N-N	N-F	F-F	F-N	N-N	N-F	F-F	F-N
Sample	3	2	1	3	18	12	7	6
Mean	**4,00**	**6,76**	**3,7**	**4,64**	**2,30**	**3,06**	**1,74**	**2,46**
	In front of lorry							
	Accepted				Rejected			
	N-N	N-F	F-F	F-N	N-N	N-F	F-F	F-N
Sample	1	1	0	0	1	3	0	1
Mean	**7,7**	**5,4**	**-**	**-**	**4,2**	**2,14**	**-**	**3,3**

Table 5.5 Gaps for lorries in the right lane going straight, static entering lorries. (seconds)

	In front of car							
	Accepted				Rejected			
	N-N	N-F	F-F	F-N	N-N	N-F	F-F	F-N
Sample	6	5	7	2	15	17	15	4
Mean	**4,05**	**5,59**	**4,74**	**3,57**	**2,71**	**2,10**	**1,64**	**2,28**
	In front of lorry							
	Accepted				Rejected			
	N-N	N-F	F-F	F-N	N-N	N-F	F-F	F-N
Sample	1	0	0	1	0	3	0	8
Mean	**5,6**	**-**	**-**	**4,0**	**-**	**3,47**	**-**	**1,99**

Table 5.6 Gaps for lorries in the right lane turning right, static entering lorries. (seconds)

	In front of car							
	Accepted				Rejected			
	N-N	N-F	F-F	F-N	N-N	N-F	F-F	F-N
Sample	26				83			
Mean	**6,25**				**2,52**			
	In front of lorry							
	Accepted				Rejected			
	N-N	N-F	F-F	F-N	N-N	N-F	F-F	F-N
Sample	2				19			
Mean	**7,10**				**3,25**			

Unfortunately the number of lorries entering the roundabout was too low during the investigated time. It was also discovered that numerous lorries forces themselves into the roundabout, so-called forced gaps. When lorries force themselves into the roundabout they make the circulating vehicles slow down and the gap is then considerable larger than it would have been if not forced. The limited camera angle did not admit the gap to be measured earlier, which makes the gap unusable for the study. Another side of it is that a forced gap results in an accepted gap even though it would have been rejected. Almost fifty percent of the accepted gaps of entering lorries were forced and those cannot be used in the study. This leads to a lack of samples in the data and would not give the correct gap acceptance for lorries. Therefore entering lorry traffic will not be included in the study ahead and hypothesis H1 and H2 will not be tested.

To test hypothesis H3 a comparison must be made between gaps were the first car of the gap is in the near lane or the far lane. Table 5.7 displays this comparison distributed on the entering right and left lane. The right turning cars are not included in the data of the right lane since they do not have to take the far lane in consideration.

Table 5.7 Comparison of accepted gaps, sorted by entering lane and which lane the first vehicle travel in. (seconds)

	Left lane		Right lane	
	Near	**Far**	**Near**	**Far**
Sample	116	103	55	49
Mean	**4,19**	**3,12**	**4,51**	**3,06**
Min.	1,7	0,9	1,9	0,6
Max.	6,6	5,6	12,8	6,1
Std.	0,99	0,99	1,69	1,25

The difference of the means between near and far lane is more than one second for the left lane and almost one and a half second for the right lane which indicates that the means are different. A Student’s t-test also shows that there is a significance difference of the means in both cases. The difference is visualised by the error bars in figure 5.1 and 5.2.

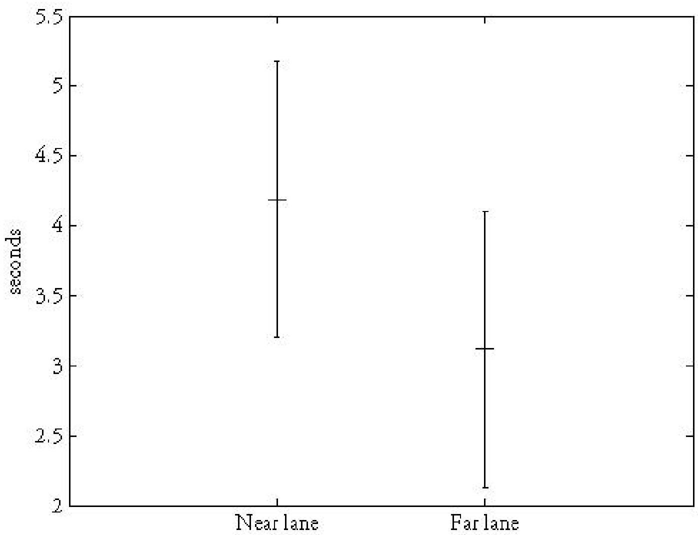

Figure 5.1 Mean and standard deviation of accepted gaps for entering left lane where the first vehicle of the gap is in the far or near lane.

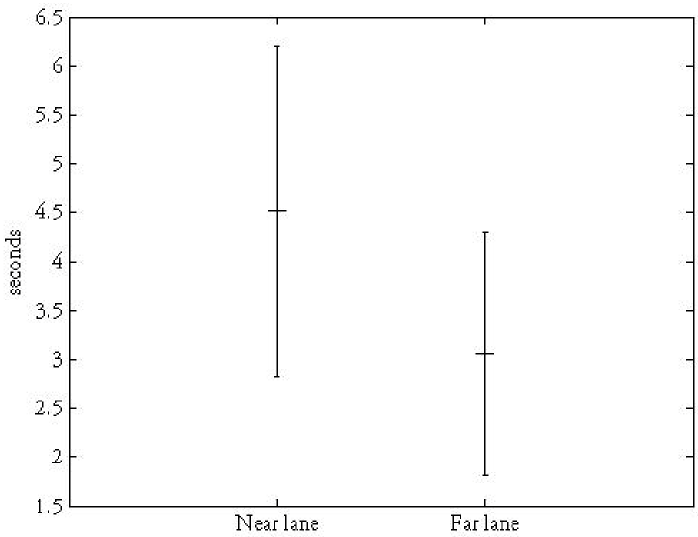

Figure 5.2 Mean and standard deviation of accepted gaps for entering right lane where the first vehicle of the gap is in the far or near lane.

The hypothesis H3 is true for both left and right lane, which means that car drivers accept shorter gaps when the front vehicle of a gap is in the far lane.

Hypothesis H4 requires a similar comparison as hypothesis H3 but concentrates on the vehicles in the right lane and their desired direction. This is to determine if drivers in the right lane have the same gap acceptance regardless if they desire to go right or straight. All gaps for the straight going cars are summarised due to the low sample of near to near gaps. Table 5.8 displays the comparison of gap acceptance depending on desired direction and the error bars in figure 5.3 visualises the difference in means and standard deviation of the accepted gaps.

Table 5.8 Comparison of accepted gaps for the right lane, sorted by direction. (seconds)

	Straight	Turning
Sample	104	127
Mean	**3,83**	**5,11**
Min.	0,6	2,1
Max.	12,8	9,7
Std.	1,66	1,88

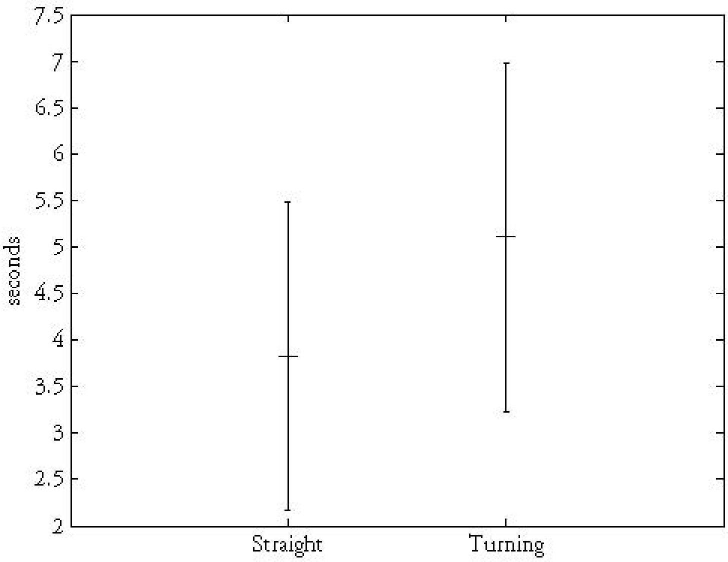

Figure 5.3 Mean and standard deviation of accepted gaps depending on direction of entering cars in the right lane.

A Student's t-test also shows that the means are different which disproves the hypothesis. This concludes that drivers in the right lane do not have the same gap acceptance regardless desired direction. In fact drivers that desire to go right have a higher gap acceptance even though they only have one lane in the roundabout to consider. Due to the low sample for near to near no comparison was made for that sort of gap but the means in table 5.2 indicates that the outcome would have been the same, that right turning drivers have a higher gap acceptance.

5.2 Floating entrance

Hypothesis H5, listed below, aims to compare the previously mentioned static entrance with its opposite, floating entrance. When a vehicle enters the roundabout without stopping at the yield line it is considered as a floating entrance.

H5 – Floating cars accept shorter gaps than static cars.

The required data to test the hypothesis is the previously presented data of gap acceptance for static entering vehicles together with gap acceptance of floating entering vehicles. Gap acceptance of floating entering vehicles is presented in table 5.9-5.11. Like for static entering cars the two categories of entering in front of car or in front of lorry is fused together in the analysis of floating entrance. They are however separated in the tables below, see appendix B for extended tables.

Table 5.9 Accepted gaps for floating cars in the left lane. (seconds)

	In front of car				In front of lorry			
	Accepted				Accepted			
	N-N	N-F	F-F	F-N	N-N	N-F	F-F	F-N
Sample	28	13	17	20	3	1	1	3
Mean	**3,74**	**4,37**	**3,28**	**2,25**	**3,36**	**4,8**	**3,2**	**2,42**

Table 5.10 Accepted gaps for floating cars in the right lane going straight. (seconds)

	In front of car				In front of lorry			
	Accepted				Accepted			
	N-N	N-F	F-F	F-N	N-N	N-F	F-F	F-N
Sample	7	1	12	3	4	1	2	2
Mean	**4,45**	**5,2**	**3,10**	**2,94**	**3,39**	**4,0**	**3,75**	**2,75**

Table 5.11 Accepted gaps for floating cars in the right lane turning right. (seconds)

	In front of car	In front of lorry
	Accepted	Accepted
	N-N	N-N
Sample	36	3
Mean	**4,27**	**3,53**

Due to the low sample of floating cars no statistical analysis was made to test hypothesis H5. Instead a comparison of the means are made and displayed in table 5.12.

Table 5.12 Comparison of gap acceptance between static and floating entrance. (seconds)

	N-N	N-F	F-F	F-N
Static left lane	4,01	4,47	3,15	3,08
Floating left lane	3,70	4,39	3,27	2,27
Static right lane	3,94	4,87	3,35	2,73
Floating right lane	4,07	4,57	3,19	2,87
Static right turn	4,98			
Floating right turn	4,21			

The floating values are not that different from the static values. The only two that differs a lot are the left lane and right turn far to near respective near to near but the samples are too few to prove anything. This makes it impossible to determine if there is any difference in gap acceptance between floating and static entrance of the roundabout. Hypothesis H5 will remain untested.

5.3 Input and calibration data

To test the hypotheses that relate to VISSIM there are some calculations and data preparations that must be done initially. The critical gap has to be calculated for each entering lane and gap type. Also the flows and turning ratios must be estimated and processed to enable the calibration of the model. Due to the importance of how the gaps are distributed a comparison was made between the measured gap distribution and the one acquired in VISSIM.

Critical gaps

By combining the values of accepted and rejected gaps the critical gap of each measured lane at static entrance is given also known as Raff's method, the graphs are presented in appendix C. Values of the critical gaps are presented in table 5.13. The critical gaps are used as data input in VISSIM and they are also used to calculate follow-up times. VISSIM cannot handle all the categories of gaps presented earlier and therefore only the near to near and far to far critical gaps are calculated to easily be implemented in VISSIM.

Table 5.13 Critical gap times. (seconds)

	Near	Far
Static left lane	2,8	2,4
Static right lane	2,9	2,4
Static right turn	3,3	

Flows

The measured flows in the roundabout of the near lane and the far lane were used to calibrate and validate the model. These values were kept at the same level through the different tests, see table 5.14 and 5.15. See appendix D for flows in the near and the far lane from the VISSIM models.

Table 5.14 Morning flows in the circulatory roadways. (vehicles / half-hour)

	Near lane				Far lane			
	Mean	Min.	Max.	Std.	**Mean**	Min.	Max.	Std.
Measured	**325**	313	332	10	**505**	503	508	3

Table 5.15 Afternoon flows in the circulatory roadways. (vehicles / half-hour)

	Near lane				Far lane			
	Mean	Min.	Max.	Std.	**Mean**	Min.	Max.	Std.
Measured	**491**	464	509	24	**440**	435	446	6

Gap distribution

As mentioned in the literature study the headway distribution is important because it can seriously affect the capacity. No headways were measured from the study object and therefore the comparison is made for the distribution of gaps. The difference in definition of headway and gap is that the headway includes the first vehicle's length in time.

The gap distributions of the morning and afternoon circulating traffic in the roundabout given by the field study are presented in figure 5.4 and 5.5. The figures also include the corresponding gap distribution from the two different VISSIM models. The models are named the AM model respectively the PM model. The study includes all gaps over two seconds, both accepted and rejected. The gaps below two seconds are of less interest because they are almost all rejected. The most important comparison in the figure is the distributions at the critical gap because as stated in the literature review that a driver will accept all gaps above the critical gap.

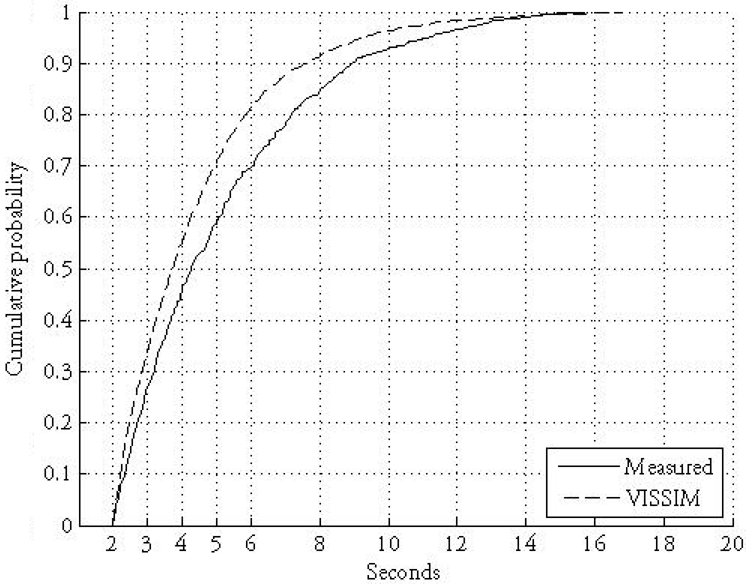

Figure 5.4 Gap distributions, morning and AM model.

As can be viewed in the figure the gap distributions in the morning differ from the AM model. The slope in the AM model is steeper. At three seconds there is a difference of 7-8 percent between the graphs. The medians are 4.3 seconds and 3.8 for the measured respectively the AM model.

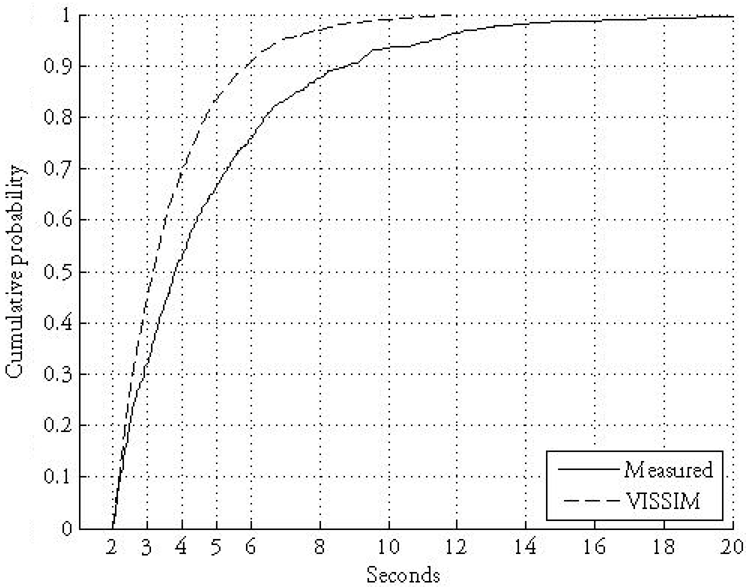

Figure 5.5 Gap distributions, afternoon and PM model.

The afternoon and PM model slopes are both steeper compared to the morning. The PM model gap distribution slope is also steeper than the measured. The difference between the measured distribution and the PM model distribution is a bit larger than in the morning and AM model situation. The difference between the morning and AM was around 7-8 percentages while the difference between afternoon and PM is the double, around 15 percent. Medians are 3.8 seconds and 3.2 seconds for the afternoon respectively the PM model.

The differences in gap distribution between the models and the measured from Spillepengen can affect the entry capacity negatively in the models. This is important to remember when viewing the VISSIM testing analysis.

5.4 VISSIM: Entry capacity

This chapter aims to investigate the entry capacity dependence on inserted gap values of priority rules in VISSIM. A number of tests will be presented to overview the change in capacity as the gap values changes. There is also one hypothesis, H6 below, which will be analysed. The hypothesis refer to see if measured critical gaps gives the same result as the predefined default values of VISSIM. Furthermore the results in entry capacity will be compared to the measured capacity of Spillepengen.

H6 – VISSIM default critical gap times generates a lower entry capacity in VISSIM than implementation of measured critical gap times from a saturated roundabout.

Since the morning situation in the roundabout is somewhat different from the afternoon the result in VISSIM from the two separate models in VISSIM will not be summarised. As a consequence of this all testing has been made once for the morning model and once for the afternoon model.

Each test was simulated with ten iterations and the models were tested with a set of priority rules as input. Output of the tests is the entry capacity that will be compared to each other as well as to the measured entry capacity of Spillepengen. The tested priority rules values of gap acceptance in the validated VISSIM models are presented in table 5.16.

Table 5.16 Tested minimum gap times of priority rules. (seconds)

	Left lane		Right lane		Right turn	
	Near	Far	Near	Far	Near	Far
Test 1	2,6	2,7	2,6	2,7	2,6	1,8
Test 2	2,5	2,6	2,5	2,6	2,5	1,8
Test 3	2,4	2,5	2,4	2,5	2,4	1,8
Test 4	2,3	2,4	2,3	2,4	2,3	1,8
Test 5	2,2	2,3	2,2	2,3	2,2	1,8
Test 6	2,1	2,2	2,1	2,2	2,1	1,8
Test 7	2	2,1	2	2,1	2	1,8
Test 8	1,9	2	1,9	2	1,9	1,8
Test 9	1,8	1,9	1,8	1,9	1,8	1,8
Test 10	2,8	2,4	2,9	2,4	3,3	0
Test 11	2,5	2	2,7	1	2,9	0
Test 12	2,7	2,1	2,9	1,9	3,1	0
Test 13	2,8	2,4	2,9	2,4	3,3	1,8

Test 1 is the default values of the VISSIM manual (PTV 2009, p 249-253).

Test 1-9 is to see how the entry capacity will be affected if the gap values are lowered 0,1 second at the time.

Test 10 is the calculated critical gap from the field study as displayed in table 5.13.

Test 11 and 12 is the minimum measured gaps from the field study with five percent respectively ten percent discarded extreme values, see appendix E. To calculate the critical gap as done in this thesis you need both accepted and rejected gaps. With the removal of a certain percentage of the accepted gaps you would not have to measure rejected gaps. This would reduce the time spent on measuring gaps with quite a lot.

Test 13 is similar to test 10, the critical gaps, but the extra value of 1.8 is added to the far lane of the right turn. This is done because the VISSIM manual (PTV 2009, p 250) recommends that value even though the right turning vehicles do not have to take the far lane into account. The VISSIM manual (PTV 2009, p 250) claim that vehicles take the far lane into consideration and therefore it is provided with a value as well.

The analysis is presented one model at the time. The entry capacity comparison for the different simulation tests of the AM model is presented in table 5.17.

Table 5.17 Entry capacity, AM model. (vehicles / half-hour)

	Left lane				Right lane			
	Mean	Min.	Max.	Std.	**Mean**	Min.	Max.	Std.
Measured	**253**	241	261	11	**268**	257	281	12
Test 1	**236**	207	264	18	**261**	228	293	18
Test 2	**244**	209	265	17	**271**	228	294	21
Test 3	**256**	239	280	13	**280**	262	313	17
Test 4	**269**	245	296	16	**292**	270	313	14
Test 5	**273**	256	298	13	**290**	272	308	14
Test 6	**287**	260	302	13	**300**	270	316	14
Test 7	**301**	280	329	15	**314**	290	337	14
Test 8	**-**	-	-	-	**-**	-	-	-
Test 9	**-**	-	-	-	**-**	-	-	-
Test 10	**245**	228	263	14	**293**	263	313	16
Test 11	**289**	261	302	13	**416**	374	435	22
Test 12	**274**	255	302	13	**327**	302	346	15
Test 13	**247**	221	273	17	**251**	218	280	18

According to the mean values in the AM model the measured entry capacity is reached already at the second and third test, see figure 5.6 and 5.7. Therefore test 8 and 9 were not done as they would differ even more from the measured values. The VISSIM default values, test 1, of the AM model has an entry capacity that is not that far away from the measured capacity. The same apply to test 10 which is the measured critical gaps from Spillepengen. As for the left lane Test 1 and test 10 is quite alike and both correspond well to the measured values. The result of the right lane indicates that the VISSIM default, test 1, are a bit closer to the measured entry capacity than the measured critical gaps, test 10. The difference between test 1 and test 10 is also a bit larger for the right lane than for the left lane.

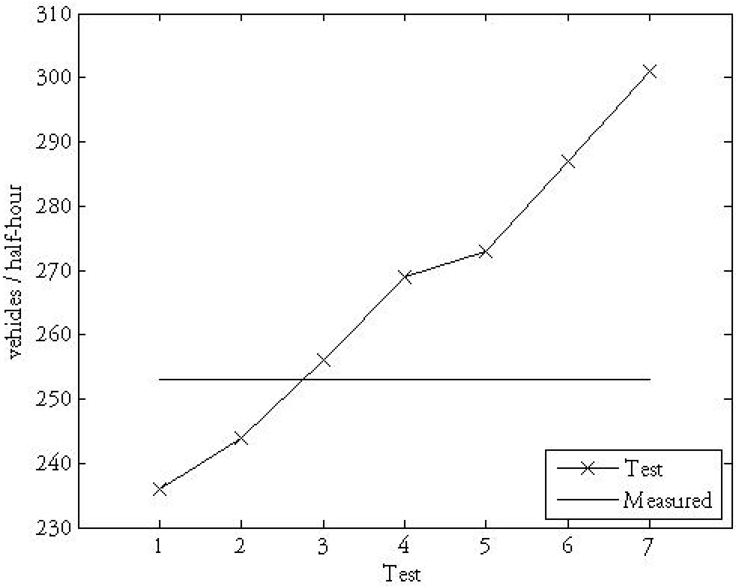

Figure 5.6 AM left lane entry capacity, test 1-7.

Test 1-5 are in the range of ten percentages from the measured value. As seen in figure 5.6 the measured values are in between test 2 and 3.

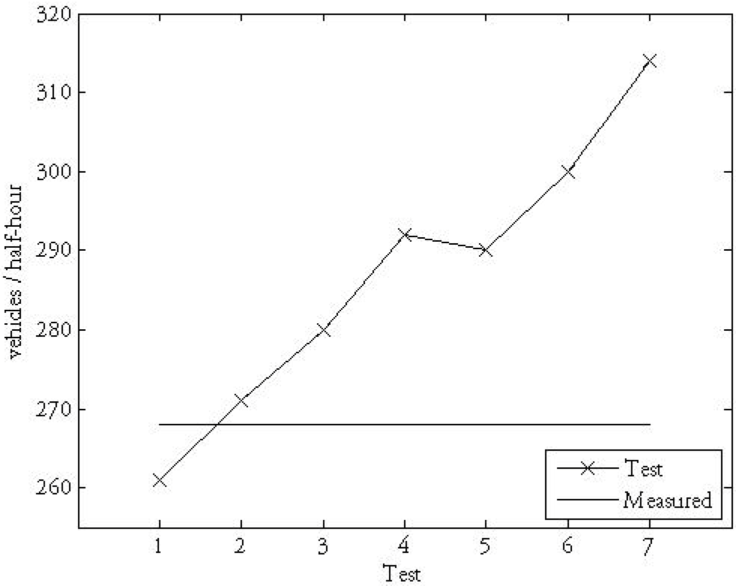

Figure 5.7 AM right lane entry capacity, test 1-7.

Like for the left lane tests 1-5 are in the ten percent range also for the right lane. The measured values are between tests 1 and 2, see figure 5.7.

Entry capacity for tests 10-13 is presented in figure 5.8 and 5.9. The critical gaps, test 10, also gives a quite close value to the measured entry capacity and is even closer for test 13 where the 1,8 consideration gap value is added for the right lane, see table 5.16. But still the measured critical gap gives a bit less entry capacity than the measured capacity. The minimum gap values, test 11 and 12, gives a high entering capacity due to the low tested gap values. It does not matter if ten or five percent is discarded, it still generates a higher flow than the measured. Worth to mention is that removal of extreme values would probably have resulted in even higher tested gap times with a larger sample size. The selected percentage five and ten percentages are probably too narrow and a higher percentage would be more suitable.

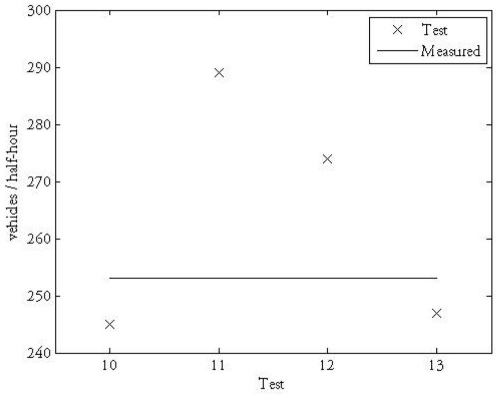

Figure 5.8 AM left lane entry capacity, test 10-13.

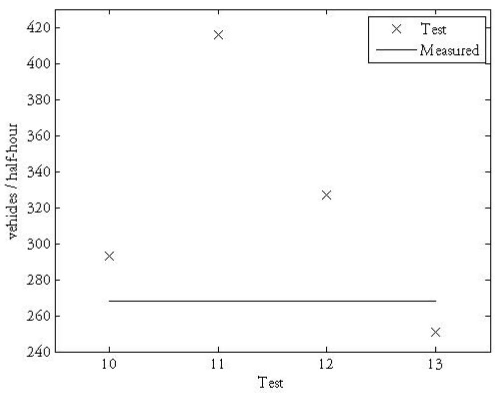

Figure 5.9 AM right lane entry capacity, test 10-13.

The PM model differs more from the measured headway distribution than the AM model but still the PM model follows the same pattern during the tests. The entry capacity of the different simulations of the PM model is presented in table 5.18.

Table 5.18 Entry capacity, PM model. (vehicles / half-hour)

	Left lane				Right lane			
	Mean	Min.	Max.	Std.	**Mean**	Min.	Max.	Std.
Measured	**232**	215	243	15	**252**	240	261	11
Test 1	**168**	151	184	12	**175**	156	202	14
Test 2	**174**	152	195	14	**180**	163	200	13
Test 3	**186**	174	204	10	**193**	184	215	11
Test 4	**196**	182	210	10	**202**	189	219	10
Test 5	**212**	194	239	14	**214**	197	236	11
Test 6	**218**	200	244	14	**219**	205	249	14
Test 7	**234**	209	257	17	**230**	208	262	17
Test 8	**249**	220	268	16	**243**	217	259	13
Test 9	**268**	247	286	12	**258**	241	287	14
Test 10	**162**	145	181	12	**182**	163	207	14
Test 11	**199**	181	228	14	**239**	208	295	24
Test 12	**179**	161	197	12	**200**	178	237	18
Test 13	**161**	138	172	10	**144**	127	162	12

In the PM model the measured entry capacity is reached first at test 7, 8 and 9, figure 5.10 and 5.11. These low values of gap acceptance gives a simulation were vehicles are not interacting in a satisfactory way even though they give the correct entry capacity. Vehicles tend to crash into one another when entering the roundabout at these low gap values. Like in the AM model the default values in test 1 gives a quite similar entry capacity as the measured critical gaps in test 10. However both test 1 and 10 are far from the entry capacity of Spillepengen.

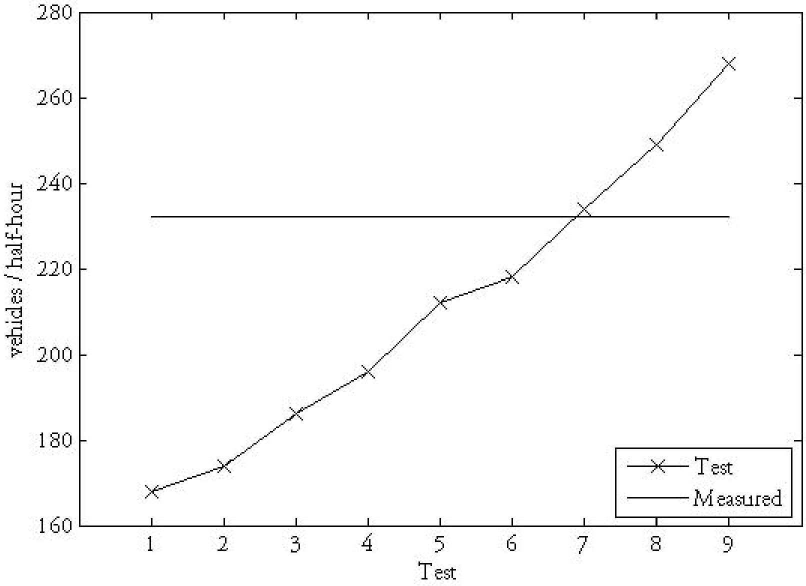

Figure 5.10 PM left lane entry capacity, test 1-9.

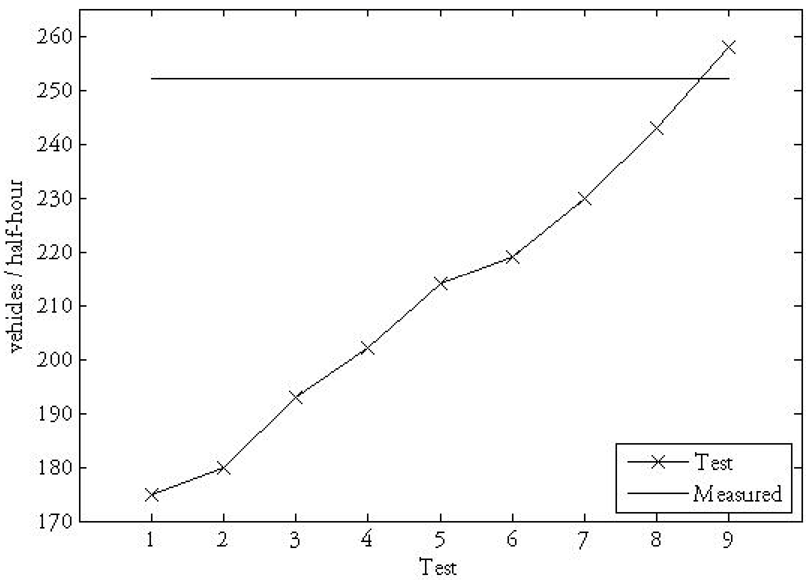

Figure 5.11 PM right lane entry capacity, test 1-9.

Entry capacity of test 10-13 is presented in figure 5.12 and 5.13. The critical gaps, test 10, are not even near to reach the measured entry capacity and the 1.8 consideration value, test 13, will not solve the problem either. The same applies to the minimum values, test 11 and 12, which also are unable to reach the measured entry capacity.

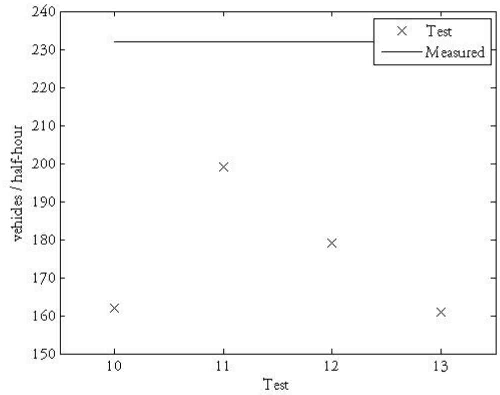

Figure 5.12 PM left lane entry capacity, test 10-13.

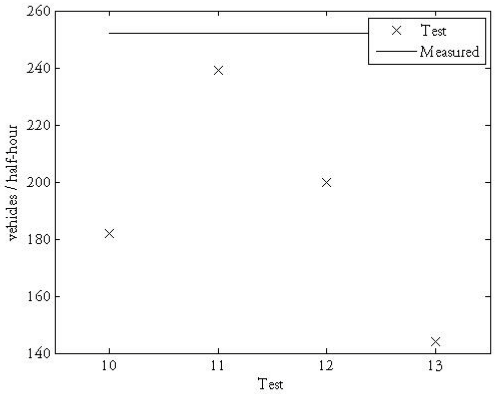

Figure 5.13 PM right lane entry capacity, test 10-13.

There is a big difference between the AM and PM models compared to their respective measured entry capacity values. The PM model is not close to simulate the correct entry capacity while the AM model is better in that aspect. The measured values for entry capacity at the two legs are quite close to each other even though the measured flow in the circulatory roadway differs. This most likely has something to do with the flow in the circulatory roadway that is not correctly simulated in the PM model. The gap distribution in the PM model differ more compared to reality than it does for the AM model.

The VISSIM default values generate an entry capacity very close to the capacity generated by the measured critical gap values. The difference is too small to make any assumptions if there really is a difference or not. This leads to that the hypothesis H6 most likely is untrue and that there is no difference between using default values or measured values in this case.

5.5 VISSIM: Mean gap times

A comparison was made for some of the tests to see how the mean gap time is influenced by the minimum gap time in VISSIM. A hypothesis was that drivers accept shorter gaps at saturation flow than those generated in VISSIM with its default values. This is interesting due to the fact that the critical gap is lowered when the waiting time is increased (Kettelson & Vandehey 1991, p 158). The tested hypothesis in this section is:

H7 – Simulation of a saturated roundabout in VISSIM at default values of priority rules generates higher mean gaps than measured mean gaps from field studies.

As previously described the accepted gaps from the field study have been measured and sorted into categories in Excel. This gave the mean, minimum, maximum, and standard deviation of the accepted gaps in Spillepengen. The same types of values were generated in Excel for the simulations in VISSIM by implementing the VISSIM output into Excel. This enables the comparison of measured gaps and the by VISSIM generated gaps.

The process of dividing the gaps in the right lane after right turning and straight moving vehicles was determined to be too time consuming and therefore the comparison only includes the left lane. The comparison is presented one model at the time.

The full statistic result from each test in the AM model is presented in appendix F and below is a comparison of means between the tests in table 5.19 and figure 5.14.

Table 5.19 Mean gaps, AM model left lane. (seconds)

	N-N	N-F	F-F	F-N
Measured	3,91	4,45	3,18	2,83
Test 1	4,36	4,86	4,28	3,76
Test 3	3,97	4,63	4,15	3,5
Test 5	3,96	4,56	3,88	3,3
Test 7	3,55	4,22	3,71	3,12
Test 10	4,26	4,64	4	3,76
Test 12	4,32	4,42	3,65	3,67

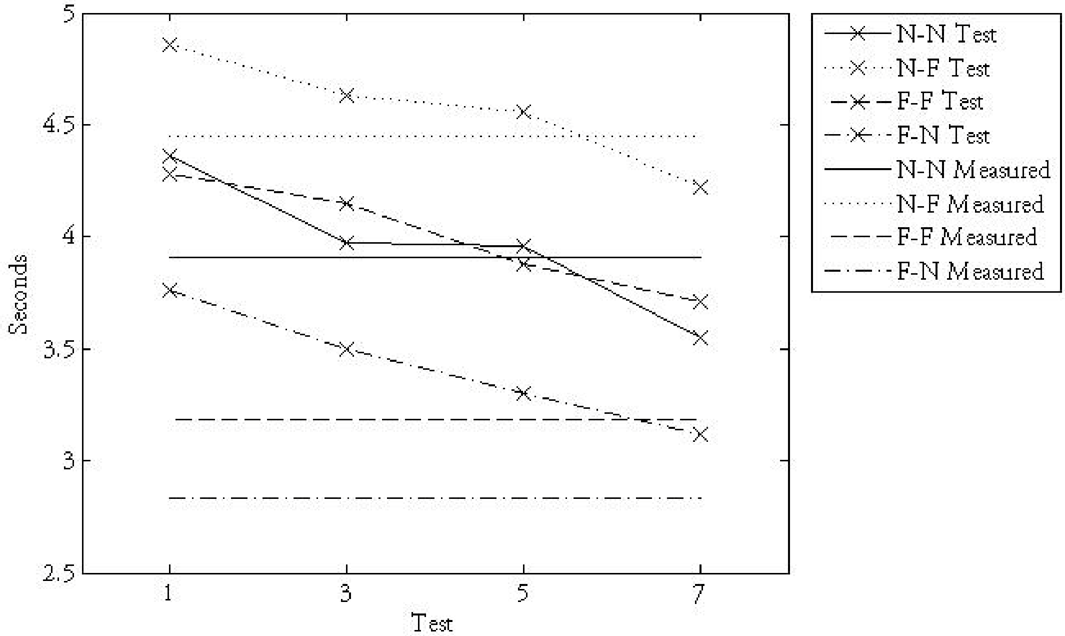

Figure 5.14 Mean gaps, AM model left lane.

The figure and table above presents a small gap time difference between measured values and simulated values for gaps where the first vehicle of the gap is in the near lane. There is also evident that there are difficulties in obtaining a value close to the measured when the first vehicle of a gap is in the far lane. The VISSIM default might then work quite well when it comes to accepting gaps where the first vehicle is in the near lane.

The full statistic result from each test in the PM model is presented in appendix F and below is a comparison of means between the tests in table 5.20 and figure 5.15.

Table 5.20 Mean gaps, PM model. (seconds)

	N-N	N-F	F-F	F-N
Measured	3,91	4,45	3,18	2,83
Test 1	4,02	4,62	4,16	3,46
Test 3	3,83	4,44	4,03	3,32
Test 5	3,59	4,4	3,8	3,09
Test 7	3,4	4,14	3,57	2,86
Test 9	3,17	3,85	3,32	2,71
Test 10	4,21	4,52	3,95	3,61
Test 12	4,06	4,16	3,62	3,56

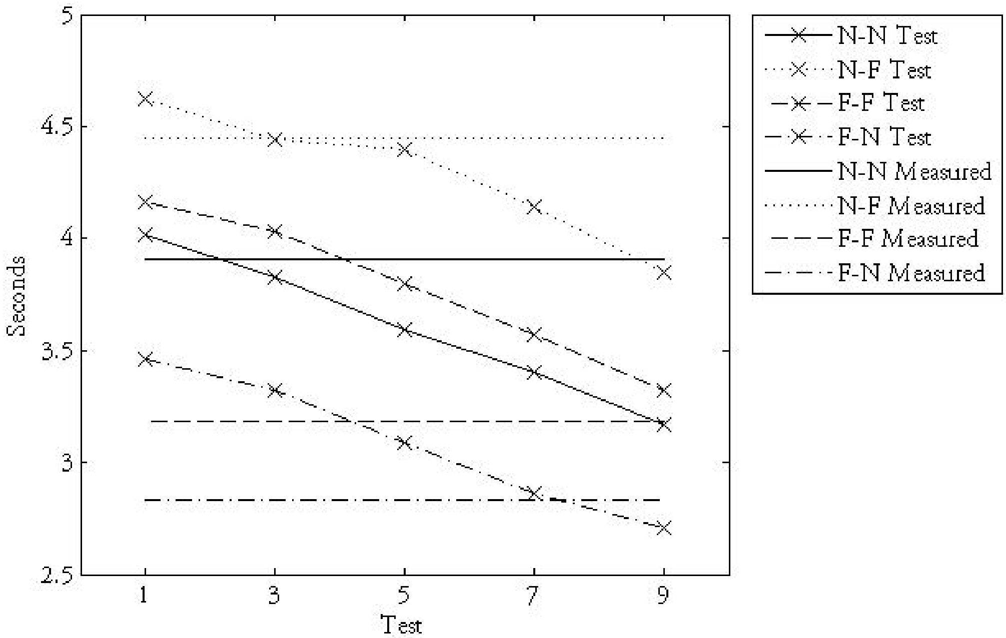

Figure 5.15 Mean gaps, PM model left lane.

The table and figure above infer the same reasoning as in the AM model for test 1-5. The near gaps accord more with the measured and the far gaps still leaves a lot more to wish for. But tests 7 and 9 are the other way around and the far gaps are more like the measured ones while the near gaps tends to drop below the measured values. The cause for this might be the very low input values of gap acceptance in priority rules. Test 10 and 12 are just as in the AM model more like the first tests were the near gap accord more than the far gaps to the measured gaps.

Hypothesis H7 should be true for the far to far gap because the calculated critical gap is lower than VISSIM default and the opposite should be true for near to near gap where the calculated value is higher than VISSIM default. But the mean gaps show that VISSIM’s accepted gaps have a higher mean than those measured. And Student’s t-test shows that there is a significant difference in far to far gaps for both the AM and the PM model. It is also a significant difference for the AM model near to near gaps. In the PM model near to near gaps he Student's t-test indicates that the means do not differ significantly. This indicates that the hypothesis H7 true for three out of four defined gaps.

5.6 VISSIM: Follow-up times

This section tests two hypotheses that involve follow-up times. The follow-up time definition used in the thesis is the critical gap subtracted from the gap divided with the number of follow-ups. Due to the method to calculate the follow-up time no separate data for each vehicle exists because only a mean follow-up time was calculated. The follow-up times are only for cars all other vehicles have been removed. The input value of minimum gap time was not used to calculate the follow-up time instead the critical gap time was calculated for every simulation with Raff's method. The tested hypotheses are:

H8 – Roundabouts at saturation flow have lower follow-up times than follow-up times generated by VISSIM.

H9 – Minimum gap time in VISSIM has no influence on follow-up times in VISSIM.

The first observation from the follow-up analysis is that even though the simulated follow-up times differ up and down they remain higher than the measured ones, see table 5.21 and 5.22. Test 1 that is VISSIM default has higher follow-up times compared to measured values so hypothesis H8 is probably proven, though the data consists only of means and not individual data for each vehicle and therefore cannot be proven statistically.

Table 5.21 Follow-up times, AM model. (seconds)

	Left lane			
	N-N	N-F	F-F	F-N
Measured	2,45	2,43	2,22	2,14
Test 1	2,77	3,29	2,91	2,94
Test 3	3,27	3,31	3,38	3,3
Test 5	3,07	3,82	3,59	3,48
Test 7	2,81	3,31	3,05	2,79
Test 10	2,93	3,11	3,25	3,09
Test 12	3,68	4,05	3,5	3,15

Table 5.22 Follow-up times, PM model. (seconds)

	Left lane			
	N-N	**N-F**	**F-F**	**F-N**
Measured	2,45	2,43	2,22	2,14
Test 1	3,1	3,72	3,07	3,26
Test 3	2,92	3,16	3,05	3,2
Test 5	3,08	3,1	3,11	3,04
Test 7	3,07	2,82	3,11	3,1
Test 9	2,74	2,87	2,95	2,99
Test 10	3,03	3,02	2,91	3,42
Test 12	3,3	3,34	3,01	3,12

To investigate if the inserted minimum gap time in priority rules somehow affect the follow up times, hypothesis H9, a comparison is made between simulated values and measured values from the field study. The comparison is displayed in figure 5.16 and 5.17.

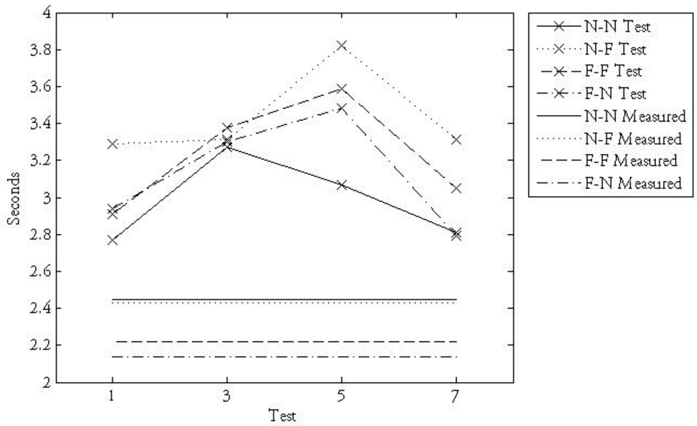

Figure 5.16 Follow-up times AM model left lane.

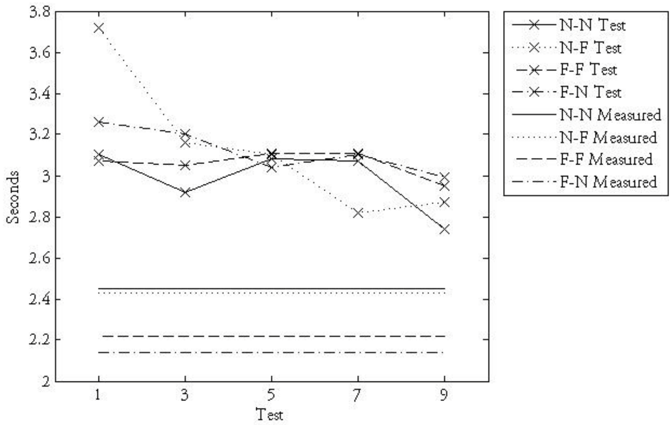

Figure 5.17 Follow-up times PM model left lane.

When looking at the follow-up times generated by VISSIM in comparison to the measured there is another observation that can be made. The inserted gap values in priority rules seems to have no consistent effect on the follow-up times as the values differ both up and down when the inserted gap values decrease. This indicates that hypothesis H9 is true.

5.7 VISSIM: Conflict areas

Conflict areas are another method to use instead of priority rules and are supposed to result in a more intelligent vehicle behaviour. The behaviour seen in the videos from Spillepengen did not match the behaviour in VISSIM when using conflict areas. One big difference in the behaviour was that the vehicles were too slow when using conflict areas. They do not consider that the gap is a bit away and stays too long at the yield line, which lead to this hypothesis:

H10 – The use of conflict areas in VISSIM when simulating two-lane roundabouts gives inaccurate results.

In an early phase of the thesis it was found that the conflict areas did not seem to allow enough vehicles to enter the circulation in comparison to the measured flows. The conflict areas were at the time on default values. Therefore another approach was tested were the front gap and rear gap parameters of the conflict areas were set to zero. The other parameters of the conflict areas were kept at default. This approach was made in attempt to get the lowest acceptance and by that raise the entry capacity.

The simulations with conflict areas were done with two different settings. One test without taking any consideration to where the vehicles stop before entering the roundabout, test 14, and one where the vehicles stop at the correct position before entering, test 15. The correct position to the yield line from the conflict area was seven meters in the AM model and eight meters in the PM model. The additional stop distance gives the vehicle a longer way to travel from stand still into the circulation. The comparison is listed in table 5.23 and 5.24 below.

Table 5.23 Am model entry capacity using conflict areas. (vehicles / half-hour)

	Left lane				Right lane			
	Mean	Min.	Max.	Std.	**Mean**	Min.	Max.	Std.
Measured	**253**	241	261	11	**268**	257	281	12
Test 14	**185**	164	203	13	**372**	319	400	26
Test 15	**166**	133	188	17	**363**	313	400	27

The field study shows that the entry capacities of the left and right lane in the morning are quite close to each other. This is not the case with conflict areas in the AM model where the right lane has a much higher entry capacity compared to the left lane. The reason for this is probably that right turning vehicles are not taking the far lane into account in VISSIM when using conflict areas while they do that in reality. This is an interesting issue due to the fact that a right turning vehicle, in reality, should not need to consider the far lane but the field study indicates that they do. When using conflict areas none conflicting vehicles are not considering each other. Furthermore the entry capacity of the left lane is much lower than the measured even though the front and rear gap are set to their minimum values. The additional stop line, test 15, seems to lower the capacity even more.

Table 5.24 PM model entry capacity using conflict areas. (vehicles / half-hour)

	Left lane				Right lane			
	Mean	Min.	Max.	Std.	**Mean**	Min.	Max.	Std.
Measured	**232**	215	243	15	**252**	240	261	11
Test 14	**85**	75	111	11	**192**	165	243	21
Test 15	**58**	45	83	12	**191**	167	229	20

The entry capacity in the afternoon is not that different from the morning according to the field study but in VISSIM there is a major difference between the PM and AM model. Further the right lane of the PM model follows the same pattern as the AM model. This meaning the substantial difference between the two entering lanes. It also seems like conflict areas has some problems to handle the larger circulating flow in the PM model according to the very low simulated entry capacity. As a consequence of this weakness the further comparison of values generated by conflict areas and measured values from the field study is made only for the AM model. The comparison only consists of the left lane.

When using conflict areas the generated gap acceptance means are a lot higher than the measured means from the field study, see table 5.25. The lower mean when the first car of the gap is in the far lane indicates that conflict areas make vehicles consider at what speed they will pass the gap, that they have a longer acceleration distance. This behaviour was also observed in the field study which strengthens the theory of more intelligent vehicle behaviour with conflict areas in VISSIM. Even though the behaviour is more intelligent and other vehicles in the circulation would retard if the conflict area is not emptied before entering it, the high means lowers the entry capacity too much.

Table 5.25 Accepted gaps using conflict areas, AM model left lane. (seconds)

	Measured				Test 14			
	N-N	**N-F**	**F-F**	**F-N**	**N-N**	**N-F**	**F-F**	**F-N**
Sample	101	60	70	74	50	52	339	238
Mean	**3,91**	**4,45**	**3,18**	**2,83**	**6,05**	**6,60**	**4,45**	**3,50**
Min.	1,7	2,3	1,4	0,6	4,9	5,4	2,6	0,3
Max.	7,5	6,3	5,5	5,6	7,5	8,6	7,5	7,4
Std.	1,09	0,99	0,91	1,11	0,64	0,77	1,08	1,23

The follow-up times, see table 5.26, when using conflict areas are in the same range as those generated using default values in priority rules. This indicates that the use of conflict areas do not affect the follow up times which again is similar to the use of priority rules. On the other hand the follow up times are not that far away from the measured ones, but this is to little help looking at the entering flows.

Table 5.26 Follow-up times, AM left lane. (seconds)

	Left lane			
	N-N	**N-F**	**F-F**	**F-N**
Measured	2,45	2,43	2,22	2,14
Test 1	2,77	3,29	2,91	2,94
Test 17	2,88	2,79	2,95	3,05

The results above demonstrate that hypothesis H10 is supported. This can be stated due to the result in entering flows which does not correspond with the measured flows and the fact that the mean gaps differ more than two seconds for some gaps. Furthermore conflict areas do generate a more intelligent behaviour but as for right turning as mentioned above the behaviour might be a little bit too intelligent which makes the behaviour unrealistic.

6 Discussion and conclusions

Our aim at the start of this thesis was to see how well VISSIM default values for critical gap apply in a two-lane roundabout at saturation flow. According to Kettelson & Vandehey (1991, p 158) the critical gap is decreasing the longer a driver has to wait at the yield line. Our purpose was then to see if the critical gap at a saturated two-lane roundabout would be lower than those suggested in The VISSIM manual. Unfortunately we had severe problems to model the gap distribution correctly and therefore it is difficult to say anything about how well the different values of minimum gap applies in VISSIM. What could be done was a comparison how the suggested values in the manual applies in the two different models compared to measured values from the investigated roundabout Spillepengen. When we carried on with the literature study, field study and model building we came up with some other hypotheses which are not dependent on gap distribution and we wanted to include them in the thesis as well.

Below is a review of each hypothesis:

H1 – Car drivers accept shorter gaps than lorry drivers.
H2 – Drivers accept larger gaps when a lorry is approaching in the roundabout.

The investigated object Spillepengen holds a lot of lorry traffic and therefore we thought it would be interesting to investigate these ideas. At the first visits to Spillepengen we were sure it would be enough lorry samples but unfortunately the video length we selected to study resulted in too few samples.

It feels natural to assume that car drivers accept shorter gaps than lorry drivers because of their faster acceleration and shorter vehicle length to consider. By this assumption hypothesis H1 would be true. Our study of the videos indicates that numerous lorry drivers forces themselves into the circulation and the actual gaps they accepted were difficult to measure because the vehicles in the circulatory roadway needed to slow down. This behaviour would, even with more samples, make it impossible to make a fair comparison. Lorry drivers could at times accept very small gaps because they know the vehicles in the circulatory roadway will decelerate.

H2 is very interesting and we were convinced that drivers were acting more careful when entering a roundabout in front of a vehicle that causes more damage if a conflict would occur. Our measured values for static cars indicate that this could be the case but the samples are too few. For floating cars it seems to be the opposite but as the samples are even fewer here it is even more impossible to make any conclusions.

The few samples of lorries during the investigated time disabled the testing of hypotheses H1 and H2. We could have decided to collect more data but the data collection from the recordings was too time consuming in this case. As a result of this no conclusion regarding these hypotheses can be made.

H3 – Drivers accept shorter gaps when the first vehicle of the gap is in the far lane.

Hypothesis H3 was founded when we discovered some very short accepted gap times when the first vehicle of the gap was in the far lane. This lead to the question if this was only random insanity or if there would be some kind of pattern in this behaviour. Also earlier studies made by Hagring (1998) show that there is a significant difference depending on which lane the first vehicle of a gap is situated.

The comparison between accepted gaps where the first vehicle is in the near or far lane in the roundabout resulted in a true H3 hypothesis. H3 was also statistical proven with a Student t-test that concluded that the two categories of accepted gaps in the comparison do not hold the same mean.

We believe that the two most important reasons for this are that drivers can plan the entrance better when a vehicle is in the far lane. The drivers can start to accelerate earlier when the first car is in the far lane due to the distance is longer before they are in conflict with each other. The longer acceleration distance gives the vehicle a greater speed and the gap can be crossed in shorter time which makes them accept shorter gaps when the first vehicle is in the far lane. The other reason would, in this particular roundabout, be that the geometry brings a more weaving entrance in the far lane than in the near lane. This needs further investigation to see if this is the case in other roundabouts as well. And if this is true the minimum gap times should be adjusted so they relate better to the reality.

H4 – Drivers in the right entering lane have the same gap acceptance regardless if they desire to turn right or go straight.

This hypothesis came from the belief that it would be easier to turn right when entering the roundabout and therefore the right turning vehicles would have shorter gap acceptance. But after observations at the site we thought that right turning would have more or less the same gap acceptance as the straight moving vehicles. H4 was proven false and the result shows that there is a significance difference between drivers going straight compared to those who turn right. Those going straight accept shorter gaps than those who turn right.

The result is a bit surprising but the VISSIM manual suggest that drivers take the far lane in to consideration and this seems to be the case also in our study. The right turning drivers probably are insecure how the vehicles in the far lane will behave because a low percentage of vehicles in the far lane shift lane when exiting the Spillepengen roundabout. The lack of indicator use in the circulation and/or the high speed of circulating vehicles might also be a reason and causes insecurity of entering drivers who do not know the destination of the circulating vehicles.

H5 – Floating cars accept shorter gaps than static cars.

The easy explanation to this hypothesis is the belief that a vehicle with just an inch of speed would easier merge into a gap than a vehicle starting at stand still position.

The samples of floating cars were too few to do a statistical analysis. The comparison of means between floating and static entering cars shows that they are quite alike. The floating means are a little bit lower but still the small sample size disables us from concluding anything in this case.

Spillepengen roundabout has a quite long distance from the circulatory roadway to the yield line. This enables vehicles that stopped at the yield line to act as a floating before entering due to the possibility to accelerate during that distance. This hypothesis would be interesting to test at a roundabout with a yield line closer to the circulatory roadway.

H6 – VISSIM default critical gap times generates a lower entry capacity in VISSIM than implementation of measured critical gap times from a saturated roundabout.

The idea behind this hypothesis is to see how well the recommended default values related to gap acceptance in VISSIM corresponds to measured values from a field study.

The suggested values from The VISSIM manual produce entry capacity in the same range as the implemented measured values. As stated in the result part this hypothesis is probably untrue for this case.

The measured critical gaps from Spillepengen are quite close to those suggested by The VISSIM manual. For both the near lane and the far lane it differs 0.3 seconds though for the near lane the measured values are higher and for the far lane they are lower. The measured value for the right turning cars are 0.7 seconds higher although The VISSIM manual suggests another approach for the right turning vehicle. It uses the same value for the near lane and adds a low critical gap for the far lane to force the cars to take that lane into account as well even though they would not have to. Our idea was to only calculate the critical gap for the near to near gap and not take the far lane in to account when looking at right turning vehicles.

The approach VISSIM uses for the right turning vehicles is preferred because if the flow is low in the near lane we would get a higher entry capacity when not considering the far lane. The measured critical gap for the right turning vehicles would not be good to use in situations where there is a greater flow in the far lane compared to the near lane.

H7 – Simulation of a saturated roundabout in VISSIM at default values of priority rules generates higher mean gaps than measured mean gaps from field studies.

This hypothesis was a result of the wish to somehow measure the ability of VISSIM to generate realistic and accurate scenarios. As this thesis focus on gap acceptance we felt it natural to compare the gap acceptance behaviour in VISSIM at the default values with the actual gap acceptance in Spillepengen.

H7 is true for far to far gaps but not for near to near gaps. There is a significant difference between the measured values and those generated by VISSIM in the far to far gaps. For the near to near gaps there is only a significant difference for one of the two models. However the one model where the near to near gaps are significantly different the difference in time is not that substantial.

H8 – Roundabouts at saturation flow have lower follow-up times than follow-up times generated by VISSIM.

The reason of this hypothesis is that follow up-times affect the entry capacity and if it proved to be true it might be an explanation to why there is such difficulty in obtaining the measured capacity in the simulation.

The result shows that all measured follow-up times are lower than the follow-up times generated in VISSIM; this indicates that the hypothesis H8 is true. The measured follow-up times corresponds well to earlier studies by Hagring (1998) and this could prove that the VISSIM follow-up times are too high, at least to the Swedish behaviour type.

Reasons why the follow-up times are higher in VISSIM could be that stand still and safety distances are shorter in reality and that the acceleration is different from the acceleration set in VISSIM. All this would be very interesting to investigate more closely and is why further studies in this area are recommended.

H9 – Minimum gap time in VISSIM has no influence on follow-up times in VISSIM.

As we lowered the inserted minimum gap while testing the different setups in VISSIM we discovered that the follow-up time seemed to not change that much. When looking closely into this we found that the follow-up times generated by VISSIM do not descend as the accepted gaps did when lowering the minimum gap time. The result indicates that minimum gap time seems to have no major influence on the follow-up time and therefore the hypothesis H9 is true.

To adjust the follow-up time in VISSIM some other parameter must be changed as mentioned in previous hypothesis. Those we are thinking on first are the acceleration, stand still distance and safety distance. This must be investigated further to see how the real acceleration curves are and how long the stand still distance is. Further studies related to these parameters would be useful.

H10 – The use of conflict areas in VISSIM when simulating two-lane roundabouts gives inaccurate results.

We decided to simulate the roundabout with priority rules as a standard approach due to the ability to implement values of gap acceptance into the model. But we felt that we should at least try to model the same roundabout with conflict areas to see if that approach gave an accurate result, therefore we decided to include hypothesis H10 in this thesis.

According to the result hypothesis H10 is true. This is mainly because of the inability to simulate entry capacity that corresponds well to the measured entry capacity in the field study. The reasons for this are a few problems that might occur when using conflict areas.

The mean accepted gaps are considerably larger than the measured gaps from Spillepengen, which affect the entry capacity in VISSIM negatively. The problem with high mean gaps is foremost when the first vehicle of the gap is in the near lane, which leads to the next cause below.

The vehicles are said to gain a more intelligent behaviour with conflict areas. This works quite well when vehicles accept shorter gaps when the first vehicle of a gap is in the far lane, which means that they seem to consider how the vehicles are distributed in the circulatory roadway. But the entering vehicles are very slow and cautious which the high mean gaps reflect. This leads to missed good gaps and lowers the entry capacity. When using priority rules this can be modified and the entering vehicles will be more on their toes and start the acceleration some time before the gap appears.

The more intelligent behaviour also creates another issue that makes the simulated entry capacity differ from the measured. This is the right turning movement of the entering vehicles. If looking only at normal traffic rules those vehicle that desire to turn right in the roundabout does not need to be cautious of the circulating vehicles in the far lane. But for some reason the field study indicates that they do take the far lane in consideration. This is also described in the VISSIM manual (PTV 2009, p 250). In this study we can only speculate in why the entering vehicles behave in such manner but one possible reason is the lack of indicator use in the circulation and/or the high speed of circulating vehicles. But thanks to the intelligent behaviour vehicles receive with conflict areas the right turning vehicles do not seem to take the far lane into account. This of course leads to a very good entry capacity for those who desire to turn right which does not correspond well to the observed situation at Spillepengen.

Conflict areas might correspond well to other traffic situations where the intersections or areas of conflict are not as skewed as in this study. It could simply be the geometry of this particular two-lane roundabout or two-lane roundabouts in general that aggravates the use of conflict areas.

At last we can conclude by the result in this study that when simulating two-lane roundabouts with VISSIM it is better to use priority rules at the entry sections rather than conflict areas. This is due to the more flexible modification that priority rules offers which come in handy when coding such a difficult traffic situation.

Last but by no means least

The result in this thesis ends up in a number of more or less strong conclusions. What must be remembered is that all conclusions made in the thesis only applies to the specific two-lane roundabout of Spillepengen but would most likely correspond well in other cases with the same type of roundabout.

Despite the fact that VISSIM generates higher accepted mean gap times and follow-up times than those measured in Spillepengen there is no major difference in entry capacity between the two. This might have something to do with the inconsequent behaviour of drivers while vehicles in VISSIM are consequent. While calculating the critical gaps for the measured values and VISSIM generated values one thing was observed which was that the accepted and rejected gaps overlapped more in the measured values. This leads to the conclusion that you cannot calibrate a VISSIM model with measured mean gap times.

The headway distribution was found to be very important to get an accurate simulation that corresponds well to the measured entry capacity, see the difference between AM and PM model. We now believe that modelling the correct headway distribution is the key feature in VISSIM simulation of two-lane roundabouts. Most likely more important than to obtain the correct minimum gap times because VISSIM default values seems to correspond well to the real situation, though an adjustment as suggested in H3 should be considered. As they conclude in the VISSIM manual:

The values used for min. gap time, (...) have been determined through research. Thus for most applications these serve as a realistic base. (PTV 2009, p 249)

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Appendix A

Table A.1 Gaps for cars in the left lane, static entering cars. (seconds)

	In front of car							
	Accepted				Rejected			
	N-N	N-F	F-F	F-N	N-N	N-F	F-F	F-N
Sample	61	40	48	43	291	222	171	90
Mean	**3,99**	**4,45**	**3,06**	**2,99**	**1,73**	**2,03**	**1,74**	**1,61**
Min.	1,7	2,6	1,4	0,9	0,2	0,6	0,4	0,4
Max.	6,6	6,3	5,0	5,6	4,3	4,8	4,0	4,5
Std.	1	0,95	0,82	1,15	0,8	0,88	0,74	0,66
	In front of lorry							
	Accepted				Rejected			
	N-N	N-F	F-F	F-N	N-N	N-F	F-F	F-N
Sample	9	6	4	8	18	25	10	29
Mean	**4,08**	**4,59**	**4,25**	**3,61**	**2,58**	**2,73**	**2,44**	**2,01**
Min.	2,7	2,6	3,7	2,2	0,4	0,7	1,3	0,9
Max.	4,9	6,0	5,0	4,3	4,3	4,9	3,6	4,0
Std.	0,71	1,09	0,57	0,72	1,04	1,2	0,8	0,79

Table A.2 Gaps for cars in the right lane going straight, static entering cars. (seconds)

	In front of car							
	Accepted				Rejected			
	N-N	N-F	F-F	F-N	N-N	N-F	F-F	F-N
Sample	16	32	25	17	105	93	74	43
Mean	**3,82**	**4,84**	**3,24**	**2,72**	**1,79**	**1,96**	**1,75**	**1,63**
Min.	2,5	1,9	1,0	0,6	0,5	0,6	0,6	0,4
Max.	5,8	12,8	5,4	5,0	4,8	4,7	3,7	3,4
Std.	0,98	2,01	1,16	1,23	0,88	0,8	0,73	0,74
	In front of lorry							
	Accepted				Rejected			
	N-N	N-F	F-F	F-N	N-N	N-F	F-F	F-N
Sample	5	2	1	6	7	13	7	7
Mean	**4,30**	**5,43**	**6,1**	**2,75**	**2,67**	**2,83**	**2,33**	**1,77**
Min.	3,8	4,9	6,1	1,5	1,2	0,7	1,3	1,0
Max.	4,9	6,0	6,1	4,0	4,0	4,9	3,3	2,8
Std.	0,49	0,76	-	1,08	0,96	1,13	0,77	0,71

Table A.3 Gaps for cars in the right lane turning right, static entering cars. (seconds)

	In front of car							
	Accepted				Rejected			
	N-N	N-F	F-F	F-N	N-N	N-F	F-F	F-N
Sample	91				341			
Mean	**4,81**				**2,08**			
Min.	2,1				0,2			
Max.	9,7				10,6			
Std.	1,89				1,22			
	In front of lorry							
	Accepted				Rejected			
	N-N	N-F	F-F	F-N	N-N	N-F	F-F	F-N
Sample	18				33			
Mean	**5,87**				**3,25**			
Min.	3,7				0,4			
Max.	9,4				7,3			
Std.	1,65				1,54			

Table A.4 Gaps for lorries in the left lane, static entering lorries. (seconds)

	In front of car							
	Accepted				Rejected			
	N-N	N-F	F-F	F-N	N-N	N-F	F-F	F-N
Sample	3	2	1	3	18	12	7	6
Mean	**4,00**	**6,76**	**3,7**	**4,64**	**2,30**	**3,06**	**1,74**	**2,46**
Min.	2,8	6,7	3,7	2,6	0,8	0,9	1,1	0,8
Max.	5,9	6,8	3,7	6,5	5,6	5,0	3,7	4,4
Std.	1,64	0,07	-	1,95	1,22	1,26	0,94	1,37
	In front of lorry							
	Accepted				Rejected			
	N-N	N-F	F-F	F-N	N-N	N-F	F-F	F-N
Sample	1	1	0	0	1	3	0	1
Mean	**7,7**	**5,4**	**-**	**-**	**4,2**	**2,14**	**-**	**3,3**
Min.	7,7	5,4	0	0	4,2	1,28	0	3,3
Max.	7,7	5,4	0	0	4,2	3,68	0	3,3
Std.	-	-	-	-	-	1,34	-	-

Table A.5 Gaps for lorries in the right lane going straight, static entering lorries. (seconds)

	In front of car							
	Accepted				Rejected			
	N-N	N-F	F-F	F-N	N-N	N-F	F-F	F-N
Sample	6	5	7	2	15	17	15	4
Mean	**4,05**	**5,59**	**4,74**	**3,57**	**2,71**	**2,10**	**1,64**	**2,28**
Min.	2,4	3,6	1,7	2,8	0,8	1,0	0,7	1,1
Max.	5,8	8,2	6,6	4,3	7,1	4,2	2,9	4,5
Std.	1,16	1,67	1,81	1,1	2,04	0,9	0,58	1,57
	In front of lorry							
	Accepted				Rejected			
	N-N	N-F	F-F	F-N	N-N	N-F	F-F	F-N
Sample	1	0	0	1	0	3	0	8
Mean	**5,6**	**-**	**-**	**4,0**	**-**	**3,47**	**-**	**1,99**
Min.	5,6	0	0	4,0	0	1,22	0	0,94
Max.	5,6	0	0	4,0	0	5,37	0	2,91
Std.	-	-	-	-	-	2,1	-	0,67

Table A.6 Gaps for lorries in the right lane turning right, static entering lorries. (seconds)

	In front of car							
	Accepted				Rejected			
	N-N	N-F	F-F	F-N	N-N	N-F	F-F	F-N
Sample	26				83			
Mean	**6,25**				**2,52**			
Min.	2,9				0,4			
Max.	12,6				7,2			
Std.	2,15				1,46			
	In front of lorry							
	Accepted				Rejected			
	N-N	N-F	F-F	F-N	N-N	N-F	F-F	F-N
Sample	2				19			
Mean	**7,10**				**3,25**			
Min.	6,1				1,5			
Max.	8,1				7,1			
Std.	1,47				1,46			

Appendix B

Table B.1 Accepted gaps for floating cars in the left lane. (seconds)

	In front of car				In front of lorry			
	Accepted				Accepted			
	N-N	N-F	F-F	F-N	N-N	N-F	F-F	F-N
Sample	28	13	17	20	3	1	1	3
Mean	**3,74**	**4,37**	**3,28**	**2,25**	**3,36**	**4,8**	**3,2**	**2,42**
Min.	1,7	2,3	1,9	0,6	1,9	4,8	3,2	1,5
Max.	7,5	6,0	5,5	4,2	4,3	4,8	3,2	2,9
Std.	1,35	1,18	1,1	0,93	1,27	-	-	0,78

Table B.2. Accepted gaps for floating cars in the right lane going straight. (seconds)

	In front of car				In front of lorry			
	Accepted				Accepted			
	N-N	N-F	F-F	F-N	N-N	N-F	F-F	F-N
Sample	7	1	12	3	4	1	2	2
Mean	**4,45**	**5,2**	**3,10**	**2,94**	**3,39**	**4,0**	**3,75**	**2,75**
Min.	2,9	5,2	1,0	2,4	1,9	4,0	2,9	2,1
Max.	6,3	5,2	4,8	3,6	4,8	4,0	4,6	3,4
Std.	1,4	-	1,18	0,6	1,18	-	1,22	0,96

Table B.3 Accepted gaps for floating cars in the right lane right turning. (seconds)

	In front of car	In front of lorry
	Accepted	Accepted
	N-N	N-N
Sample	36	3
Mean	**4,27**	**3,53**
Min.	1,5	2,4
Max.	8,2	4,3
Std.	1,38	0,98

Appendix C

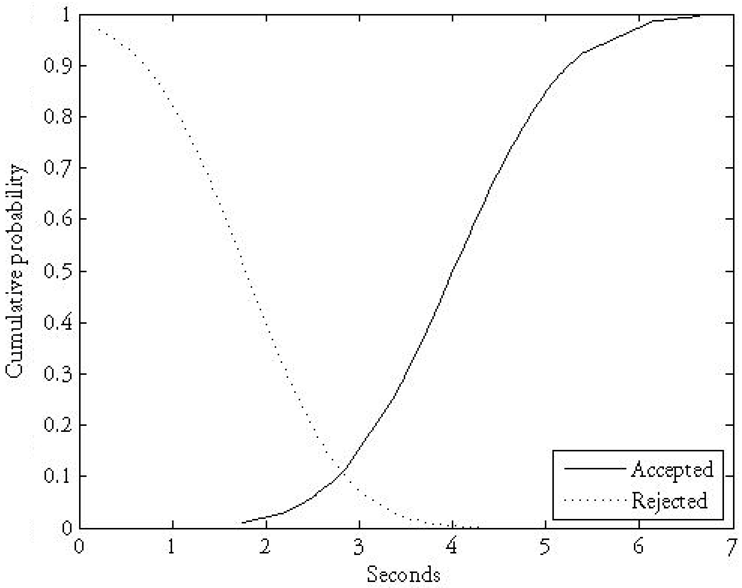

Figure C.1 Critical gap for near to near gaps in the left lane.

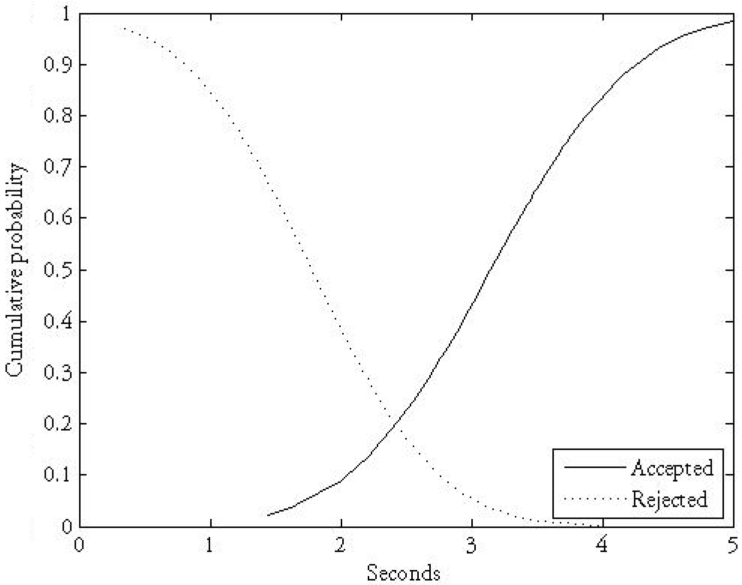

Figure C.2 Critical gap for far to far gaps in the left lane.

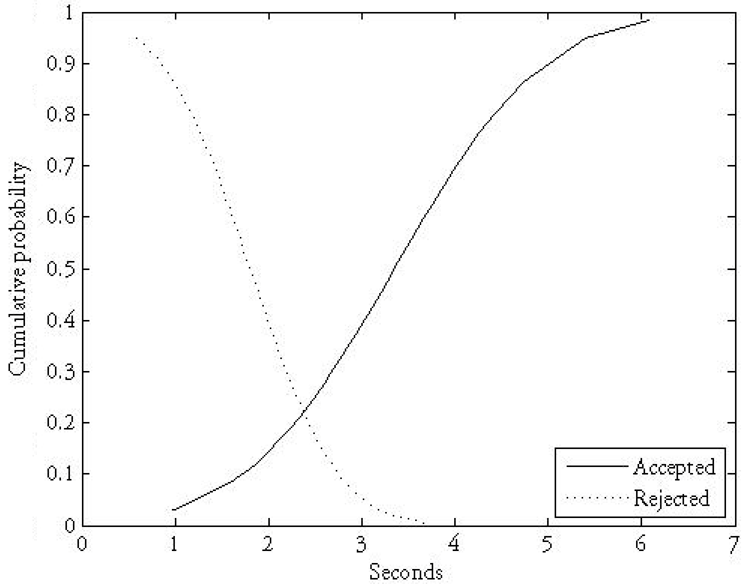

Figure C.3 Critical gap for near to near gaps in the right lane.

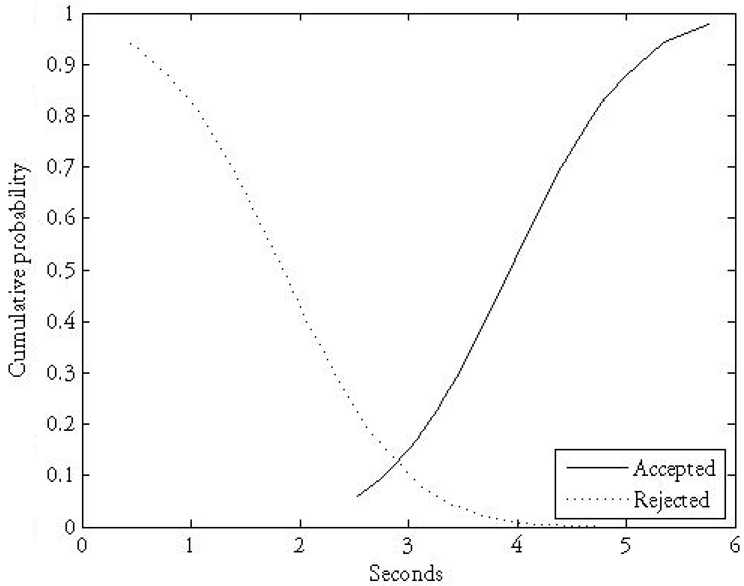

Figure C.4 Critical gap for far to far gaps in the right lane.

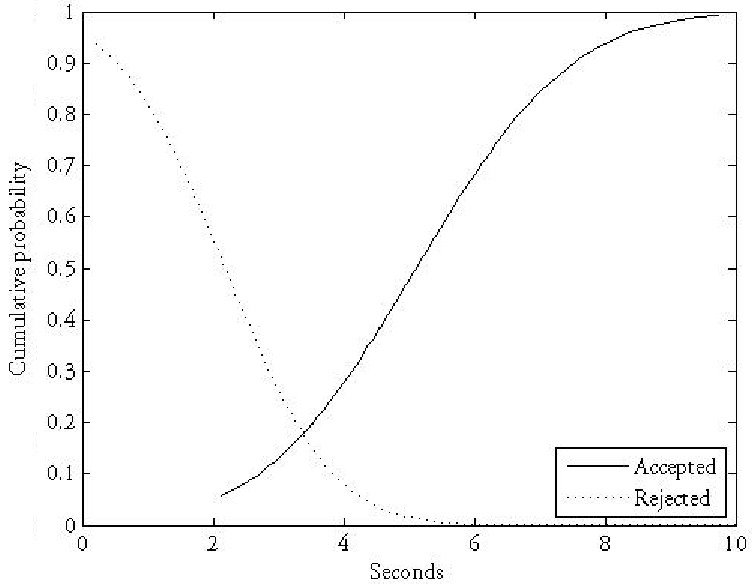

Figure C.5 Critical gap for near to near gaps for right turning cars in the right lane.

Appendix D

Table D.1 AM calibration.

	Near lane				Far lane			
	Mean	Min.	Max.	Std.	**Mean**	Min.	Max.	Std.
Measured	**325**	313	332	10	**505**	503	508	3
Test 1	**315**	285	353	22	**493**	439	509	21
Test 2	**316**	287	350	21	**492**	443	506	19
Test 3	**313**	285	351	22	**494**	442	510	20
Test 4	**314**	285	350	22	**492**	441	508	20
Test 5	**315**	287	351	21	**492**	443	507	20
Test 6	**314**	284	355	24	**493**	446	507	18
Test 7	**314**	288	351	21	**492**	449	504	16
Test 8	**-**	-	-	-	**-**	-	-	-
Test 9	**-**	-	-	-	**-**	-	-	-
Test 10	**315**	285	350	21	**495**	448	513	19
Test 11	**315**	286	353	22	**492**	447	506	18
Test 12	**315**	286	350	22	**492**	444	506	18
Test 13	**316**	287	359	23	**495**	444	511	20
Test 14	**315**	289	352	22	**493**	445	508	19
Test 15	**315**	285	354	22	**495**	442	519	21

Table D.2 PM calibration.

	Near lane				Far lane			
	Mean	Min.	Max.	Std.	**Mean**	Min.	Max.	Std.
Measured	**491**	464	509	24	**440**	435	446	6
Test 1	**495**	442	525	24	**439**	414	469	20
Test 2	**493**	442	528	24	**442**	416	476	21
Test 3	**496**	439	529	25	**440**	413	476	20
Test 4	**494**	432	526	27	**440**	413	471	19
Test 5	**495**	443	524	23	**439**	412	465	19
Test 6	**496**	442	523	24	**442**	419	470	19
Test 7	**494**	442	525	25	**439**	416	477	20
Test 8	**495**	444	528	24	**441**	414	470	20
Test 9	**493**	444	533	24	**441**	414	470	18
Test 10	**492**	441	516	23	**441**	416	473	21
Test 11	**495**	440	530	25	**440**	415	469	19
Test 12	**493**	441	526	24	**440**	416	473	20
Test 13	**493**	438	525	25	**442**	417	473	19
Test 14	**494**	439	524	25	**441**	418	469	18
Test 15	**494**	442	522	24	**439**	417	472	20

Appendix E

Table E.1 Discarded values.

	Left lane		Right lane		Right turn
Total sample	70	52	21	26	109
5 % of total	4	3	1	1	5
10 % of total	7	5	2	3	11
	Near	**Far**	**Near**	**Far**	**Near**
	1,74	1,44	2,53	0,97	2,13
	2,17	1,65	**2,74**	**1**	2,27
	2,27	1,66	**2,85**	1,59	2,42
	2,42	**2**	3,09	**1,86**	2,69
	2,5	2,03	3,1	2,25	2,85
	2,53	**2,12**	3,26	2,39	**2,85**
	2,54	2,13	3,29	2,39	2,89
	2,67	2,21	3,48	2,6	2,92
	2,69	2,31	3,5	2,67	2,92
	2,85	2,32	3,75	2,94	3,05
	2,87	2,39	3,84	3,16	3,1
	2,89	2,56	3,98	3,27	**3,12**
	3,35	2,56	4,12	3,34	3,18
	3,37	2,6	4,33	3,53	3,18
	3,45	2,62	4,37	3,66	3,24
	3,46	2,65	4,67	3,75	3,28
	3,49	2,67	4,81	3,98	3,32
	3,5	2,67	4,85	3,98	3,39
	3,52	2,77	4,98	4,16	3,4
	3,57	2,8	5,35	4,26	3,41
	3,6	2,82	5,76	4,33	3,46
	3,64	2,89		4,33	3,46
	3,66	2,9		4,43	3,49
	3,66	2,94		4,74	3,52
	3,72	2,94		5,4	3,53
	3,73	3,06		6,07	3,57
	3,73	3,09			3,58
	3,73	3,25			3,6
	3,74	3,32			3,6
	3,75	3,34			3,64
	3,75	3,43			3,64
	3,84	3,46			3,66
	3,87	3,47			3,73
	3,99	3,52			3,73

Appendix F

Table F.1 AM data.

	Measured				Test 1			
	N-N	N-F	F-F	F-N	N-N	N-F	F-F	F-N
Sample	101	60	70	74	91	83	397	366
Mean	**3,91**	**4,45**	**3,18**	**2,83**	**4,36**	**4,86**	**4,28**	**3,76**
Min.	1,7	2,3	1,4	0,6	2,9	1,5	1,7	2,0
Max.	7,5	6,3	5,5	5,6	7,0	6,9	6,4	6,1
Std.	1,09	0,99	0,91	1,11	0,87	0,84	0,81	0,86
	Test 3				Test 5			
	N-N	N-F	F-F	F-N	N-N	N-F	F-F	F-N
Sample	106	104	422	378	115	104	450	365
Mean	**3,97**	**4,63**	**4,15**	**3,50**	**3,96**	**4,56**	**3,88**	**3,30**
Min.	2,6	3,0	2,6	1,7	2,6	3,0	2,3	1,4
Max.	5,9	6,8	6,3	5,6	5,9	7,0	6,1	5,4
Std.	0,78	0,82	0,78	0,82	0,84	0,83	0,81	0,82
	Test 7				Test 9			
	N-N	N-F	F-F	F-N	N-N	N-F	F-F	F-N
Sample	128	120	433	354				
Mean	**3,55**	**4,22**	**3,71**	**3,12**				
Min.	2,2	2,7	2,2	1,2	Not tested			
Max.	5,5	6,0	5,6	5,7				
Std.	0,76	0,82	0,8	0,83				
	Test 10				Test 12			
	N-N	N-F	F-F	F-N	N-N	N-F	F-F	F-N
Sample	85	119	425	354	85	116	471	377
Mean	**4,26**	**4,64**	**4,00**	**3,76**	**4,32**	**4,42**	**3,65**	**3,67**
Min.	3,1	2,9	2,3	2,1	2,9	1,4	2,1	2,2
Max.	6,1	6,6	6,1	5,7	6,1	6,2	5,7	5,9
Std.	0,84	0,79	0,76	0,78	0,75	0,85	0,81	0,79

Table F.2 PM data.

	Measured				Test 1			
	N-N	N-F	F-F	F-N	N-N	N-F	F-F	F-N
Sample	101	60	70	74	282	94	159	462
Mean	**3,91**	**4,45**	**3,18**	**2,83**	**4,02**	**4,62**	**4,16**	**3,46**
Min.	1,7	2,3	1,4	0,6	2,7	3,2	2,8	1,9
Max.	7,5	6,3	5,5	5,6	6,1	6,5	6,0	5,6
Std.	1,09	0,99	0,91	1,11	0,77	0,71	0,78	0,79
	Test 3				Test 5			
	N-N	N-F	F-F	F-N	N-N	N-F	F-F	F-N
Sample	319	105	175	510	357	123	180	560
Mean	**3,83**	**4,44**	**4,03**	**3,32**	**3,59**	**4,40**	**3,80**	**3,09**
Min.	2,4	3,0	2,7	1,8	2,3	3,0	2,4	1,5
Max.	6,1	6,3	5,9	5,8	5,5	6,1	6,3	5,6
Std.	0,78	0,7	0,81	0,84	0,75	0,74	0,72	0,81
	Test 7				Test 9			
	N-N	N-F	F-F	F-N	N-N	N-F	F-F	F-N
Sample	379	118	215	563	420	150	250	683
Mean	**3,40**	**4,14**	**3,57**	**2,86**	**3,17**	**3,85**	**3,32**	**2,71**
Min.	2,2	2,8	1,9	1,4	2,0	2,8	1,8	1,0
Max.	5,4	5,9	5,7	5,2	5,3	5,8	5,3	5,1
Std.	0,77	0,75	0,78	0,75	0,74	0,7	0,75	0,8
	Test 10				Test 12			
	N-N	N-F	F-F	F-N	N-N	N-F	F-F	F-N
Sample	262	117	195	444	291	111	201	454
Mean	**4,21**	**4,52**	**3,95**	**3,61**	**4,06**	**4,16**	**3,62**	**3,56**
Min.	3,0	3,3	2,7	1,9	2,8	2,8	2,3	2,1
Max.	6,4	6,5	6,3	5,6	6,0	5,9	5,6	5,7
Std.	0,74	0,79	0,78	0,81	0,77	0,8	0,79	0,79

Table F.2 PM data.

	Measured				**Test 1**			
	N-N	**N-F**	**F-F**	**F-N**	**N-N**	**N-F**	**F-F**	**F-N**
Sample	101	60	70	74	282	94	159	462
Mean	**3,91**	**4,45**	**3,18**	**2,83**	**4,02**	**4,62**	**4,16**	**3,46**
Min.	1,7	2,3	1,4	0,6	2,7	3,2	2,8	1,9
Max.	7,5	6,3	5,5	5,6	6,1	6,5	6,0	5,6
Std.	1,09	0,99	0,91	1,11	0,77	0,71	0,78	0,79
	Test 3				**Test 5**			
	N-N	**N-F**	**F-F**	**F-N**	**N-N**	**N-F**	**F-F**	**F-N**
Sample	319	105	175	510	357	123	180	560
Mean	**3,83**	**4,44**	**4,03**	**3,32**	**3,59**	**4,40**	**3,80**	**3,09**
Min.	2,4	3,0	2,7	1,8	2,3	3,0	2,4	1,5
Max.	6,1	6,3	5,9	5,8	5,5	6,1	6,3	5,6
Std.	0,78	0,7	0,81	0,84	0,75	0,74	0,72	0,81
	Test 7				**Test 9**			
	N-N	**N-F**	**F-F**	**F-N**	**N-N**	**N-F**	**F-F**	**F-N**
Sample	379	118	215	563	420	150	250	683
Mean	**3,40**	**4,14**	**3,57**	**2,86**	**3,17**	**3,85**	**3,32**	**2,71**
Min.	2,2	2,8	1,9	1,4	2,0	2,8	1,8	1,0
Max.	5,4	5,9	5,7	5,2	5,3	5,8	5,3	5,1
Std.	0,77	0,75	0,78	0,75	0,74	0,7	0,75	0,8
	Test 10				**Test 12**			
	N-N	**N-F**	**F-F**	**F-N**	**N-N**	**N-F**	**F-F**	**F-N**
Sample	262	117	195	444	291	111	201	454
Mean	**4,21**	**4,52**	**3,95**	**3,61**	**4,06**	**4,16**	**3,62**	**3,56**
Min.	3,0	3,3	2,7	1,9	2,8	2,8	2,3	2,1
Max.	6,4	6,5	6,3	5,6	6,0	5,9	5,6	5,7
Std.	0,74	0,79	0,78	0,81	0,77	0,8	0,79	0,79