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BEDRIJFSECONOMISCHE WETENSCHAPPEN

master in de verkeerskunde: verkeersveiligheid
(Interfacultaire opleiding)

Masterproef

Interactions between pedestrians and motor vehicles at signalized intersections - Traffic behaviour and traffic conflict studies

Promotor :
dr. Stijn DANIELS

Promotor :
Dr. ASE SVENSSON

Joram Langbroek

Masterproef voorgedragen tot het bekomen van de graad van master in de verkeerskunde , afstudeerrichting verkeersveiligheid

universiteit hasselt
KNOWLEDGE IN ACTION
Universiteit Hasselt | Campus Diepenbeek | Agoralaan Gebouw D | BE-3590 Diepenbeek
Universiteit Hasselt | Campus Hasselt | Martelarenlaan 42 | BE-3500 Hasselt

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Preface

This research project has been conducted in the context of an Erasmus Traineeship of three months at the research institute Traffic and Roads at Lund University. This traineeship was a good way to experience life in Sweden and a working at a Swedish workplace. After two weeks of courses about the Swedish Traffic Conflict Technique and Vulnerable Road Users, I started my own research project. The topic of my research project about traffic conflict observations and behavioural observations has been selected because Lund University has a lot of expertise in this research field.

I would like to thank my promoters and supervisors dr. Stijn Daniels, Tim De Ceunynck, dr. Åse Svensson and dr. Aliaksei Laureshyn for their help throughout my master thesis project. I would also like to thank all my colleagues at the institute Traffic and Roads for the nice talks during coffee breaks and practical help during my stay in Lund. In special I would like to thank my colleagues Anna, Per och Zsuzsanna for a lot of help and a lot of fun.

I would like to thank Bengt Persson for providing me information about all signalized intersections in Lund, Thomas Johnsson for providing me crash data of the intersection in Lund and the police station in Hasselt for providing me crash data of the intersection in Hasselt. I would like to thank Wannes for helping me with the graphical representation of traffic conflicts.

Last but not least, I would like to thank my family for supporting me and my stay in Sweden, and my friends some of whom have visited me in Copenhagen during my stay in Lund.

Samenvatting

Voetgangers zijn de meest kwetsbare weggebruikers. De meeste verkeersongevallen met voetgangers gebeuren op kruispunten. Lichtengeregelde kruispunten met twee fasen zijn gemiddeld nog onveiliger dan kruispunten zonder verkeerslichten, terwijl lichtengeregelde kruispunten met een aparte groenfase voor voetgangers veiliger zijn. De vraag is welke processen een invloed hebben op de verkeersveiligheid voor voetgangers op lichtengeregelde kruispunten.

Het onderzoeken van ongevallendata is tot nu toe de meest gebruikte methode geweest om verkeersveiligheid te meten. Het bestuderen van ongevallengegevens is echter niet voldoende om inzicht te verwerven in de processen die leiden tot verkeersongevallen. Daartoe kunnen ter aanvulling gedragsstudies worden uitgevoerd.

Het doel van deze explorative studie is het onderzoeken van verkeersinteracties tussen voetgangers en gemotoriseerde weggebruikers op lichtengeregelde kruispunten en een indicatie te geven voor de koppeling tussen normale verkeersinteracties enerzijds en verkeersconflicten anderzijds. Verkeersinteracties zijn situaties waarbij twee partijen zich op botsingskoers bevinden en dus moeten interageren: minimaal één van de partijen moet actie ondernemen om een verkeersongeval te voorkomen. Verkeersconflicten zijn specifieke verkeersinteracties waarbij er niet veel tijd over is voor een ontwijkingsactie. Indien de tijd die overschiet totdat er een ongeval zou gebeurd zijn lager is dan een bepaalde kritieke waarde, spreekt men van een ernstig verkeersconflict. Indien het niet meer lukt om een bepaalde ontwijkingsactie uit te voeren eindigt de situatie in een verkeersongeval. Verkeersongevallen, verkeersconflicten en verkeersinteracties worden dus verondersteld deel uit te maken van een continuüm.

Conflictobservatiestudies worden gebruikt als een proxy voor verkeersongevallen. Dit heeft een aantal voordelen boven verkeersongevallenanalyse. Zo is het mogelijk om meer data te krijgen binnen een beperkt tijdbudget.

Dit onderzoek is zowel uitgevoerd in Zweden als in België. In beide landen zijn lichtengeregelde kruispunten met twee fasen gebruikelijk. Het risico voor voetgangers om bij een dodelijk verkeersongeval betrokken te raken is in België echter 80 procent hoger dan in Zweden. Bij het bestuderen van verkeersinteracties en de processen die tot verkeersconflicten leiden zouden er verschillen kunnen zijn tussen verschillende landen.

Voor dit onderzoek zijn twee conflictobservatiestudies van 30 uren uitgevoerd, waarvan één op een kruispunt in Lund (Zweden), en één op een kruispunt in Hasselt (België). Daarnaast zijn drie gedragsstudies uitgevoerd van elk 8 uren. Deze studies zijn

uitgevoerd op de twee bovengenoemde locaties, maar daarnaast ook op een kruispunt in Leuven. Deze laatste observatiestudie is uitgevoerd om te testen hoe sterk de resultaten van een soortgelijk kruispunt variabel zijn.

Op het vlak van verkeersinteracties zijn de volgende zaken geobserveerd: roodlichtnegatie, communicatie (kijkgedrag en gebruik van richtingaanwijzers) en voorrangsgedrag. Alle observaties in Lund en Hasselt zijn op camera opgenomen.

Een opmerkelijk resultaat is dat het percentage voetgangers dat door rood loopt op het Zweedse kruispunt veel hoger lag dan op beide Belgische kruispunten. Mannen lopen vaker door rood dan vrouwen en jongeren meer dan ouderen. Groepen voetgangers lopen niet vaker door rood dan individuele voetgangers. Opmerkelijk is het feit dat de beslissing om door rood te lopen niet significant afhankelijk lijkt te zijn van het zich al dan niet voordoen van een verkeersinteractie.

Het aantal verkeersconflicten met voetgangers die door rood lopen is hoger dan te verwachten zou zijn indien het risico op een verkeersconflict onafhankelijk is van het al dan niet door rood lopen.

Wat betreft kijkgedrag kijkt nagenoeg elke automobilist die linksaf of rechtsaf slaat over zijn schouder. Voetgangers echter kijken slechts in 71 % van de gevallen over hun schouder voordat ze beginnen oversteken. Wanneer we de verkeersconflicten bestuderen blijkt dat voetgangers die niet over hun schouder kijken vaker betrokken zijn bij verkeersconflicten.

De meeste automobilisten verlenen voorrang aan voetgangers wanneer zij linksaf of rechtsaf slaan. Aan oudere voetgangers wordt iets vaker voorrang verleend en vrouwen verlenen vaak eerder voorrang dan mannen. Ook aan voetgangers die door rood lopen wordt even vaak voorrang verleend. Opmerkelijk is dat voetgangers die door rood lopen zelf slechts in 22% van de gevallen voorrang verlenen.

Op het Belgische kruispunt zijn er meer conflicten met voetgangers met linksaf slaande voertuigen. Dit kan veroorzaakt zijn door het feit dat de verkeersintensiteiten op dit kruispunt veel hoger zijn dan op het Zweedse kruispunt.

De resultaten van deze studie zijn indicatief. Het is wenselijk om in volgende onderzoeken de resultaten van deze studie op grotere schaal te testen. Daarnaast is het wenselijk om de observaties met meerdere mensen uit te voeren, zodat gedragsobservaties en conflictobservaties simultaan kunnen worden uitgevoerd. Op die manier kan met meer zekerheid worden vastgesteld welke gedragingen tot een significant hogere kans op verkeersconflicten leiden. Tevens zouden dit soort studies in de toekomst op andersoortige kruispunten of met andere weggebruikers kunnen worden toegepast.

Sammanfattning

Fotgängare är såkallade oskyddade trafikanter. De flesta trafikolyckor med fotgängare inträffar i korsningar. Vanliga signalreglerade korsningar är i genomsnitt till och med osäkrare än icke-signalreglerade korsningar, medan signalreglerade korsningar med separat fotgängarfas är säkrare. Frågan är vilka processer det är som påverkar fotgängares trafiksäkerhet i signalreglerade korsningar.

Att studera olycksdata har hittills varit den mest använda metoden för att mäta trafiksäkerhet. Det räcker tyvärr inte för att få insikt i processerna som leder till trafikolyckor. Beteendestudier kan användas för att få insikt i dessa processer.

Det övergripande syftet med denna explorativa studie är att studera trafikinteraktioner mellan fotgängare och motoriserade trafikanter i signalreglerade korsningar samt om möjligt koppla vanliga trafikinteraktioner till trafikkonflikter. En trafikinteraktion är en situation där två trafikanter är på kollisionskurs och där åtminstone en av parterna anpassar sitt beteende för att förebygga en kollision. Trafikkonflikter är specifikka trafikinteraktioner där det inte finns mycket tid kvar för att undvika en kollision. Ifall tiden som återstår är lägre än ett kritiskt värde, kallas konflikterna 'allvarliga konflikter'. Trafikolyckor är situationer där det inte längre finns någon möjlighet att väja och undvika en kollision. Trafikolyckor, trafikkonflikter och trafikinteraktioner anses vara del av samma kontinuum.

Det har funnits ett samband mellan trafikkonflikter och trafikolyckor. Det finns fördelar med att använda trafikkonflikter för trafiksäkerhetsstudier. Det är bland annat möjligt att samla mer data inom en begränsad tidsram.

Studierna genomfördes i både Sverige och Belgien. I båda länder är signalreglerade korsningar med totalt två faser vanliga. Två 30-timmar långa konfliktstudier genomfördes, en i en korsning i Lund och en i en korsning i Hasselt (Belgien). Det genomfördes även tre beteendestudier om vardera 8 timmar. Dessa studier genomfördes på samma ställen men också i en korsning i Leuven. Den sista beteendestudien genomfördes för att testa hur variabla resultaten är i en likadan korsning.

Med hänsyn till trafikinteraktioner observerades följande: att köra mot rött ljus/gå mot röd gubbe, avsökningsbeteende och att använda körriktningsvisaren. Samtliga observationer i Lund och Hasselt spelades in.

Ett anmärkningsvärt resultat är att procenttalet fotgängare som går mot röd gubbe är mycket högre i den svenska korsningen än i båda belgiska korsningar. Män går oftare mot röd gubbe än kvinnor och ungdomar oftare än äldre – däremot går grupper av fotgängare inte oftare mot rött ljus än individuella fotgängare. Man tycks inte oftare gå

mot rött på grund av motorfordon på korsande kurs.

Antalet trafikkonflikter med fotgängare gående mot röd gubbe är högre än man skulle kunna förvänta sig. I korsningen in Lund, det fanns 4 konflikter (44,4%) med fotgängare som gick mot rött. I beteendestudien, bara 32 procent av alla fotgängare i korsningen i Lund gick mot rött ljus.

Med hänsyn till avsökningsbeteende så tittar nästan samtliga bilister som svänger till vänster eller till höger över sin axel. Fotgängare tittar däremot bara i 71 fall av 100 innan de börjar korsa gatan. Det visar sig från konfliktstudierna att fotgängare som inte tittar över sin axel oftare är involverade i trafikkonflikter.

De flesta bilister lämnar företräde till fotgängare ifall de svänger till vänster eller till höger. Det lämnas företräde i lite högre grad till äldre fotgängare och kvinliga bilister lämnar företräde lite oftare än män. Man lämnar företräde till fotgängare gående mot rött ljus lika ofta som till fotgängare som går mot grönt ljus. Det är märkligt att fotgängare som går mot röd gubbe själva bara lämnar företräde till bilister i 22 fall av 100.

I den belgiska korsningen finns det flera konflikter med korsande fotgängare och motorfordon som svänger till vänster. Det kan förorsakas av högre trafikflöden i denna korsning jämfört med den svenska korsningen.

Resultaten i denna studie är indikativa. Det är önskvärt att testa resultaten av denna studie i större skala. Dessutom är det önskvärt att genomföra observationerna med flera människor, så att beteendestudier och konfliktstudier kan genomföras samtidigt. På så sätt kan man vara säkrare på vilket beteende som leder till en signifikant högre risk för trafikkonflikter. I framtiden skulle likadana studier även kunna genomföras i olikartade korsningar eller med andra trafikanter.

Summary

Pedestrians are the most vulnerable road users. Most accidents with pedestrians take place at intersections. Two phased signalized intersections are on average still more unsafe than non-signalized intersections, while signalized intersections with a separate green phase are somewhat more safe for pedestrians. The question is which processes are of influence on traffic safety for pedestrians at signalized intersections.

Until now, the most frequently used study method to measure traffic safety has been accident data research. However, for understanding the processes that lead to traffic accidents, it is not enough to study accident data. Therefore, behaviour studies could be used to complement accident data research.

The aim of this explorative study project is to study traffic interactions between pedestrians and motorized road users at signalized intersections and to give an indication for the link between normal traffic interactions on the one hand and traffic conflicts on the other hand. Traffic interactions are situations where two parties are on collision course and they must interact: at least one of the parties must take evasive action to avoid a crash. Traffic conflicts are specific traffic interactions where there is not much time left for an evasive action. If the time that is left before a traffic accident would happen is lower than a certain critical value, there is a severe traffic conflict. If it is not possible to take evasive action, the situation ends in a traffic accident. Traffic accidents, traffic conflicts and traffic interactions are supposed to be part of a continuum.

Traffic conflicts are used as a proxy for traffic accidents. There are certain advantages of preferring traffic conflict studies above traffic accident data analysis. For example, it is possible to obtain more data within a limited time budget.

This research project has been executed in both Sweden and Belgium. In both countries, two phased signalized intersections are usual. The risk for pedestrians to get involved in a fatal crash is 80 per cent higher in Belgium than in Sweden. When studying traffic interactions and the processes leading to traffic conflicts, there could be differences between both countries.

For this research, two conflict studies of 30 hours have been executed, one at an intersection in Lund (Sweden) and one at an intersection in Hasselt (Belgium). Moreover, three behavioural studies have been executed, 8 hours each. These studies have been executed at the intersections mentioned above, but also at an intersection in Leuven

(Belgium). The last behavioural study has been executed in order to test to which degree the results at a similar intersection vary.

Regarding traffic interactions, the following things have been observed: red light violation, communication (looking behaviour and use of directional lights) and priority behaviour. All observations in Lund and Hasselt were video-recorded.

A remarkable result was that the percentage of pedestrians violating the traffic lights was much higher at the Swedish intersection than at both Belgian intersections. Men are violating the traffic signal more often than women and young people more often than old people. Groups of pedestrians do not violate the traffic signal more often than individual pedestrians do. Remarkable is the fact that the decision to violate the traffic signal does not seem to depend on whether or not there is a traffic interaction.

The number of traffic conflicts with pedestrians violating the traffic signal is higher than to be expected if the risk for a traffic conflict would be independent of red light violation.

Regarding looking behaviour: almost every car driver looks over his shoulder when turning to the left or turning to the right. Pedestrians only look over their shoulder in 71 per cent of all observed cases. When studying traffic conflicts it seems that pedestrians not looking over their shoulder before crossing are involved in traffic conflicts more frequently.

Most car drivers yield to pedestrians when turning to the right or to the left. Car drivers yield to older pedestrians somewhat more frequently and women yield more often than men. Car drivers yield to pedestrians violating the traffic signals just as much as to pedestrians respecting the traffic signals. It is remarkable that pedestrians violating the traffic signal only yield in 22 per cent of the cases.

At the Belgian intersection, there are more conflicts with pedestrians and car drivers turning to the left. This could be caused by the fact that the traffic volumes at this intersection are much higher than at the Swedish intersection.

The results of this study are indications. It is desirable to test the results of this study on a larger scale in following research projects. Moreover, it is desirable to execute observations with more people, so that behavioural studies and conflict studies can be executed simultaneously. In that way, it is possible to be surer about what behaviour tends to be associated with a significantly higher chance for traffic conflicts. This kind of studies could also be applied at different types of intersections or other road users in the future.

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1 Introduction

Traffic safety is an important issue in every part of the world. More than 1,2 million people die annually because of traffic crashes. Far more people get injured and the damage for traffic accident victims and for society as a whole is huge (Elvik et al, 1997). Besides a societal issue, road crashes also constitute a major economic problem. The economic loss is estimated to be around 2 per cent of the gross national product in Western countries (WHO, 2004). Therefore, policy makers are motivated to improve road safety.

During the past decades, a lot of research has been conducted in order to get an improved understanding of the processes and determinants of traffic crashes. Among others, researchers have been trying to improve the understanding of human factors regarding traffic safety. It has been stated that human factors are the most frequent causes of accidents. Human factors alone account for 68 per cent of traffic crashes. Overall, 91 per cent of traffic crashes are at least partially caused by human factors (Elvik et al., 1997).

Human factors can be seen as the way humans behave when being in traffic. Some factors have been shown to contribute to the occurrence of accidents. Examples are driving under the influence of alcohol or speeding (Evans, 2004). The question is whether or not there are also patterns of behavioural aspects at a specific type of location that are related to the occurrence of traffic crashes? The hypothesis is that getting insight in traffic behaviour at specific locations helps in understanding the processes that lead to traffic accidents.

The chance of getting involved in a traffic crash is not equally distributed among all people. Men are more likely to be involved in traffic crashes than women. Poor countries have more traffic fatalities than wealthy countries. Bus passengers are less likely to die in a crash than motor drivers. Pedestrians are especially vulnerable, et cetera (Evans, 2004).

Because pedestrians are that vulnerable, traffic crashes can be fatal even at relatively low speeds. At these speeds, traffic crashes between cars would only result in material damage or slight injuries. Most pedestrians get involved in traffic crashes in urban areas (Zhu et al., 2008 & SWOV, 2012). This is logical, because there are simply more pedestrians in urban areas. Most traffic crashes with pedestrians occur at intersections. However, the traffic accidents are not evenly distributed over all intersections throughout Europe. When looking at accident statistics across Europe, there are a lot of differences among the different member states of the European Union. The number of traffic fatalities per million inhabitants differs heavily among the European countries. In figure 1, the traffic fatality rate of the EU member states is shown (European Commission, 2012). Sweden, United Kingdom and the Netherlands are performing best. Some eastern European countries are performing worst. The average of all EU member states is 61 traffic fatalities per million inhabitants.

Figure 1: Fatality rate in Europe (European Commission, 2012)

If we look at pedestrian fatalities, there is a slightly different picture. Great Britain, for example, has a relatively low overall fatality rate, while the pedestrian fatality rate is at the same level as in Belgium and Denmark. Again, Sweden is performing well. Only the Netherlands have a lower pedestrian fatality rate (European Commission, 2012).

Parts of those differences can be explained by physical and environmental differences. Besides that, differences in traffic volumes can influence the number of traffic crashes. The design of the traffic system (geometry of roads, to which degree pedestrians and bicyclists are separated, the state of the infrastructure, et cetera) is another explanation. Countries with many new, safer cars and a better emergency system could perform better than countries with older cars. Also differences in road user behaviour can attribute to differences in traffic safety.

On figure 2, the fatality rate of pedestrians in Europe is indicated. Again, there are large differences among the European countries. Therefore, it can be interesting to investigate traffic safety with a cross-national study.

Figure 2: Pedestrians fatality rate across EU (European Commission, 2012)

2 Problem statement

Studying traffic behaviour is studying interactions between road users and the environment, but also among road users. Pedestrians are among the most vulnerable road users. A high percentage of all pedestrian accidents happens at signalized intersections.

The aim of this thesis is to study the relationship between safety-related traffic behaviours with regard to pedestrian-vehicle interactions at signalized intersections in Belgium and Sweden and traffic conflicts at the same locations. The hypothesis is that differences in traffic safety are partly caused by differences in traffic behaviour. Studying traffic behaviour could uncover certain problems that could be addressed in traffic safety policy, like traffic engineering, education or enforcement.

This study is an explorative study. Observational research of traffic behaviour and the relation with traffic safety is a relatively new field of research. This research project focused on a very limited number of intersections. In Sweden, one intersection has been examined, while in Belgium, two signalized intersections have been examined. The intention is not to give final answers about the relation between certain traffic interaction behaviours at these intersections and traffic safety, but first and foremost to explore some possible indicators that could have a relation with traffic safety. The results of this study should be used as an input for further research on a larger sample. The aim of this study is also to try to make a modest contribution to the development of behavioural observation studies with regard to traffic safety.

The main research questions of this research project are the following:

- How do pedestrians and motorized road users interact at signalized intersections?
    - To which degree do pedestrians violate the traffic signal when there is a traffic interaction?
    - To which degree do car drivers violate the traffic signal when there is a traffic interaction?
    - To which degree do car drivers yield to pedestrians when they cross the street at a signalized intersection having green light?
    - To which degree do pedestrians yield to car drivers when they cross the street at a signalized intersection having red light?
    - To which degree do car drivers turn their heads before turning at a signalized intersection?

  - To which degree do pedestrians turn their heads before crossing the street at a signalized intersection?
  - To which degree do car drivers use their directional lights at signalized intersections?
  - Are there differences in red light compliance, yielding behaviour, looking behaviour and use of directional lights between males and females?
  - Are there differences in red light compliance, yielding behaviour, looking behaviour and use of directional lights between different age groups?
  - Are there differences in red light compliance, yielding behaviour, looking behaviour and use of directional lights between a Swedish intersection and Belgian intersections?
- What kinds of traffic conflicts do occur at urban signalized intersections?
- Which behavioural characteristics in interactions between pedestrians and motorized road users at signalized intersections tend to be related to traffic conflicts?
  - Are traffic conflicts more likely to occur when violating the traffic signal?
  - Are traffic conflicts more likely to occur when not looking?
  - Are traffic conflicts more likely to occur when not yielding early?
  - Are traffic conflicts more likely to occur when not using the directional lights?
  - Do the processes that lead to traffic conflicts differ between the Belgian and the Swedish intersection?

To try to find an answer to these questions, a conflict observation has been executed on a Swedish and a Belgian signalized intersection. The aim of this conflict observation was two-fold. The most important reason to conduct conflict observation studies was to link the behavioural studies to traffic safety, as traffic conflicts can be considered as a proxy for traffic safety (Hydén, 1987). The second reason to conduct conflict observations was to get more insight in the processes and behaviours that occur at signalized intersections. On the basis of the first conflict observation period in Sweden, an observation list for the behavioural observation has been set up.

The basis for the behavioural study were interactions between pedestrians and car drivers. The observations are pedestrian-driven. This means that the occurrence of pedestrians was a trigger for observation, regardless of the presence of motor vehicles.

The conflict observations have been videotaped in order to be able to review certain parts of the observation period for validation purposes.

After the data collection, the results of the behaviour study have been analysed with the statistical software package SPSS. Chi-square tests are the most important statistical tests that have been performed.

The remainder of this report has been structured as follows: first, in chapter 3 there will be a background chapter on the topics "traffic safety at signalized intersections", "Observation of traffic behaviour", "Observation of traffic conflicts" and "Links between normal traffic interactions and traffic conflicts". This literature study has formed the foundations for the empirical research that has been conducted. In chapter 4, the methodology will be discussed. In chapter 5, the research design will be discussed. In chapter 6, the data will be described and the results of the research will be analysed in chapter 7. In chapter 8, the results will be discussed and recommendations about the research process will be made in order to improve future research on this topic. In the last chapter, the research questions will be answered.

3 Background

3.1 Introduction

Traffic crashes are caused by a breakdown in infrastructural, vehicle or human factors. Something goes wrong or more likely, several things go wrong simultaneously, and there is no way to avoid a crash. A lot of factors, both individual, inter-personal, societal and community factors, or external factors, have an influence on traffic behaviour, road infrastructure and vehicle engineering. Differences in these factors can evoke differences in traffic safety between different countries (Özkan, 2006).

Özkan (2006) defined traffic culture as the informal and formal rules, norms and values of a country. These rules, norms and values are influenced by all kinds of economic, cultural, social and political processes on different levels and they affect the traffic behaviour of individual road users, the road system and the vehicles that are used in traffic. The interplay between road user, vehicle and environment influences the occurrence of traffic crashes and its consequences. In Figure 3, the model of Özkan is displayed.

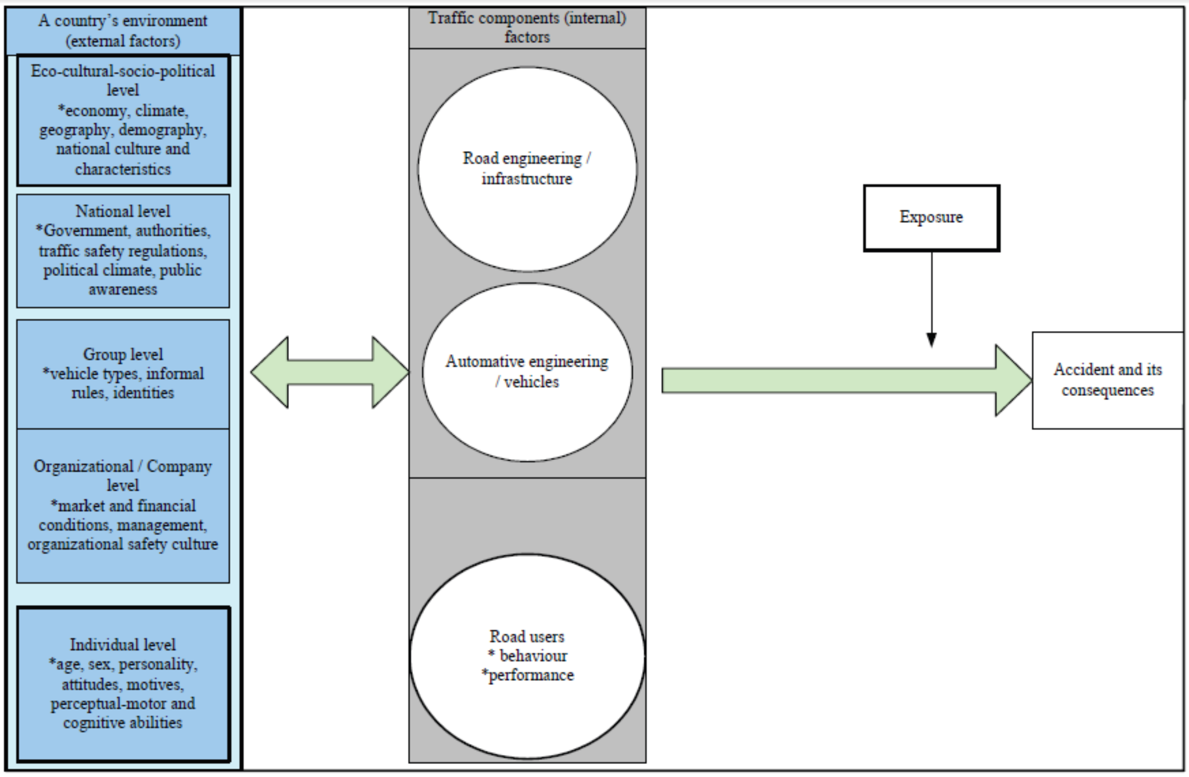

Figure 3: Traffic culture and traffic safety (Özkan, 2006)

This model provides a framework for explaining differences in traffic safety between different locations. This is a reason why it is interesting to conduct behavioural studies in different countries. In this study, there will be focused on traffic behaviour and traffic safety, where so-called traffic conflicts will be used as a proxy for traffic crashes. However, some external factors having an influence on the so called traffic components will also be discussed shortly in this literature study.

This background part starts with general issues about traffic safety on signalized intersections. After that, the concept of traffic interaction between motorized road users and pedestrians will be explained. Then, behavioural factors that influence the way traffic interactions evoke will be dealt with. After that, the influence of factors such as age, gender and culture on traffic behaviour is discussed.

3.2 Traffic safety at signalized intersections

3.2.1 Comparison traffic safety with and without traffic signals

Installing traffic lights on an intersection is a way to decrease the number of possible interactions among road users. When everyone would respect the traffic lights, these kinds of intersections reduce the number of interactions between crossing road users, because most road users are separated in time. However, there can be interactions between turning vehicles and crossing pedestrians. Elvik et al. (2008) investigated the effect of installing traffic lights on traffic safety, based on a number of traffic safety evaluation studies (e.g. Brüde and Larsson, 1992, Seim, 1994, Poch and Mannering, 1996, Mitra and Washington, 2007 and Harkey et al., 2008) and concluded that the total number of crashes on an intersection is likely to decrease by around 29 per cent when traffic signals would be installed, although this overall decrease is not statistically significant. Four-leg intersections are likely to have a greater decrease in crashes than three-leg intersections. In case of three-leg intersections where there used to be priority to the right, the number of traffic crashes is likely to increase by 11 per cent when installing traffic signals (Elvik et al., 2008).

Overall, it is not sure whether there will be an increase or a decrease in the total number of traffic crashes as a consequence of installing traffic signals. Nevertheless, the number of traffic crashes between crossing road users is likely to decrease by 77 per cent. In case there is left turning traffic, the crash probability decreases on average by 60 per cent. Both results are statistically significant. However, the number of rear-end traffic crashes is likely to increase by 69 per cent (Elvik et al., 2008).

As rear-end crashes tend to be less severe than head-on crashes or side crashes, the safety effects of installing traffic lights will be advantageous for car drivers (Evans, 2004).

3.2.2 Traffic safety for pedestrian-motor vehicle interactions

Traffic crashes between motor vehicles and pedestrians tend to be much more severe for pedestrians than for motor vehicles because of the high mass and speed difference and the lack of protection for pedestrians (Evans, 2004). When we look at traffic safety at signalized intersections especially for pedestrians, there are certain specific interactions between car drivers and pedestrians that can occur and that can evoke traffic crashes. In a case where both the car driver and the pedestrian respect the traffic light, there might be conflict situations when the car driver turns left or right. In case one of them is not respecting the traffic lights, there might be conflict situations at significantly higher speeds with a chance for side impact crashes.

Lord et al. (1998) investigated pedestrian conflicts with left-turning traffic and came to the conclusion that vehicles turning to the left were around four times more likely to be involved in traffic conflicts with pedestrians than vehicles driving straight on. The reason for this high number is the cognitive load of car drivers turning to the left. They have to think of passing vehicles, traffic lights and crossing pedestrians at the same time in case the intersection is not conflict-free.

Elvik et al. (1997) also investigated the likeliness of pedestrian accidents with and without traffic signals. The chance of pedestrian accidents increases by 8 per cent at two-phased signalized intersections compared to non-signalized intersections. However, this figure is not statistically significant. In case of a separate green-phase for pedestrians, the chance of pedestrian accidents decreases by 29 per cent. This figure is statistically significant at a 95 per cent confidence level.

In Sweden, 35 per cent of all traffic accidents between motor vehicles and pedestrians occur at signalized intersections. It is striking that, while pedestrians are reinforced to cross on pedestrian crossings, accident risk is higher at pedestrian crossings than outside these crossings, even if we take exposure into account (Ekman, 1988). People are feeling safer, while in fact, they are not. It is also striking that the crash risk at signalized intersections is just somewhat lower than the risk at non-signalized intersections with marked pedestrian crossings, but much higher than the risk when crossing outside pedestrian crossings. This could be because people feel safer at marked pedestrian crossing. In fact, they are not (Ekman, 1997). When distinguishing different age groups, people between 16 and 60 years old are even at higher risk for getting involved in a traffic accident at a signalized intersection than at a non-signalized intersection (Ekman and Hydén, 1999). Knoblauch et al. (2001) concluded that pedestrians are not less cautious at marked pedestrian crossings than at unmarked pedestrian crossings. Nevertheless, the looking behaviour of pedestrians at pedestrian crossings is less extensive and pedestrians tend to be slower when crossing a marked non-signalized pedestrian crossing than when crossing the street outside marked pedestrian crossings (Fehlig Mitman et al., 2010). Again, this might be because pedestrians feel safer. At signalized intersections, this effect could be even stronger because pedestrians do not expect interactions with motorized road users.

3.2.3 Infrastructure

The road infrastructure contains the geometry of the intersection, but also the direct environment of the intersection. Visibility is an important feature. People tend to behave differently in case of bad visibility (Hawkins, 1988). Lack of overview has an influence on traffic interactions, because there is less time available between the moment of detection and the moment of required evasive action. However, car drivers can adapt to this situation by slowing down.

Regarding the geometry of signalized intersections, there are certain characteristics that have an influence on traffic safety. Also the presence of a left turn lane would enhance traffic safety (Ewadh and Neham, 2011).

Left turns at two-phased signalized intersections are difficult and potentially dangerous manoeuvres, because there must be kept attention to oncoming traffic, but also to pedestrians crossing at the left side of the road (Yan and Radwan, 2007).

Even when corrected for exposure, some road environments like four-leg intersections give a greater probability for traffic crashes between motorists and pedestrians. Three-leg intersections are associated with a lower probability for accidents in general. (Dumbaugh and Li, 2010).

However, Lord (1995) discovered that, at two-phased signalized intersections, traffic conflicts between car drivers and pedestrians are more likely to occur at three-leg intersections than at four-leg intersections because most pedestrians cross at the beginning of the green-phase. At four-leg intersections, in many occasions, left-turning vehicles must wait for oncoming traffic. When they make their turn, most pedestrians have already crossed the street.

The presence of a refuge is associated with a lower probability for traffic conflicts (Ekman, 1996). This is because pedestrians can divide their crossing in two parts and by doing so decrease the time they are exposed to danger.

The location of pedestrian the crossing does play an important role. Research has shown that the location of most pedestrian crossings is quite dangerous (Holmberg and Hydén, 2005). Most pedestrian crossings have been located between 2 and 10 meter from the intersection. The consequence is that pedestrian crossing visibility before turning is not optimal compared to a situation where the pedestrian crossing is located directly next to the intersection area. On the other hand, when turning, much attention is devoted to the manoeuver and less attention to the road environment. If the pedestrian crossing would be located further away from the intersection area, the turning manoeuver has been fully executed and there is more cognitive capacity available to detect and react on the presence of pedestrians. However, locating pedestrian crossings that far away will cause a significant detour for pedestrians, evoking an increase in jaywalking (Holmberg and Hydén, 2005).

In case there are right turn "smart channels", right turn lanes decreasing the angle to the road one intends to merge into to 70 degrees, it has been shown that the probability of traffic conflicts decreases significantly, both between pedestrians and motorized road users and between two motorized road users (Autey et al., 2012).

3.3 Definition of interactions between pedestrians and car drivers at signalized intersections

3.3.1 Traffic interactions

Svensson (1998) defined a traffic interaction as "A traffic event with a collision course where interactive behaviour is a precondition to avoid an accident". Persson (1987) defined traffic interactions as "influencing another's traffic behaviour through one's own behaviour". In other words, a traffic interaction is an event in which two or more road users have to react on each other when manoeuvring through a specific traffic situation.

In most situations, there is enough time to react on each other. A turning car driver turning to the right observes a crossing pedestrian and brakes smoothly in order to let the pedestrian pass comfortably is an example of a traffic interaction. At least one of the road users must do something to avoid a collision, but if one of them reacts in time, there is relatively little danger. Interactions are very normal events, occurring many times when participating in traffic. Installing traffic lights influences these traffic interactions, because there is both interaction among road users and interaction between road users and traffic lights. The chance for interacting with crossing pedestrians when driving straight on decreases strongly.

However, this chance is not eliminated because of a risk of red walking by the pedestrian or red running by the car driver. If either the pedestrian or the motorized road user does not respect the traffic signals, there could be an unintended interaction between both road users. As these interactions with pedestrians when driving straight on are not expected any more, the occurrence of these interactions is a surprise for the rule-abiding road user, who is often not prepared for this kind of situation. The result is that there tends to be less time to conduct interactive behaviour in order to prevent an accident, resulting in more severe interactions (Svensson and Hydén, 2006).

3.3.2 Traffic conflicts

A severe interaction, caused by the break-down of the traffic system, is called a traffic conflict. The traffic conflict is defined by Svensson (1998) as "an interaction between road users where the evasive action is started late and the impression is that the situation easily could have ended up in an accident instead."

Hydén (1987) considered traffic events as a continuum between undisturbed passages and accidents. Undisturbed passages are traffic events where there is a free flow and where the traffic behaviour is not influenced by the presence of another road user. These are the most frequent events. Potential conflicts are traffic interactions where there is still relatively much time to make an evasive action. Slight conflicts are traffic interactions where there must be reacted quite quickly to avoid an accident. Serious conflicts are traffic interactions where one succeeds just in time to avoid an accident (near accident) or where it is not possible any more to avoid an accident (traffic crash). The most severe traffic interactions are much less likely to occur than the least severe traffic interactions. In figure 4 Hydéns pyramid is displayed.

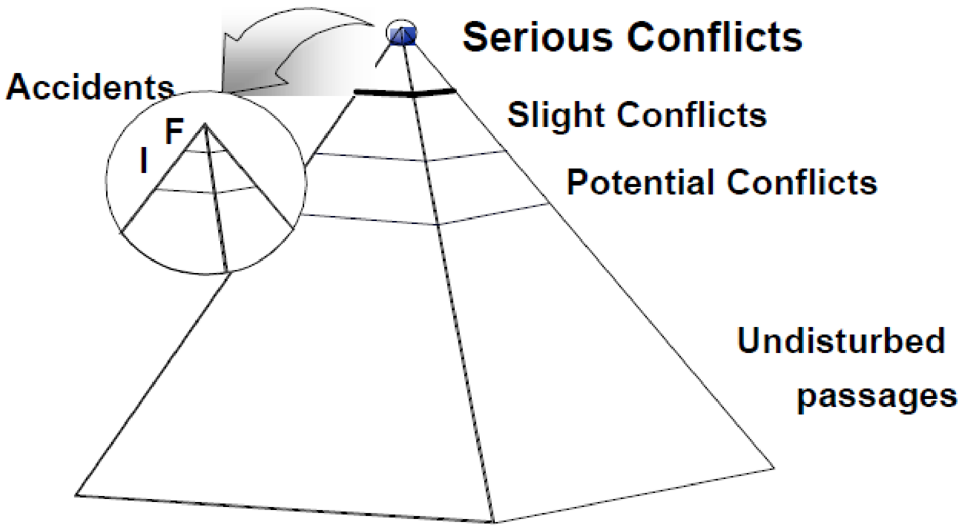

Figure 4: Hydéns pyramid (Hydén, 1987)

Svensson (1998) argued that the severity of traffic interactions heavily depends on the type of intersection control, traffic flow, speed, geometry et cetera. For example, Svensson (1998) expected traffic interactions regarding crossing road users, where one of them neglected red signal, to be more severe than traffic interactions between crossing pedestrians and car drivers turning to the left and to the right.

3.3.3 Possible traffic interactions between motorized road users and pedestrians

As stressed above, a traffic interaction requires both collision course and an evasive action. When we consider a four-leg signalized intersection (two-phased), there are four possible ways of traffic interaction between car drivers and pedestrians at a signalized intersection:

1. The motor vehicle is driving straight on and has a green signal. The pedestrian has red light and crosses the street.

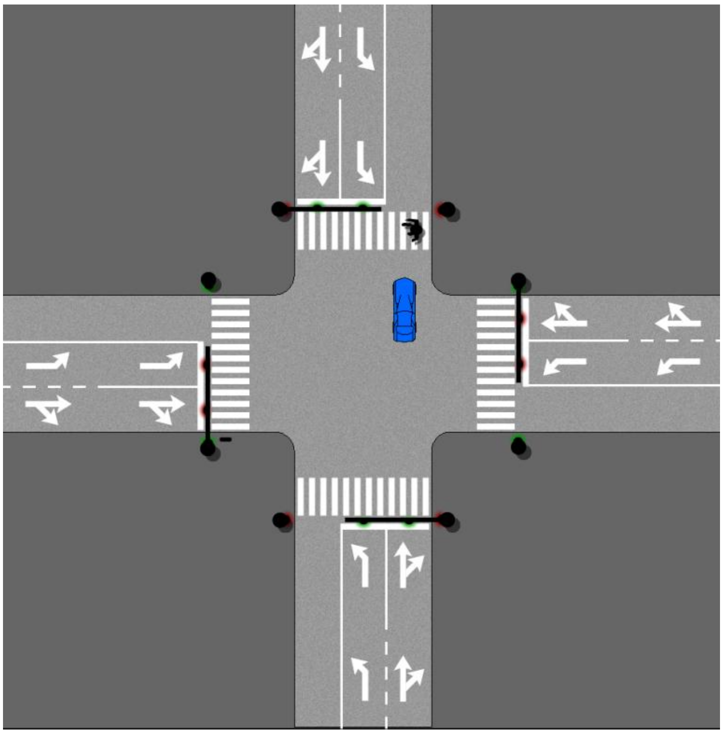

Figure 5: Car drives straight on, pedestrian violates the traffic signal

2. The motor vehicle is driving straight on and has a red signal. The pedestrian has green light and crosses the street.

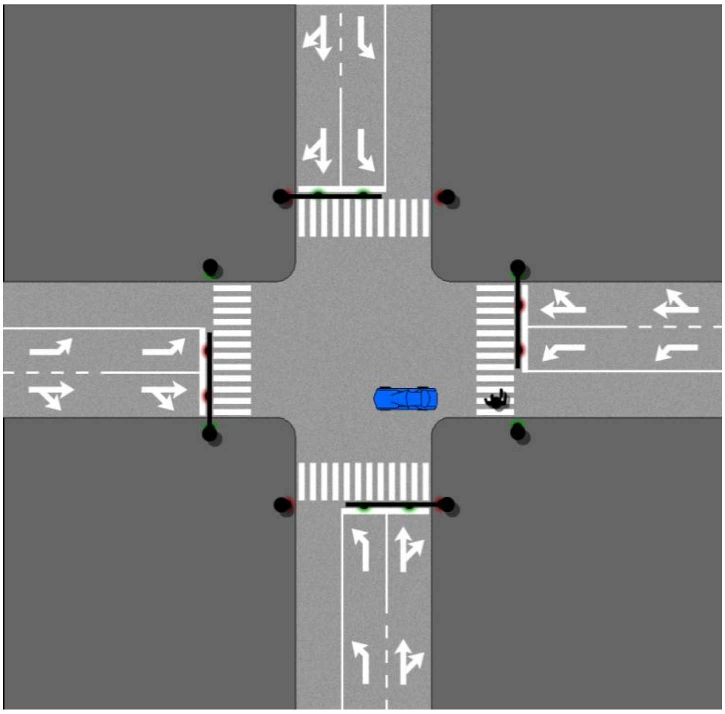

Figure 6: Car violates the traffic signal, pedestrian is crossing

3. The motor vehicle is turning to the right, while the pedestrian having green signal is crossing simultaneously

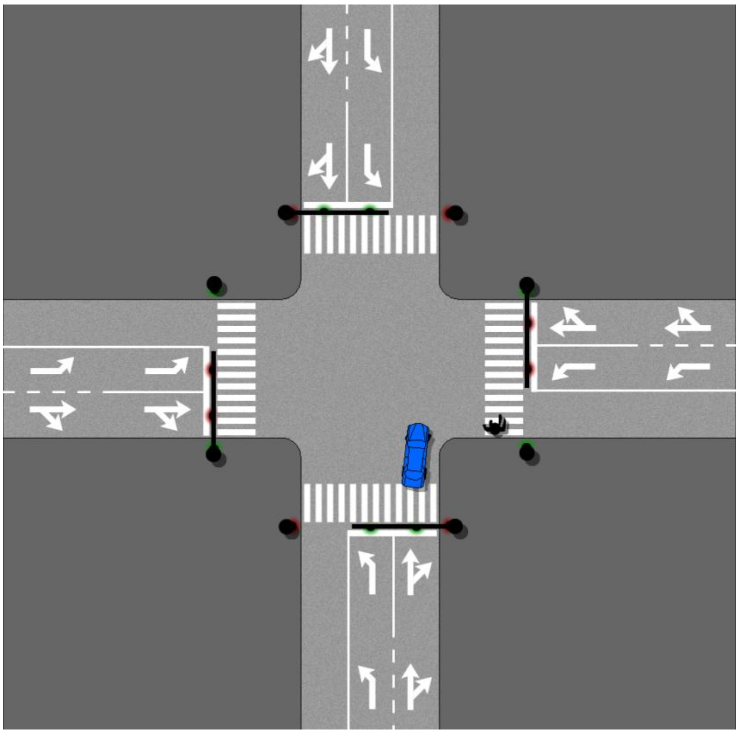

Figure 7: Car turns to the right, pedestrian is crossing

4. The motor vehicle is turning to the left, while the pedestrian walking straight on is crossing simultaneously

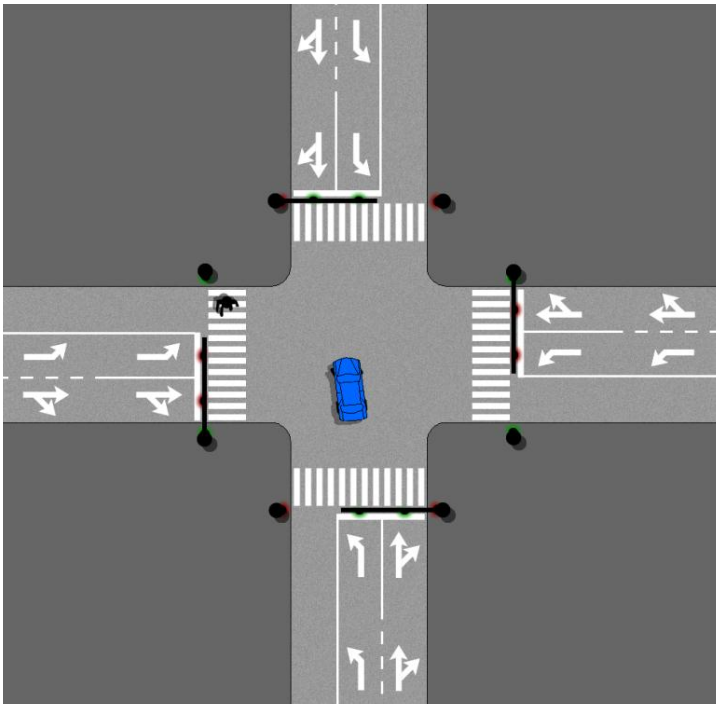

Figure 8: Car is turning to the left, pedestrian is crossing

Apart from these four possible ways of interaction, it is also possible that pedestrians are crossing at another location near the intersection and then interact with motor vehicles.

Shortly, in this definition, you can speak of a traffic interaction between motor vehicles and pedestrians if these road users are reacting on each other's presence or behaviour. If there would be secondary involved road users interacting with one of the road users, then there is possibly no direct interaction between the motor vehicle and the pedestrian, but between the motor vehicle and (in most cases) another motor vehicle. An example is a car driver who intends to turn to the left. On the left side of the street, a pedestrian is crossing the street. The car driver must wait for oncoming traffic driving straight on. In this case, neither the pedestrian is reacting on the car driver intending to turn to the left, nor is the car driver intending to turn to the left reacting on the behaviour of the pedestrian. However, when there would be no passing traffic left and the pedestrian is still crossing, then there would be an interaction between car driver and pedestrian.

3.4 Behavioural Sequence Model: describing interactions between pedestrians and motorized road users

It is impossible to influence the occurrence of a traffic interaction. One can never know in advance whether or not there is another road user at the intersection that one has to react on. However, traffic safety can be influenced by early and adequate actions.

Snyder and Knoblauch (1971) developed the 'Behavioural Sequence Model' when describing traffic interaction between pedestrians and motor vehicles. Both pedestrians and motorized road users must follow a sequence of six steps in order to adequately react on the other's presence, given that there is a collision course. Each of these steps is influenced by different factors that influence whether or not a certain action will be performed.

The steps that must be conducted are: searching, detecting, evaluating, decision, human action and vehicle action.

First, the road user must be concentrated and look in these directions where there could be dangers. The road user must then detect the pedestrian respectively the car driver with which he interacts. In the next phase, the road user must evaluate the situation. As we presume the presence of a collision course, something must be done to prevent an accident to occur. There are several actions that can be taken. One must decide which option to choose. The most logical actions are braking, accelerating or swerving or a combination of evasive actions in order to quit from the collision course. After having decided which action to choose, the road user has to perform the intended action. The last step (only applicable to the motorized road user) is the vehicle that reacts on the human action.

If one fails in performing one step, the other steps are not performed and the situation could end up in an accident. For example, if the car driver does not detect the pedestrian, he can't evaluate the situation and doesn't know that there is a need for an evasive action. As there are two road users, there is always the possibility that the failure of one road user is compensated by the action of the other road user. A pedestrian, who concludes that the car driver is not looking, although he is supposed to give priority, can decide to wait to cross the street until the car has passed. However, the combination of failures of both road users in this sequence of behaviours is likely to end up in a traffic crash.

Beside non-performance of certain steps, it is also important to note that each step takes time. Each step must be performed in time. For example, if a car driver detects a pedestrian too late, he can evaluate the situation and decide to brake, but as there is not enough time left to execute the necessary action, the situation can end up in a crash.

For each step, there are influential factors related to the driver, the pedestrian, the vehicle and the environment. These factors interplay with the performance of each step.

3.4.1 Searching

An important influential factor for the first step (searching) is distraction. A pedestrian walking while using his cell phone can be distracted and, although he knows that he has to cross at a certain intersection, he doesn't scan the road to search for possible dangers. Shinar (2007) reviewed different studies about distraction and concluded that between 20 and 80 per cent of traffic crashes were due to distraction. As people have a limited cognitive capacity, they may not be able to focus on both the distracting factor and the searching task (Shinar, 2007).

3.4.2 Detection

Detection failure (second step) could also be caused by different predisposing factors. An environmental factor could be for instance the presence of a tree that limits visibility for the car driver. The car driver could fail to detect a pedestrian walking next to a tree. In dark environments, pedestrian visibility is an important issue. Sullivan and Flannagan (2001) investigated the effect of darkness on traffic crash probability by studying the same hours during three weeks just before and after changing from summertime to wintertime. The dark/light fatality ratio for pedestrians is estimated 4,1. For moving motor vehicles, this figure is only 1,3.

Expectation is a very important issue as well. If humans expect something, it is likely to be detected much faster. An old study of Roper and Howard (1938) already showed that the average driver detects an expected pedestrian twice as far away as an unexpected pedestrian. If we translate this finding to the context of two-phase signalized intersections with pedestrian signals, it would be logical that a car driver would expect pedestrians when turning to the left or turning to the right. Following the traffic rules, you should give priority to pedestrians walking straight on. However, the question is whether drivers expect pedestrians walking against red light. Do drivers expect pedestrians crossing at another location near the signalized intersection? The combination of a relatively high speed compared to left/right turnings and non-expectancy could lead to a much later detection. In accordance to the study of Roper and Howard (1938), Green (2000) found out that the reaction time increases strongly when the level of expectancy decreases. This result is in accordance with Svensson's (1998) statement that the severity of unexpected traffic interactions tends to be higher. Green (2000) distinguished expected events, unexpected events and intrusion. Expected events are events where drivers know when they have to act and what they have to do. These events have been used as a reference for the other two categories. Unexpected events were events that are likely to happen, but there is a higher uncertainty. It is likely that traffic lights change from green to red, but there is a temporal uncertainty. You do not know exactly when the traffic signals change colour. It is likely that car drivers ahead brake suddenly, but again, you do not know when. Intrusion is described as a rare event that really surprises the road user. As the probability for this kind of events is so low, the driver is often not able to react automatically. Intrusion causes reaction time to increase because detection is slower. Drivers must use the peripheral retina, because the event happens quite near the car driver and this usually takes more time (Green, 2000).

3.4.3 Evaluation

Evaluation failure means failing to acknowledge that there is a collision course and that something must be done to avoid an accident. People having problems with depth sight could fail in evaluating speed and distance of other road users and could perceive that there is no collision course, while in fact, there is. Also, if car drivers do not use their direction lights, pedestrians crossing the street do not expect that there is a collision course. Intrusion also slows reaction time because it takes more time to interpret the need to act (Green, 2000).

3.4.4 Decision

Failures could also occur when deciding which evasive action is to be taken. Pedestrians could decide to run across the street in order to avoid an accident but when they overestimate their own speed, it could be that they make the wrong decision. The chance that a wrong decision is taken also depends on the expectancy of the event. Surprising events often evoke wrong decisions, because there is no automatic response and no experience to react correctly in the short time that is left before a collision would have happened (Green, 2000).

3.4.5 Human action

There could also be certain factors that influence the possible failure of the action of the road users. Making errors when running across the street could result in falling down the street. Car drivers can push the gas pedal instead of pushing the brake.

3.4.6 Vehicle response

Besides human action, the vehicle response plays a role. If the vehicle does not respond to the human action as it should do, the result could be a crash. For instance, lack of maintenance of cars could result in decreased braking power.

3.4.7 Topics related to the Behavioural Sequence Model

In the next paragraphs some topics that are closely related to the "Behavioural Sequence Model" specified for interactions between pedestrians and motorized road users at signalized intersections will be discussed.

Speed

If the speed of car drivers is lower, then, ceteris paribus, there is more time for both the pedestrian and the car driver to make an evasive action. Referring to the "Behavioural Sequence Model", there are more reasons why approach speed is an important issue when studying traffic interaction between car drivers and pedestrians. Road perception is different when driving different speeds. When driving speed is higher, then drivers perceive the road environment differently. Perception of peripheral stimuli decreases when speed increases (BIVV, nd). Consequently, it takes more time when a pedestrian, approaching the street, is detected.

Another aspect of speed is the distance that is needed to come to a stop. The braking distance increases exponentially with increasing speed (Shinar, 2007). Therefore, the probability of a traffic crash increases with increasing speed.

Certain studies emphasise the importance of speed differences rather than absolute speed. The reasoning is that the more speed differences are present in a traffic stream, the more interactions will be needed among road users. It could be better if all vehicles drive with a constant speed (Hauer, 1971). The effects of speed differences on pedestrians have not been investigated, but there might be an effect on gaps in case of red-walking. A chain of vehicles driving at a constant speed gives no possibility to cross the street within the chain but good possibilities to cross after the chain has left. However, if there are big differences between fast and slow vehicles, gaps between vehicles will be more irregular, possibly leading to wrong decisions.

Furthermore, there is also a connection between impact speed and the severity of crashes. Nilsson (2000) investigated the consequence of changes relating to maximum speed on injury accidents and fatal accidents. While the change of the number of injury accidents was approximately the square of the relative speed difference, the number of fatality accidents increased much stronger: by the fourth power of the relative speed difference.

When looking specifically at crashes between motor vehicles and pedestrians, an S-shaped relation has been found between the impact speed and the chance for traffic crashes to be fatal for the pedestrian. Impact speeds under 20 km/h rarely cause severe injuries for pedestrians. However, pedestrian injuries get far more severe when speed increases. At an impact speed of 30 km/h an hour, the probability for a pedestrian to be killed is around 10 per cent. At an impact speed of 50 km/h, the probability increases to 50 per cent and at an impact speed of 70 km/h, nearly no pedestrian will survive (Shinar, 2007). The results of Rosén and Sander (2009) were somewhat more optimistic. They concluded, based on empirical research, that the chance of surviving at an impact speed of 70 km/h is still around 50 per cent. However, also this study confirms that the chance for a vulnerable road user to die in a traffic crash increase by a factor 5 at an impact speed of 50 km/h compared to an impact speed of 30 km/h.

The speed of car drivers is an important issue. A higher speed results in a higher probability of a traffic crash and a higher speed results in a more severe traffic crash, given that the crash occurs. However, the speed of the pedestrian also plays an important role. Pedestrian safety improves when crossing speed increases, because the crossing time and therefore the risk exposure reduces (Shinar, 2007). Knoblauch et al. (1996) investigated the speed of pedestrians specifically at signalized intersections. There were some interesting conclusions regarding crossing speed and influential factors. In every case, the speed of younger pedestrians was higher than the speed of older pedestrians. Males were faster than females. However, there were also some environmental features that had an influence on crossing speed. For example, pedestrians walk faster when the road is wide than when the road is narrow. When it is cold outside, pedestrians also walk faster. The average speed of pedestrians walking through red light is also higher than the speed of pedestrians having green light.

Drivers crossing a major street tend to accept smaller time gaps if the speed of the car on the major street is high than if its speed is low. That's one more reason why there is a positive relationship between approach speed at an intersection and accident probability (Spek et al., 2005). A reason for this finding could be that on the moment of evaluation, the car is further away in case it is driving faster than in case it is driving slower. Pedestrians base their evaluation to cross or not cross only on distance rather than on a combination between distance and speed of oncoming vehicles. In case of a time constraint, this is even more prevalent (Brewer et al., 2007). Therefore, it is likely that there will also be a positive relationship between vehicle approach speed at an intersection and accident probability between a motor vehicle and a pedestrian.

Communication

Another very important issue in traffic interaction is communication between road users. Communication is important in order to make clear what one intends. Persson (1987) made a framework for future research about road user communication. He distinguished two types of communication. The first type is deliberate communication like eye contact, different gestures and signals by using the car's light systems. The other type is using acting signals, which means showing what one is intending by simply executing these actions. An example of this second type is showing to the other road user that one is taking priority. In some cases, pedestrians are not making eye contact in order to maximize their goals. When crossing a street, it can be a strategy to feign not to look to the oncoming car. The reaction of the car driver is that he does not know what is going to happen and to give the pedestrian priority instead. This way of communicating is communication by no-action (Persson, 1987).

Persson (1987) mentioned the lack of cooperation in the traffic system. Traffic can be seen as an "empty" or "antisocial" system. It is all about maximizing one's own goals. The problem is, however, that road users often start cooperating when there is nearly a breakdown in the interaction. In these cases, dangerous situations could occur.

Making eye contact, using direction lights or simply decreasing speed are some examples of ways in which car drivers can make contact with pedestrians. Pedestrians can also show what they are intending by making eye contact or by acting signs: for example walking to the crosswalk without decreasing speed. Beside justifying one's own interests, a second important goal of communication is system interests. System interests are related to traffic safety. One uses his direction lights for other road users, to show that one is going to turn and is likely to decrease speed. Car drivers slowing down show to pedestrians that they have been seen and that they can cross first. A third motive for communication is ruthlessness, showing a lack of cooperation. Using aggressive hand gestures or light blinking can be used to communicate anger.

Visual contact between pedestrians and car drivers on pedestrian crossings are quite rare. Tom and Granié (2011) showed that out of 400 pedestrians in interaction with motor vehicles, only 7,25 per cent made eye contact with car drivers. There was no statistically significant difference between non-signalized and signalized intersections.

A research of drivers' speed at an non-signalized zebra crossing showed that car drivers are stopping more often for pedestrians when they drove quite slowly, when the pedestrian did not look at the vehicle, if there was a long distance between the vehicle and the pedestrian, and if there is a group of pedestrians intending to walk across the street (Várhelyi, 1998). The chance that an interaction between a car driver and a pedestrian ends up with a traffic crash increases when speed increases. This study is an empirical application of the more theoretical concepts of Persson and confirms most of the constructs explained above, be it on a zebra crossing without traffic lights. The higher the speed, the more traffic crashes. The lower the speed, the more time to slow down for pedestrians and the higher the chance that one is effectively slowing down. Pedestrians intending to go first who feign not to have seen the car driver are more successful in getting priority than pedestrians searching eye contact with the car driver. However, if the former are not successful, there is a risk for a crash.

Respecting the traffic lights

Another very important aspect when studying interaction behaviour at signalized intersections is respecting the traffic lights. As road users interact with traffic lights, non-compliance can lead to unexpected and therefore dangerous situations. However, in certain situations, pedestrians deliberately walk against red because they don't perceive any danger. At non-signalized intersections, pedestrians in general tend to accept a margin between 1 and 13 seconds when crossing the road. This is the time between finishing crossing and the moment the conflicting car is reaching the conflict zone (Das et al., 2005 & Oxley et al., 2005). Above this limit, all pedestrians cross the road. It is remarkable that older pedestrians, who are on average slower than younger pedestrians, made quite dangerous decisions.

Schmidt and Färber (2009) came to lower values between 3 and 7 seconds, irrespective of the speed of the cars (35 km/h, 45 km/h and 60 km/h). They also concluded that, with a certain time to accident, pedestrians were more likely to cross when the car was approaching with a higher speed. This is because of the fact that the distance is higher with a certain time to accident in case of a higher speed.

There are a number of infrastructural aspects that coincide with red light violation. Thorson et al. (2003) investigated red walking of pedestrians in Spanish cities. They concluded that there were some infrastructural features that had a relation with the number of accidents. For example, they found out that the percentage of pedestrians walking through red light decreased when the width of the crossing increases and when the traffic volume increases. However, the chance that a pedestrian will walk against red light increases when the waiting time increases. Young and old persons tend to be more careful than persons between 20 and 60 years old.

Pedestrians tend to comply with traffic signals if there is much traffic, if there are other waiting pedestrians and if waiting time is shorter than 30 seconds. Older persons, females in general and impaired persons comply better with traffic signals. In case it is obvious that you can cross the street safely, pedestrians cross most of the time regardless of the traffic signal (Kennedy and Sexton, 2009).

The compliance rate differs between countries. In Great Britain, the level of non-compliance is quite high compared to the level of non-compliance in Poland and Australia. Kennedy and Sexton (2009) argued that this difference could be because of cultural differences, but also because of differences in law enforcement. There are differences among different countries, but nevertheless, red light violation is common for pedestrians. However, the consequences for traffic safety are bad. Around 60 per cent of pedestrian fatalities at signalized intersections happen when a pedestrian crosses with red signal. Most dangerous are traffic light installations that provide green to an oncoming stream of motor vehicles just after the pedestrian signal has turned red, because there is a conflicting stream driving with a quite high speed (Kennedy and Sexton, 2009). Thus, notwithstanding the fact that red light violation can be very dangerous, it is done frequently. In some cases, there is no oncoming traffic, but also if there is, a long waiting time can stimulate red light violation.

Traffic Volume

The more traffic, the higher the chance is that there is an interaction between road users. In case there is no traffic at all, then you do not have to adapt your behaviour because of the presence of other road users. However, the question is whether there is also a higher chance for traffic crashes. It could be traffic interactions can be managed better when these interactions occur more frequently.

Ekman (1996) investigated the relation between traffic flow and the number of conflicts between motorized vehicles and pedestrians. He concluded that the number of traffic conflicts increases with increasing car traffic, but rather than a linear function, he discovered a step function. On the other hand, there was not really a connection between the number of pedestrians and the number of conflicts. Only in case of a very limited number of pedestrians, there is a higher number of pedestrian conflicts per pedestrian. Ekman suggested that this could be because from 30 pedestrians per hour, car drivers expect pedestrians to be present, and then it does not matter whether there are 100 or 200 pedestrians per hour. Only in case of a very large number of pedestrians, the number of conflicts per pedestrian increases again. This could be explained by the fact that pedestrians block the crossing during such a long time that car drivers will accept small gaps to pass the crossing, thereby sometimes evoking traffic conflicts.

According to Dumbaugh and Li (2010), there is a positive relationship between population density and pedestrian injuries. It was stated that population density could be a proxy for pedestrian volumes. This finding is related to the finding of LaScala et al. (2000), who investigated pedestrian injuries by making use of a Geographic Information System. Pedestrian injuries were positively related to both traffic flow and population density.

Leden (2002) found out that, at two-phased signalized intersections, especially the chance for pedestrians of getting involved in a traffic conflict with a left-turning vehicle increases dramatically with increasing traffic volumes. A reason for this could be that there are only small gaps in the traffic flow and that the left-turning car drivers are therefore focused on the car traffic from the opposed direction instead of the presence of vulnerable road users.

3.5 Factors influencing road user behaviour

The ways road users behave are influenced by individual characteristics like personality, attitudes, and perceptual-motor and information-processing capacities. Characteristics like age, sex and cognitive limitations influence traffic behaviour and accident proneness all over the world. However, what is the role of cultural and social factors? What is the role of other road users? Traffic behaviour differs between different countries, but also between different regions within a country and between different persons in general. In this paragraph there will be focussed on age, gender and culture.

3.5.1 Age

In traffic safety research, age of road users plays an important role. Young adults are much more prone to be involved in traffic crashes than older people. The combination of a lack of driving experience, overestimation of own skills and sensation seeking results on average in more dangerous traffic behaviour and a higher probability for traffic crashes (Evans, 2004). They also drive more during nights, and are more often under the influence of alcohol and drugs (Shinar, 2007). There are also differences in crash severity between different age groups. Given a certain crash, the probability for getting severely or fatally injured are higher for older people because older people on average are more vulnerable than younger people (Evans, 2004).

The type of traffic behaviour leading to a crash also differs by age. Certain behaviours leading to pedestrian traffic crashes have been investigated. The most important pedestrian factors are running into the road, failing to yield, stepping from parked vehicles, walking in the wrong direction, stepping into the road, talking or standing in the road, jaywalking and failing to obey traffic signals. Primary pedestrian crash causes for pedestrians strongly depend on the age of pedestrians. While kids more often run into the street or from between parked vehicles, teens are more likely to fail to obey traffic signals. Alcohol impairment is an important contributing factor for persons between 20 and 44 years. For pedestrians older than 45 years old, jaywalking is an important contributing factor for traffic crashes (Hunter et al., 1995).

3.5.2 Gender

All over the world, males are more involved in traffic crashes than females, also when corrected for exposure. Males generally tend to take more risks, both inside and outside traffic environments (Evans, 2004). Pedestrian risk behaviour and violations at signalized intersections are more prevalent for males than for females (Roosenbloom et al., 2004).

Tom and Granié (2011) concluded that males are more likely to neglect red signals than females. However, when looking at jaywalking, there is no significant difference between males and females.

3.5.3 Culture

Traffic behaviour differs among countries. Nordfjærn et al. (2011) investigated the relationship between attitudes and risk perception on self-reported traffic behaviour in Norway, Russia, India, Tanzania, Ghana and Uganda. For Norway, Russia and India, a satisfactory part of the variance in driving behaviour was explained by the predictive model of risk perception and attitudes. In these countries, there have been found differences in attitudes towards speeding and driving under the influence of alcohol and differences in self-reported traffic behaviour.

In Israel, there has been investigated whether there are differences in pedestrian behaviour between an ultra-orthodox city and a non-orthodox city. The inhabitants of the ultra-orthodox city have, on average, a lower income and lower car possession than the inhabitants of the non-orthodox city. Behavioural factors that have been observed in these cities are respecting traffic signals, jaywalking, looking behaviour, walking along the road and taking a child's hand when crossing. The results showed that all of the factors related to unsafe pedestrian behaviour were significantly more prevalent in the ultra-orthodox city, beyond the fact that males committed far more violations than females and that there are age-related differences. Still, corrected for age and gender, inhabitants of the ultra-orthodox city committed more than three times more violations than inhabitants of the non-orthodox city. Also, the so called age effect did not occur in case of the ultra-orthodox city, where young pedestrians are supposed to behave responsibly from an early age (Roosenbloom et al., 2004).

Based on these results, Roosenbloom et al. (2004) tried to explain the differences by looking at religious and socio-economic characteristics that could have links with unsafe pedestrian behaviour and breaking the law. It has been shown that obeying the (governmental) law is less prevalent in case there is a strong legitimacy of other laws, in this case religious laws. Belief in afterlife and thinking positively about life after death are also correlated to more unsafe behaviour. Moreover, a low socio-economic position could be associated with more cynicism towards laws.

Drivers in the ultra-orthodox city are aware of the reckless traffic behaviour of pedestrians in their city and they are more careful, because there was no significant difference in pedestrians involved in traffic crashes between the ultra-orthodox and the non-orthodox city.

This research has been based on behavioural observations and has some methodological drawbacks. For example, there is not so much background information available about the pedestrians involved. There could be other, unknown factors that influence pedestrian behaviour. Nevertheless, this study indicates that cultural features can have an influence on traffic behaviour.

Özkan et al. (2006) investigated the link between driving culture, driving behaviour and traffic safety in a cross-national study in six different countries: Finland, the Netherlands, Great Britain, Greece, Turkey and Iran. An important finding was that speeding is a universal problem, while other behavioural problems are country-related. In different countries, different countermeasures should be taken. Southern European countries should focus their policy on countering aggressive violations by promoting positive traffic behaviour.

Some studies (e.g. Melinder, 2007, Gaygisiz, 2010) investigated the link between some cultural characteristics, like religion, welfare, the degree of hierarchy in a society, the degree of individuality and uncertainty avoidance. It has been found that there are statistically significant links between these cultural and economic characteristics and traffic accidents. However, it has not yet been investigated what the effect of these characteristics is on traffic behaviour as such.

4 Methodology

4.1 The Swedish Traffic Conflict Technique

4.1.1 Introduction

The most logical unit to measure traffic safety seems to be the number of traffic crashes. However, there are some severe problems when assessing traffic safety on a smaller scale. As traffic crashes are rare events, it is difficult to assess whether a certain intersection is dangerous and that there is a need for intervention because of a lack of sufficient data for reliable analyses. There is always a lack of data, and if there is data available, there are always random aspects that do not uncover structural, systematic problems (Varhélyi, 2011).

When there have been changes in the road environment, for example in order to improve safety for pedestrians at an intersection, one must wait for several years before one can conclude whether or not there has been improvements in traffic safety. The evaluation process is therefore very extensive.

Another disadvantage of using police accident data is the fact that these data do not cover the process that leads to the traffic crash and the situation just before the traffic crash (Hydén, 1987). An example is a traffic situation where the sight for a pedestrian is limited by a bus standing still at a bus stop. The pedestrian walks across the street and is hit by a car. At the time the police arrives, the bus has left and in the police accident data, nothing is written about limited sight because of the bus (Várhelyi, 2011).

Under-registration is another important disadvantage. Not every crash is reported by the police. The consequence is that we do not know exactly about the number of crashes at a certain location. Moreover, the level of registration is unevenly distributed. Less sever crashes are more likely to not be reported. In Sweden, also vulnerable road users involved in crashes are less well registered than motorized road users (Berntman, 1994).

Traffic conflicts, as mentioned above, are traffic situations with a collision course and a small time margin to take an evasive action and avoid a crash. Conflict studies have several advantages compared to only using accident data. As traffic conflicts occur way more frequently than traffic crashes, there will be far more data available. In many cases, it is possible to make conflict observations for 30 hours and make a fair assessment of certain types of dangerous situations and the processes that lead to these situations at a certain location. Another advantage is the fact that conflict observations result in more information about the circumstances of traffic conflicts than the use of accident data gives for crashes.

Already in 1967, there were attempts to use conflict observation studies as a proxy for traffic crashes in order to make traffic safety assessments (Perkin and Harris, 1967). In the years that followed, there has been many different approaches that use a kind of conflict observation. One method that is used extensively nowadays is the Swedish Traffic Conflicts Technique.

The Swedish Traffic Conflicts Technique builds on the principle that traffic interactions are a continuum of safety related events (Hydén, 1987). Like displayed in figure 4, Hydén stressed that there is a continuum, going from undisturbed passages through potential conflicts, slight conflicts and serious conflicts to traffic crashes. Hydén hypothesised that there is a close relationship between traffic conflicts and traffic crashes. Not many people want to get involved in a crash. "Traffic conflicts are also situations that nobody puts him/herself into deliberately" (Hydén, 1987). The consequence is that it should be possible to make a traffic safety assessment based on traffic conflicts instead of traffic crashes.

4.1.2 Principles of the Swedish Traffic Conflict Technique

The definition of a serious conflict is based on some quantitative aspects: collision course, evasive action, conflicting speed, distance to the conflict point and time to accident.

A collision course is a prerequisite for a traffic conflict. A collision course means that two road users would have collided if both road users would have continued their speed and direction (Hydén, 1987). An evasive action is an action to avoid a collision. There are three kinds of evasive actions. You can decelerate, you can accelerate and you can swerve.

Just before executing the evasive action, the conflicting speed and the distance to the conflict point is estimated. The conflicting speed is the speed of the vehicle, bicycle or pedestrian before the evasive action. The distance to the conflict point is the distance to the point where the road users would have collided if there would not be any evasive action.

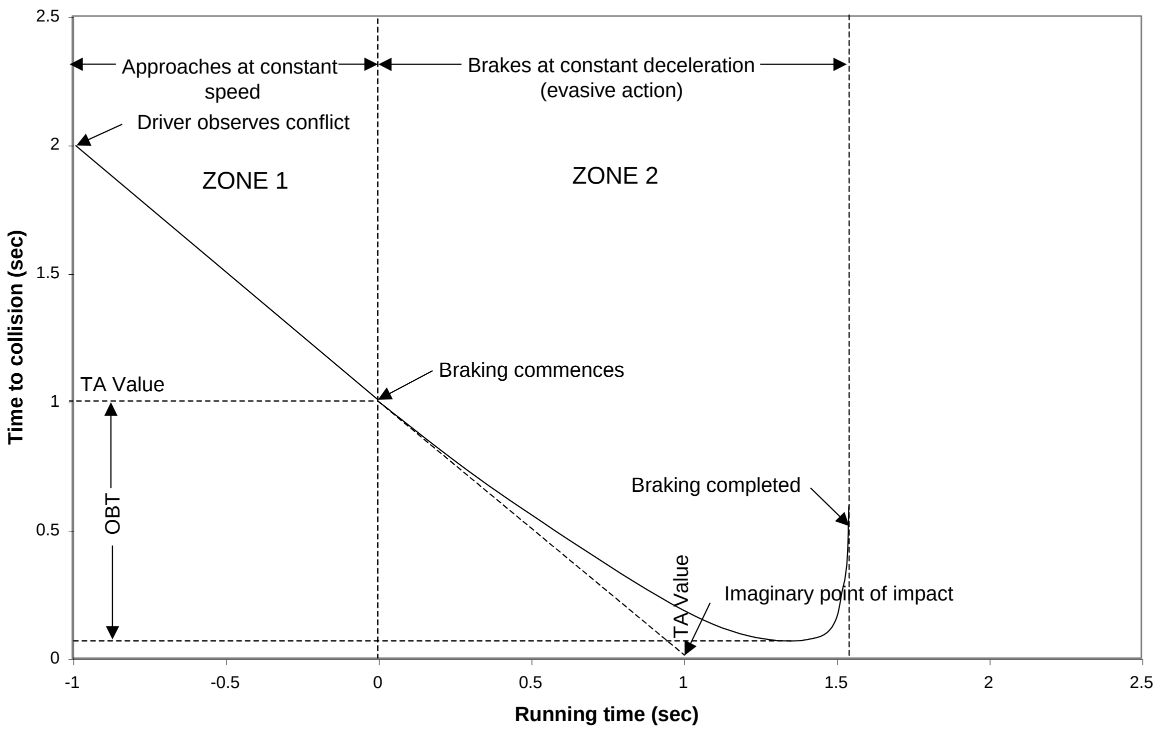

Figure 9: Time to collision values and time to accident (De Ceunynck, 2012)

It can be that one of the road users undertakes an evasive action, but it can also be that both road users undertake evasive actions. In case of two road users taking evasive actions, the so called relevant road user is the road user with the highest margin.

The time to accident is computed with the conflicting speed and the distance to the conflict point. If both road users undertake evasive actions, this results in two time to accident values. The highest value (least severe value) is deciding whether you can speak of a serious conflict.

Shbeeb (2000) emphasizes that the concept of relevant road user can be misleading in case of a traffic conflict between a pedestrian and a motorized road user. Because of the low speed of pedestrians, the pedestrian most often turns out to be the road user with the highest time margin so the relevant road user. However, the validity of the traffic conflict technique would increase if, in case of traffic conflicts between pedestrians and motorized road users, the most severe time to accident was taken to decide whether a traffic conflict is severe.

Example: A red car intending to turn to the left and a passing green bus driving straight on. The car driver underestimates the speed of the bus and the vehicles are on a collision course. The car (conflicting speed 30 km/h) brakes abruptly four meter in front of the conflict point. The bus (conflicting speed 45 km/h) also brakes abruptly ten meter in front of the conflict point. The time to accident for the car is 0.5 seconds, while the time to accident for the bus is 0.8 seconds. Because the bus had more time left and a larger safety margin, the time to accident of the bus defines the seriousness of the traffic conflict.

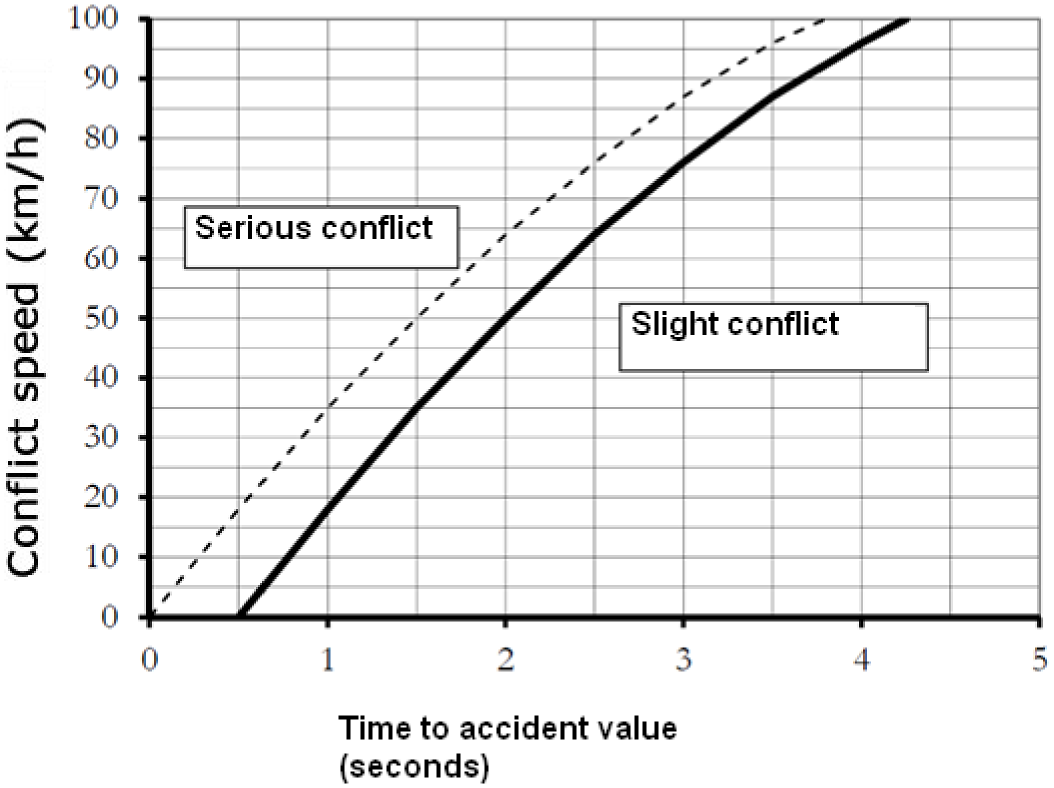

Figure 10: Distinction serious conflicts - slight conflicts

Serious conflicts are traffic conflicts with a low Time to Accident. At higher speeds, traffic conflicts are serious even at higher Time to Accident values. This relationship is approximately linear. According to figure 10, traffic conflicts with a Time to Accident-value less than 0.5 are always serious conflicts. The dashed line is considering the case of optimal braking power, while the normal line is taking a time margin of 0.5 second. Traffic conflicts with a combination of TA and conflict speed right from the black line are slight conflicts. Traffic conflicts left from the black line are serious conflicts.

Traffic crashes can also be described in terms of conflicting speed, distance to the conflict point and time to accident. However, in this case, the road users are not able to make the evasive action in time.

In some cases, there is no collision course and no evasive action, but nevertheless a potentially dangerous situation. A second indicator that can be used when assessing traffic safety is the so called post-encroachment time (PET).

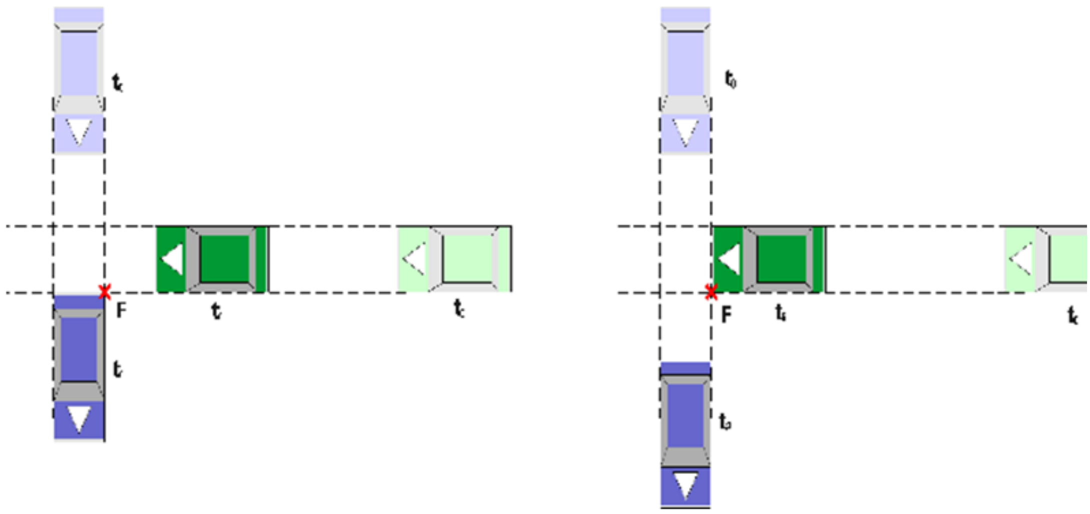

Figure 11: Post encroachment time (PET)

Post-encroachment-time is defined as the time frame between the moment road user 1 (on figure 11 the blue car) leaves the conflict zone and the moment road user 2 (on figure 11 the green car) enters the conflict zone. If road user 2 reaches the conflict point just after road user 1 has left it, you speak about a small post-encroachment time. This also means that, if road user 2 would have decreased his speed a little bit, or if road user 1 would have accelerated a little, there would have been a collision course and no evasive action. The consequence could be a crash. A PET less than or equal to 1 second can be considered as severe (Kraay et al., 1986)

The Swedish Traffic Conflict Technique is based on conflict observations at a particular location, in most cases at an intersection. One or more observers are standing along the road and are studying traffic interactions. When there are traffic conflicts, the observers describe the process that have led to the conflict and estimate speed and distance to the conflict point.

4.1.3 Validity and reliability of the Swedish Traffic Conflict Technique

In theory, the use of conflict data instead of, or in addition to traffic accident data, is clear. However, if traffic conflicts are a prediction of traffic crashes, there should be a certain numeric relationship between the number of traffic conflicts on the one hand and the number of traffic crashes on the other hand. If you make observations on two locations and find out that the number of traffic conflicts is twice as large at location 1 as at location 2, the expectation is that location 1 is more dangerous and that there will happen more traffic crashes or more severe traffic crashes at location 1 than at location 2, but it is still uncertain whether the expected number of crashes is also twice as high.

There are different views on validity of traffic conflict studies. Should conflict studies predict the number of accidents, or should there be a correlation between traffic conflicts and traffic crashes? As there is an important random factor in the occurrence of traffic crashes, the aim of traffic conflict studies should not be to exactly predict the number of traffic crashes. However, this ratio can be biased by registration failures of traffic accidents. As many accidents are underreported, it can be that there is a poor fit between e.g. traffic conflicts involving pedestrians and pedestrian accidents (Chin and Quek, 1997). Therefore, the Traffic Conflict Technique should be good in estimating the expected number of traffic crashes (Hauer and Gårder, 1986). There should be some kind of "accident-to-conflict ratio" to be able to relate traffic conflicts to traffic crashes.

The fact that there should be some accident-to-conflict ratio does not mean that this accident-to-conflict ratio has to be the same for every type of traffic conflict. The accident-to-conflict ratio is higher for side conflicts than for rear-end conflicts. The conflict-to-accident ratio differs between 1 accident for 1000 conflicts and 1 accident for 100.000 conflicts. For side conflicts, it has been estimated that there is approximately 1 accident for 8.000 traffic conflicts. For rear end conflicts, it has been estimated that there are approximately 36.000 traffic conflicts for each crash (Svensson, 1998).

Nevertheless, one should try to link traffic conflicts and traffic crashes statistically. Recently, a two-phase model has been estimated to judge the relationship between some characteristics of both signalized and un-signalized intersections and traffic conflicts, and between traffic conflicts and traffic crashes (El-Basyouny and Sayed, in review). The link between traffic conflicts and collisions is not linear. In this case, a negative binomial model has been used. For the link between geometrical and traffic characteristics and traffic conflicts, a lognormal model has been used. A good correlation has been found between the model based on traffic conflicts and the model based on crashes.

Beside a statistical link between conflicts and traffic crashes, there should also be a similarity between the processes preceding traffic conflicts on the one hand, and the processes preceding traffic crashes on the other hand. This is called process validity. The processes leading to conflicts should be the same as the processes leading to traffic crashes (Hydén, 1987).

Another important issue is reliability of the Traffic Conflict Technique. This means that results should be the same regardless of the conflict observers. However, because of human failures, there are always some differences between the results of different observers. It could be that one observer judges a traffic event as a traffic conflict, while another observer does not. This is called intercoder reliability. Intracoder reliability is the consistency of observations by one observer. It could be, for example, that two identical situations are coded differently by a different estimation of speed and distance. An important question is whether conflict observers can distinguish traffic conflicts from other traffic interactions. However, conflict observers both underestimate (estimate a time to accident that is lower than the real time to accident) and overestimate (estimate a time to accident that is higher than the real time to accident) the severity of traffic conflicts. The average speed bias was 3 kilometre an hour. Conflict observers failed to judge 26 per cent of the traffic events as traffic conflicts (Svensson, 1998).

Video-based conflict observations can be used to increase reliability, because in that case, there are no more human observers, but cameras observing traffic conflicts. A set of algorithms is used to decide when there are traffic conflicts. Another advantage of video-based conflict observations is that it is relatively cheap to increase the observation time. The consequence is that there will be more data available. Human observations are usually conducted during a limited period of time, for example 30 hours. However, using cameras, the observation time can be lengthened tremendously (Laureshyn, 2010).

4.1.4 Findings of the Traffic Conflict Technique regarding conflicts at signalized intersections

Svensson (1998) found that, opposed to traffic conflicts at non-signalized intersections, traffic conflicts at signalized intersections are more spread out and there is a tendency towards lower severity. This is a bit counter-intuitive, because a lot of possible interactions have decreased because of the signalized intersection. However, these interactions are not entirely eliminated. The result is that these interactions are infrequent, but unexpected. There do happen severe crashes with pedestrians at signalized intersections. However, there are less interactions with high severity because of interactions between the road users and the signals (Svensson and Hydén, 2006). The results of this comparison are based on one signalized intersection and one non-signalized intersection and should therefore be treated with prudence.

4.2 Behavioural research

A comprehensive traffic safety diagnosis includes not only crash data, but also data about the circumstances that precede the crashes. When facing a traffic safety problem, one considers the problem in terms of accidents, injuries or fatalities. These figures are the outcome of a process, in which a lot of variables are included. There are environmental factors, vehicle factors and human factors. All of these factors play a role in the explanation of why traffic crashes occur. Therefore, one should not only investigate traffic safety by studying accident data, but also by observing traffic behaviour and trying to find explanations for traffic behaviour (Muhlrad, 1993).

Both surveys and field observations have been used to investigate pedestrian and car driver behaviour. The advantage of surveys is that the results can be linked to a more advanced analysis of personal characteristics, opinions et cetera. The advantage of observations, however, is that they are more objective. Social desirability is a bigger problem when asking people how they behave than when observing how they behave, especially if they do not know that they are being observed.

Just like traffic conflict observations, behavioural research can discover the processes that could lead to traffic crashes. According to Svensson (1998), normal traffic behaviour, traffic interactions and crashes are part of the same continuum. The only factors that differ are the TA-values. These traffic interactions could have certain aspects that could explain why they sometimes lead to traffic conflicts or even crashes.

Laureshyn (2010) describes behavioural studies as studying the outcome of internal psychological processes. It is about measurable parameters, for example speed, distance, yielding, signalling, et cetera. Observation studies for safety research are often connected to traffic interaction: the way different road users react on each other. In this paragraph some behavioural studies that have been conducted within the field of traffic interactions between pedestrians and motor vehicles will be discussed.

Because of the high fatality rate of Estonian pedestrians, a behavioural research has been conducted. It has been shown that 1,6 per cent of the car drivers and 26 per cent of the pedestrians did not respect traffic signals. 26 per cent of the car drivers did not use turning signals and more than two-third did not give priority to pedestrians when they should (Antov and Sööt, 2002).

Sisiopiku and Akin (2003) studied pedestrian behaviour at intersections, both at signalized and unsignalized intersections. They used both a survey and field observation. They concluded that red walking was an important problem, especially if traffic volume is relatively low. If pedestrian crossings are not properly located, many pedestrians will jaywalk instead. An interesting finding of this study is the fact that there were no big differences between the results of the survey on the one hand and the results of the observation on the other hand. This indicates that social desirability is not a very important problem in this case.

These studies, although executed in other countries than Belgium or Sweden, can give more insight in interactions between pedestrians and motorized road users.

5 Study design

In this study, both normal traffic interactions and traffic conflicts at signalized intersections in Sweden and Belgium have been investigated. For this purpose, two signalized intersections have been selected: one in Sweden and one in Belgium. To increase the amount of data, another signalized intersection in Belgium has been selected for behavioural studies. Certain behavioural aspects have been investigated.

In this chapter, the methodology will be explained. This chapter consists of the following topics:

- Selection of locations in Sweden and Belgium
- Behavioural observations
- Conflict observations
- Practical organisation

5.1 Selection of locations

This cross-sectional behavioural and conflict observation study has been executed in both Sweden and Belgium. For purposes of comparability, it is important that the intersections as such are as similar as possible.

5.1.1 Comparable intersections

The intersections in Sweden respectively Belgium should be comparable. This means, there should not be too many differences between the Swedish and the Belgian intersection that could influence possible behavioural aspects.

Ideally, the intersections are identical both with regard to layout, environment and use. In that case, the only thing that differs is the traffic behaviour of the people involved, namely mostly Swedes in Sweden and mostly Belgians in Belgium. However, there are always differences between two intersections, since each intersection is unique. Nevertheless, measures should be taken to choose intersections that are as similar as possible with regard to the most essential properties.

A list has been made about properties that, in an ideal situation, should be similar for all intersections investigated.

- The geometry of the intersections should be similar
    - Number of lanes
    - Type of regulation (signalized intersection, roundabout, priority road, ..)
    - Sight distance to the crossing from each leg

  - Angle of the different legs
  - Presence or absence of refuge islands
  - Allowed maximum speed
  - Type of pavement
  - Position of the pedestrian crossing
  - Presence of a cycle lane next to the pedestrian crossing
  - Speed limiting measures
- Traffic flow on each of the legs should be similar (motor vehicles and pedestrians)
- The environment of the intersections should be similar
  - Trees along the road
  - Presence of parked cars near the intersection
  - Presence of houses, schools, public services, et cetera near the intersection
  - Position with respect to the city centre
  - Demographic composition of road users
  - The width of the lanes
- There should not have been major geometric or traffic control changes during the last three/five years when comparing observations with crash data.

5.1.2 Ranking of properties that should be similar

As it is not feasible to find two intersections that are completely identical, one should look for finding similarities with regard to the most essential properties in order to make a proper comparison. Nevertheless, the results will always be somewhat biased. In this paragraph those properties are discussed that are considered as essential to be as similar as possible.

1. Number of legs and number of lanes from each leg

The behaviour of pedestrians depends on the layout of the pedestrian crossing. When the distance to cross is bigger, pedestrian behaviour could be different from short distance crossings. As discussed above, the speed of pedestrians increases with an increasing crossing distance (Knoblauch et al., 1996). Moreover, one should not compare a three-leg intersection with a four-leg intersection, because these intersections also have different interaction patterns (Elvik et al., 2008).

2. Regulation system

The regulation system should be the same. As discussed above, there is a difference in traffic safety between intersections with two phases and intersections with separate phases for pedestrians (Elvik et al., 1997). In Sweden and Belgium, most of the intersections considered have mixed phases. Therefore, both the Swedish and the Belgian intersection should be two-phased signalized intersections.

3. Sight distance

It should be possible to have an overview on the intersection from each leg from approximately the same distance at both intersections.

4. Angle of the crossing roads

There should be similar intersection angles because of the kind of interactions that could be different in case of different angles. Lack of overview could arise from a combination of very small and very high angles. Therefore, the intersection angles should be similar.

5. Presence of a refuge island

Refuge islands make it possible for pedestrians to cross in two phases if the traffic situation enables this. In case there are refuge islands present, then pedestrian behaviour is expected to change, because they can cross in two phases. At low traffic volumes, red light violation could increase because of this. Ekman (1996) found that the probability of traffic conflicts decreases when there are refuge islands.

6. Allowed maximum speed

Traffic behaviour depends to a certain extent on approach speed. For instance, on non-signalized pedestrian crossings, road users give way more often if they are driving at low speeds than if they are driving at high speeds, as described above (Várhelyi, 1998).

7. Traffic volume (motor vehicles and pedestrians)

The traffic volume also has implications for the chance of getting involved in any kind of traffic interaction. At higher traffic volumes, the exposure is higher. However, road users also tend to be more conscious about the presence of others. Traffic behaviour could depend on the number of vehicles and pedestrians from each leg of the intersection.

8. Environment of the intersection

As mentioned above, there are some aspects relating to the environment of the intersection that should be similar in an ideal situation.

There are many other properties of intersections that should be similar to make the intersections as comparable as possible. Factors like the pavement material, the distance from the intersection to the city centre, whether there are trees alongside the road, the presence of parked cars, the presence of public buildings, schools, housing blocks, etcetera, could also have an influence on traffic behaviour on a particular site. However, the more criteria that have to be respected, the more difficult it becomes to find a match between two intersections.

The selection process of the signalized intersections went as follows: starting point was an overview of all signalized intersections in Lund. A first selection was made on the basis of the presence of pedestrians: only intersections with a moderate to high number of pedestrians were taken into consideration. Beside this, there should not be any particular infrastructural features that could influence the way pedestrians and motorized road users interact. An example is the presence of bicycle facilities at the intersection. Bicycles can depart in front of the motorized traffic instead of at the right side. Traffic accidents with right-turning traffic can be avoided in this way. In this case, pedestrians first interact with bicyclists when both road users depart at the start of the green time.

Five intersections were preselected and there has been tried to find a match between one of those intersections and a Belgian intersection in the environment of Hasselt. For increasing the number of data, a second Belgian intersection was selected by matching this intersection to the first Belgian intersection. This process resulted in the selection of the intersection in Leuven. At the intersection in Leuven, only behavioural studies have been conducted.

Because the intersections are not similar in all respects, the differences in interactions between the different intersections will be analysed as well.

5.2 Description of the selected intersections

In this section, there is a short description of the different selected intersections.

5.2.1 Tunavägen-Ole Römersväg/Warholmsväg (Lund, Sweden)

The first intersection is situated in the city of Lund in the southern part of Sweden. Lund is a university city with approximately 80.000 inhabitants (Lund, 2011). The intersection is close to the faculty of engineering of the University of Lund (Lunds Tekniska Högskola) with more than 8.000 students.

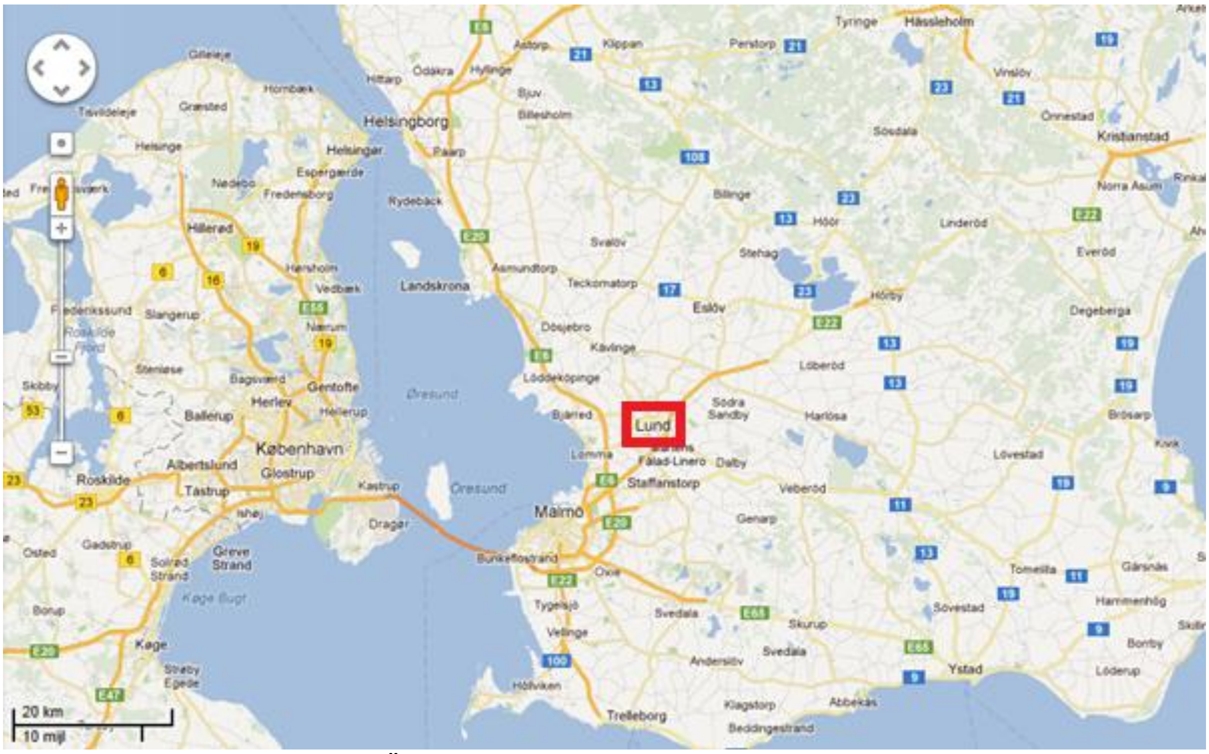

Figure 12: Location of Lund within the Öresund region

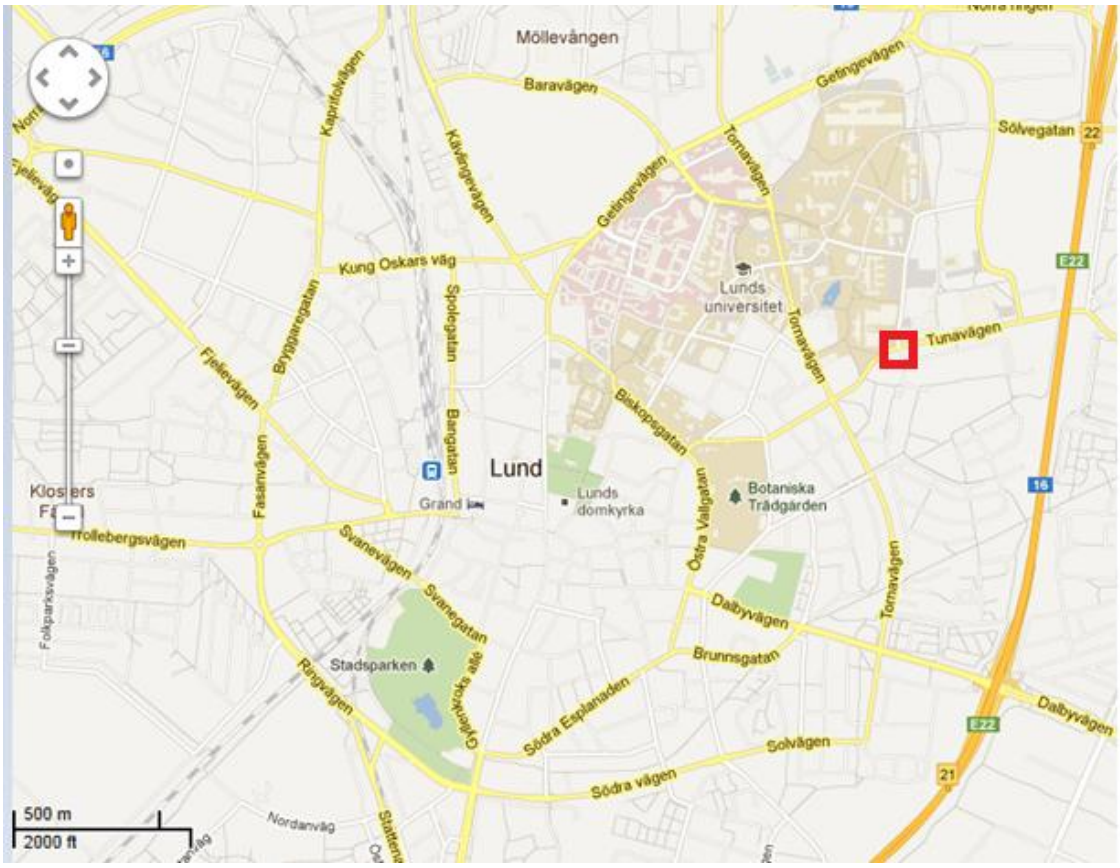

Figure 13: Location of the intersection within Lund

Figure 14: Orthophoto of the intersection in Lund

The intersection has four legs and one lane in each direction. On Tunavägen there is a left turn lane in two directions. To each direction, there are combined bicycle/walking tracks. Figures 15 until 19 show photographs of the intersection from different points of view.

Figure 15: Intersection Tunavägen-Ole Römersväg/Warholmsväg from different points of view

Traffic volumes

Tunavägen is the major road at this intersection. Nevertheless, the traffic volumes on each leg are relatively low. The traffic volumes are measured at those moments of the day where the pedestrian volumes are the highest. This means that there are other rush hours where the amount of car traffic is somewhat higher, but because of the lower number of pedestrians, there were less traffic interactions. Remarkable is the fact that the number of vulnerable road users is so high compared to the amount of motorized road users.

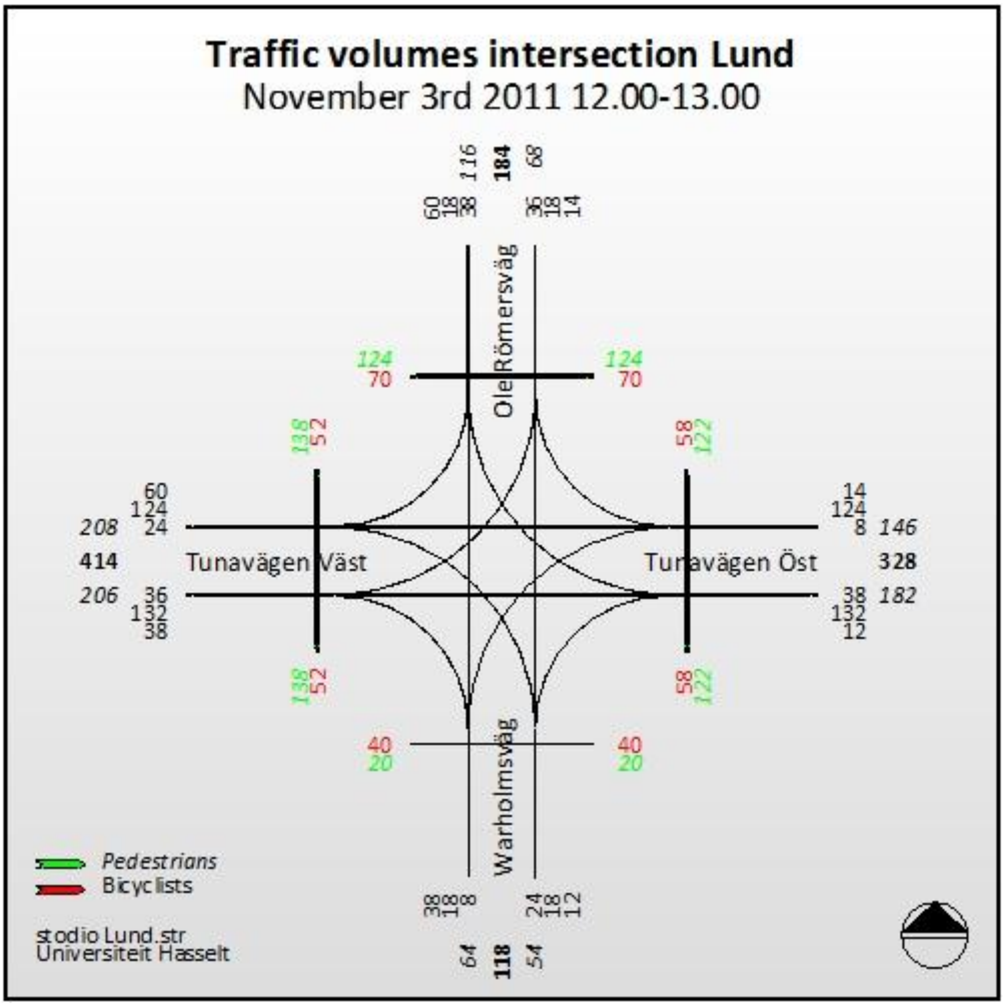

Figure 16: Traffic volumes intersection Lund

5.2.2 Diestersteenweg-Koorstraat/Kermtstraat (Hasselt, Belgium)

The second intersection is situated in the city of Hasselt in the eastern part of Belgium, in one of the outer villages belonging to this city. The intersection has a similar layout with respect to the number of lanes, but at the Belgian intersection, there are no bicycle crossings on the minor road. At the intersection in Lund, there is a small refuge island, while at the intersection in Hasselt, there is no refuge island. The major road is an arterial road from Hasselt to Diest.

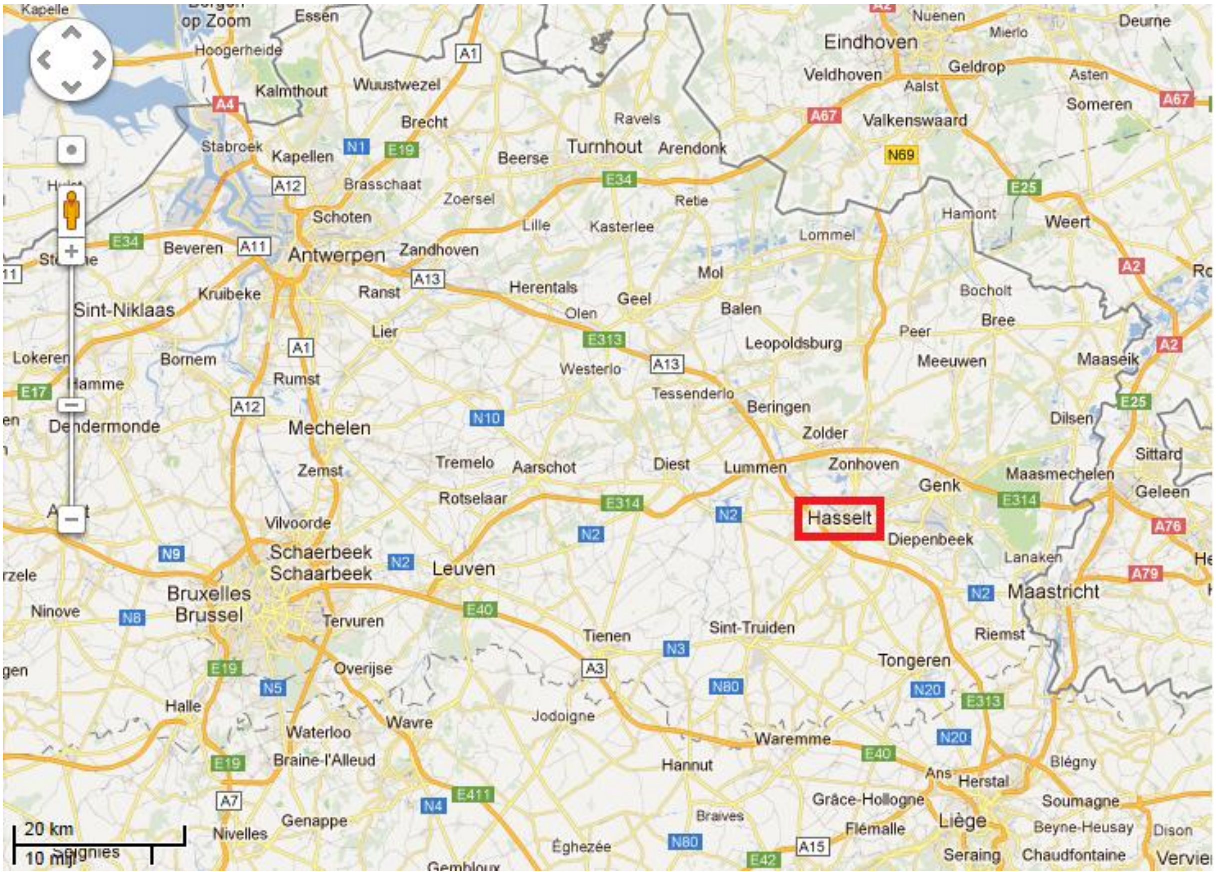

Figure 17: Location of Hasselt within the north-eastern part of Belgium

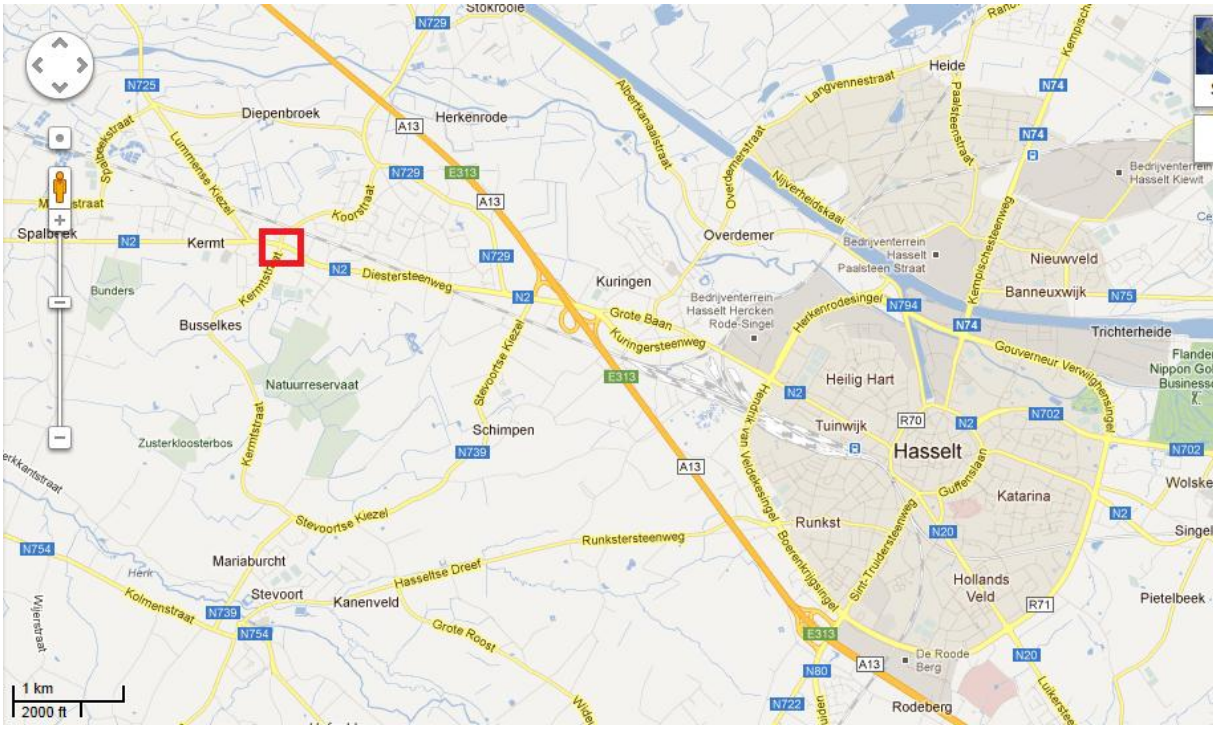

Figure 18: Location of the intersection in relation to the city of Hasselt

Figure 19: Orthophoto of the intersection in Hasselt

Figure 20: Intersection in Hasselt from different points of view

Traffic volumes

Compared to the intersection in Lund, the amount of motorized traffic is much higher and the amount of pedestrians and bicyclists is much smaller. Diestersteenweg is clearly the major road at this intersection with high traffic volumes. This measurement has been taken place between 4 PM and 5 PM, so there is a higher traffic volume from Hasselt westwards than in the other direction (see Figure 21).

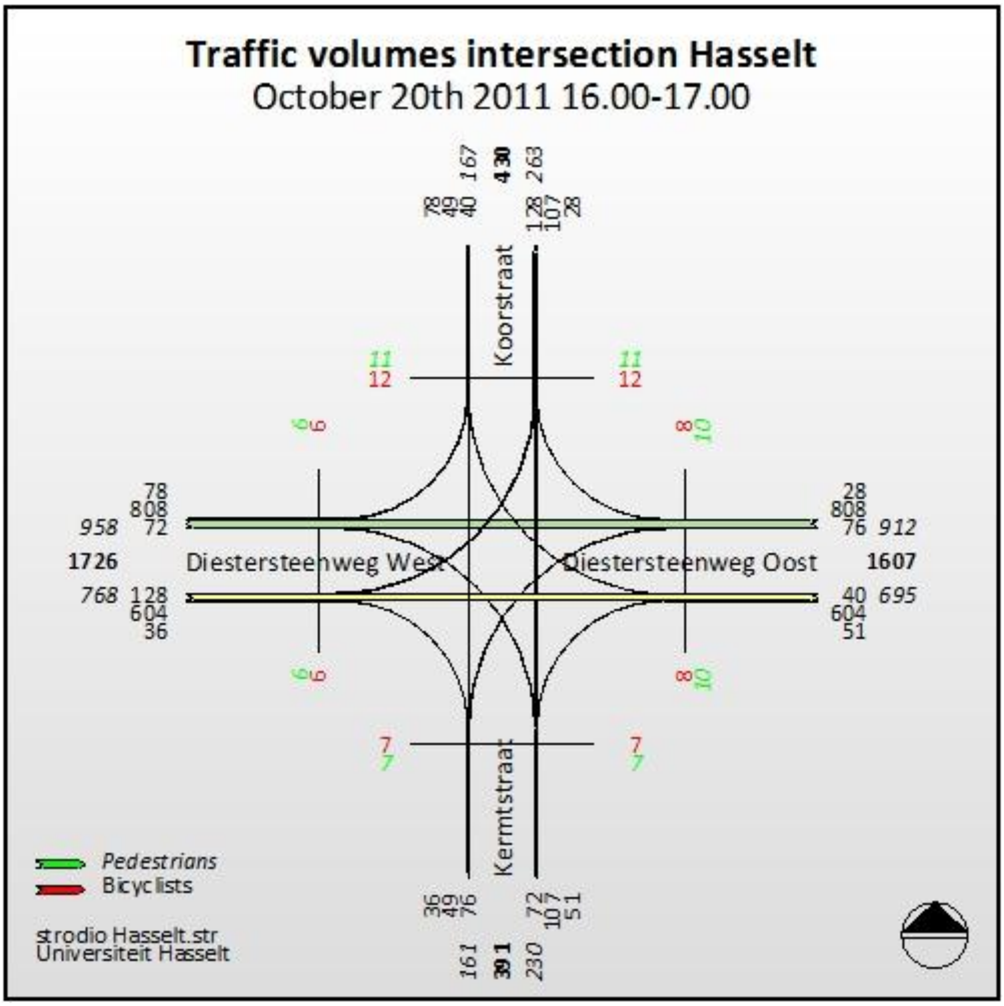

Figure 21: Traffic volumes intersection Hasselt

5.2.3 Diestsesteenweg-Borstelsstraat/Rerum Novarum (Leuven, Belgium)

The third intersection is situated in Leuven, a midsized city in the centre of Belgium. The intersection is located in Kessel-Lo, 2 kilometres from the central station. The major road of the intersection is an arterial road from Leuven to Diest.

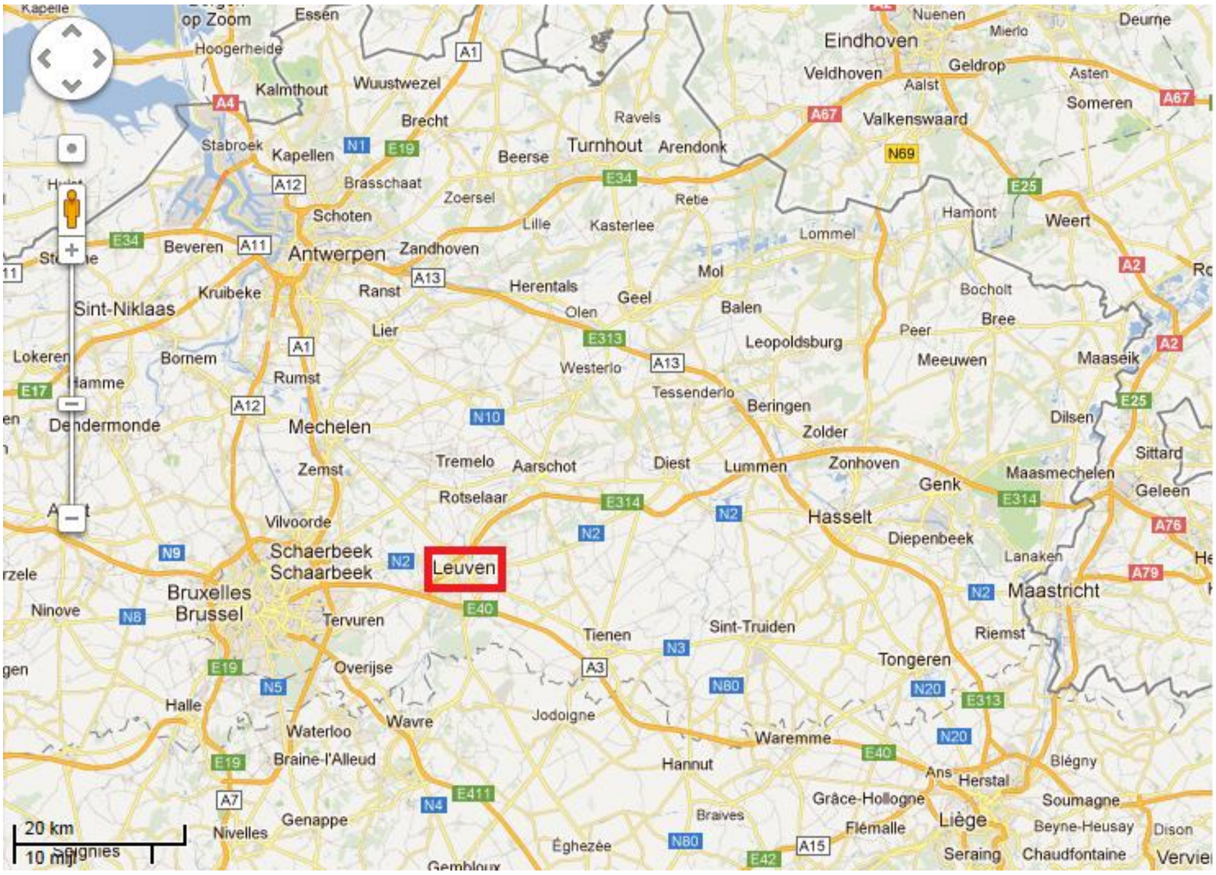

Figure 22: Location of Leuven within the north-eastern part of Belgium

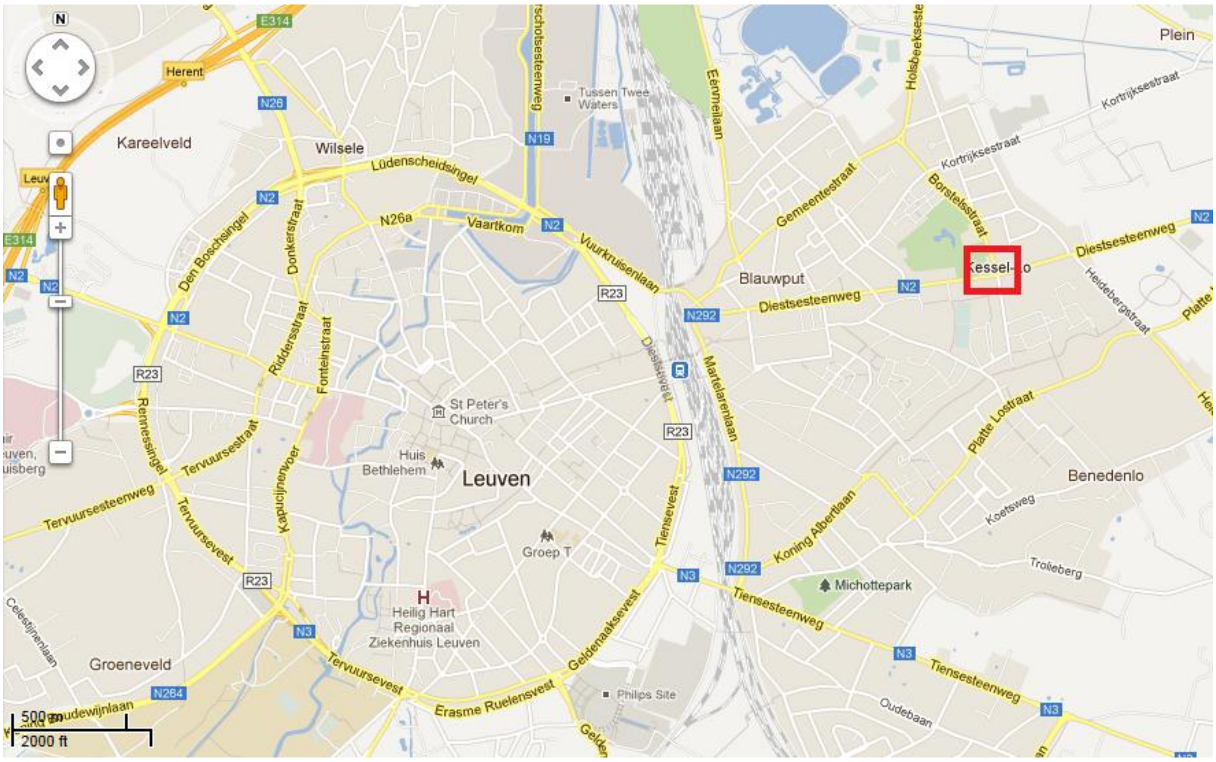

Figure 23: Location of the intersection within Leuven

Figure 24: Orthophoto of the intersection

Figure 25: Intersection in Leuven from different points of view

Traffic volumes

The amount of pedestrians and bicyclists is somewhat higher at this intersection than at the intersection in Hasselt. Nevertheless, there is a big difference between the intersection in Lund and the intersections in Hasselt and Leuven. The amount of traffic on Diestsesteenweg is clearly higher than the amount of traffic on the minor roads.

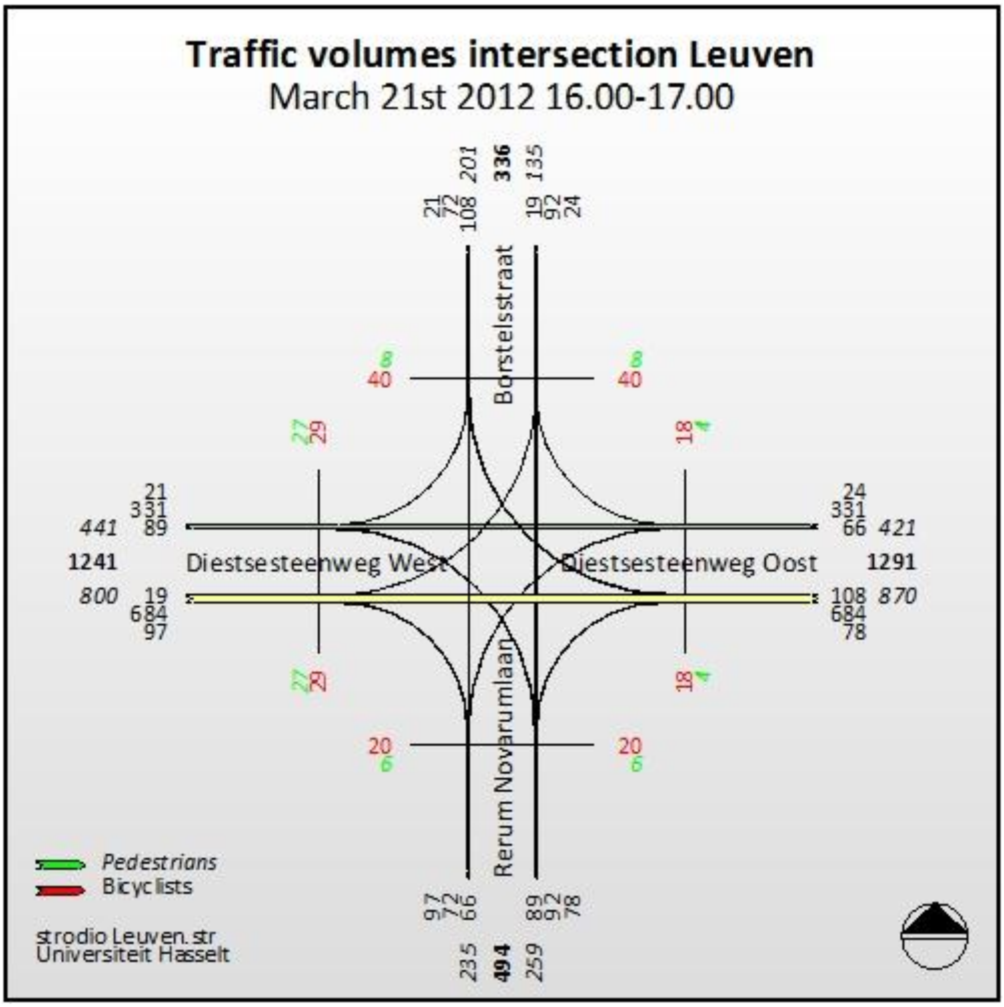

Figure 26: Traffic volumes intersection Leuven

5.3 Conflict observations

During 30 hours at two locations, a conflict observation has been conducted. The main topic of this master thesis is interactions between pedestrians and motorized vehicles. However, for a more complete image of the traffic safety state at these locations, all traffic conflicts have been observed, not only traffic conflicts with pedestrians involved.

The conflict observation form exists of the identification of the type of road users, the presence of secondary involved road users, gender and age of pedestrians. The following part exists of the conflict speed, distance to collision point and time to accident value. These variables are needed to decide how serious traffic conflicts are. The kind of evasive action, i.e. braking, swerving or acceleration, has been noted as well. A basic sketch of the intersection makes it possible to indicate where on the intersection the conflict has happened. A description of the causes of the event can indicate under which circumstances the traffic conflict has occurred. At the top of the observation form, important background information is added, like the location, the date and time when the traffic conflict occurred, the weather circumstances, whether the road surface is dry or wet at the time of the conflict and the number of the traffic conflict.

5.4 Behavioural observations

5.4.1 Topics behavioural observations

When studying traffic interaction between motor vehicles and pedestrians, there are several important topics that have to be taken into account.

- First and foremost, signal compliance is important. As described in the literature study, road users not only interact with other road users, but also with traffic signals. This interaction weakens the expectancy of other road users. There are much fewer interactions, but if there is an interaction, it is likely to be a more severe interaction.
- Communication between road users is another important issue. By using direction lights and making eye contact with other road users, one can indicate ones intention.
- Yielding is a third important aspect. Pedestrians have priority when respecting traffic signals. Car drivers have to yield. However, this is not always the case Pedestrians walking against red are expected to yield to motor vehicles having green signal.

These three topics are especially important when studying traffic interactions between pedestrians and motorized road users. Correct yielding behaviour and traffic light compliance avoid serious traffic conflicts between pedestrians and motorized road users. However, if one of them is not complying with traffic signals or not yielding, then there is a possibility of traffic conflicts and even traffic accidents. Looking behaviour and use of directional lights are a way for communication between pedestrians and motorized road users and are necessary to be able to compensate for the wrong decisions that the other party has made. For example, if a car driver is not yielding, the pedestrian who turns his head prior to crossing can observe an approaching car using his directional lights. He can anticipate and decide to not cross before the car driver notwithstanding his right to cross first. Looking behaviour is also an important feature in the behavioural sequence model, in the process of searching and detecting other road users (Snyder and Knoblauch, 1971). Adequate looking behaviour is necessary to be able to yield to pedestrians. Prior to turning, the car driver should make sure that there is no crossing pedestrian.

Beside these three topics, there are other types of information that could be of importance. In literature, it has been shown that there are differences in traffic behaviour related to age and gender. That is why age and gender of the involved road users have been added to the observation list. Another variable that has been added to the observation list is the time of arrival: who is first. In case the pedestrian is first, then there could be a different yielding pattern than in case the car driver would be first. Because it has been found in literature that pedestrian behaviour is influenced by the presence of other pedestrians, a variable "number of pedestrians" has been added. Last but not least, the observation is pedestrian-driven. This means that each pedestrian is included in the observation, but only motor vehicles that interact with pedestrians. The operationalization that has been described above has been used to decide whether or not there was a traffic interaction.

In the following paragraph, the different variables and parameters are described.

5.4.2 Observation Form

The observation form exists of the following variables:

- Number of pedestrians (1/>1)
- Presence of a car (0/at least 1)
- Gender pedestrian (man/woman)
- Age pedestrian (child (0-17 years old)/young (18-30 years old)/middle (31-65 years old)/old (65+))

This classification is somewhat subjective, because it is not possible to be certain about the age of persons when observing. However, this classification gives an indication, given the presumption that overestimation and underestimation are equally likely.

- Gender car driver (man/woman)
- Age car driver (young (18-30 years old)/middle (31-65 years old)/old (65+))
- Arrival (pedestrian arrives first/motor vehicle arrives first)

The time of arrival has been operationalized as the time that the intersection is entered. For the car driver, the point of entry is behind the stop line of the traffic light. For the pedestrian, the point of entry is at the entrance of the pedestrian crossing.

- Yielding pedestrian (yielding/not yielding)

In case of violating traffic signals, pedestrians who interact with motor vehicles should yield to motor vehicles having green signal.

- Yielding car driver (yielding early/yielding late/not yielding)

Yielding by car drivers has been divided in two possible ways: yielding early and yielding late. If car drivers are yielding early, then pedestrians don't have to alter their behaviour because they have the idea that the car is not yielding. Yielding late means that pedestrians alter their behaviour because they have the idea that the car is not yielding, while he does so at the last moment. In case of not yielding at all, the car driver passes before the pedestrian.

- Traffic light pedestrian (green/red)
- Traffic light car driver (green/yellow/red)
- Head turning pedestrian (yes/no)

The pedestrian should move his head towards the conflicting direction prior to crossing the road in order to make sure that there is no potentially dangerous situation. Pedestrians looking down at the ground and looking to other directions are categorized as not head turning.

- Head turning car driver (yes/no)
- Use of direction lights (yes/no)

Most of the variables in this observation list are dichotomous variables with only two possible values. To make it possible to do quantitative analyses, it is necessary to standardize qualitative interaction characteristics.

5.5 Practical organisation

In October 2011, the largest part of the data collection for this research project has been executed. The first half of October, the Swedish intersection was observed. The second half of October, the Belgian intersection was observed. Because of weather conditions, one observation day in Sweden had to be executed after the two-week stay in Belgium. The observations took place during daytime with dry weather conditions. This is for eliminating effects from darkness on interaction behaviour. Visibility in dark conditions is different from visibility during daytime. This is why most observations took place between 8.30 and 17.00. The observations only took place on weekdays, but no distinction was made with regard to special days of the week. The effect of which days of the week the observations take place is assumed to be negligible.

In total, this sample exists of 24 hours of behavioural observations, executed on three different locations in Lund, Hasselt and Leuven. The observations in Lund and Hasselt are executed in order to make a link with the conflict observations at these intersections. A number of traffic conflicts between pedestrians and motorized road users have taken place. These traffic conflicts have been preceded by behavioural factors like the speed prior to the traffic conflict, looking behaviour of the pedestrian and the car driver, red light violation and use of directional lights. This raises the question about the occurrence of these behavioural factors in normal traffic interactions between pedestrians and motorized road users. To increase the amount of information, red signal compliance and looking behaviour of pedestrians has also been recorded without the presence of a traffic interaction. In other words, the observations have been pedestrian-driven. In order to increase the data set, additional behavioural observations have been executed at an intersection in Leuven.

5.6 Statistical analysis of categorical data

Most of the data that have been collected during the behavioural observations are categorical data. Man or woman, yielding or not yielding, walking against red or not walking against red, et cetera. In order to find an answer on the research questions related to the behavioural observations, it is necessary to investigate the link between different variables. For this purpose, there exist different statistical methods. In this thesis, the chi-square test, Cramer's V, Fisher's Exact test, odds ratio and multiple logistic regression will be used. In the following paragraphs, each of these methods will be explained shortly. The examples that are used for this chapter make use of fictional data, but comparable topics as in the behavioural observations are discussed.

5.6.1 Chi-square test

The chi-square test is used to test whether two variables are independent. For example, in the literature it has been shown that males are more likely to commit red light violations than females. With the chi-square test it is possible to test whether this finding is supported by the collected data for this research project. The null hypothesis is independency of the two variables. If the null hypothesis is rejected, then there is statistical evidence for an association between two categorical variables. The expected values in each cell should be equal to or more than 5 (McClave et al., 2006).

Example 1

The null hypothesis is independency between gender and red light violation. In a perfectly independent situation, there are just as many males as females respecting red signals.

	Respecting traffic signal	Violating traffic signal	Total
Males	25	25	50
Females	25	25	50
Total	50	50	100

Table 1: Example observed values under independency

In this example, there are 50 men and 50 women in the sample. Half of them are respecting the traffic signals, and half of them is violating. Is there is no dependency at all between gender and red light violation, it is possible to fill in the cells only by looking at column totals and row totals and by adding all row or all column totals.

The expected value for a cell, for example the number of males respecting the traffic signal, can be computed as follows:

$$\hat{\mathrm{E}}(nij) = \frac{(row\ total) * (column\ total)}{Sample\ total}$$

- where n_{ij} is the number of observations in row i and column j

Equation 1: Computation of expected values

The row total is 50, the column total is also 50 and the sample total equals 100. Thus, the expectancy is that 50*50/100=25 males will respect traffic signals.

In this example, 50 per cent of the males and 50 per cent of the females are violating traffic signals. Also, 50 per cent of the sample consists of males and 50 per cent of females. However, the expected value of the different cells can also be computed for any combination.

<u>Example 2</u>

The number of persons respecting traffic signals in this example is not exactly the same as the number of violations and the number of males is not exactly equal to the number of females. Let us look at the expected values if we know that there are 100 observations, 60 males and 40 females, while there are 70 persons respecting the traffic signal and 30 persons violating the traffic signal.

	Respecting traffic signal	Violating traffic signal	Total
Males	42	18	60
Females	28	12	40
Total	70	30	100

Table 2: example chi square test expected values

By using Equation 1: Computation of expected values, the following expected cell values can be computed.

$$\hat{E}(n11) = \frac{60 * 70}{100} = 42$$

$$\hat{E}(n12) = \frac{60 * 30}{100} = 18$$

$$\hat{E}(n21) = \frac{40 * 70}{100} = 28$$

$$\hat{E}(n22) = \frac{40 * 30}{100} = 12$$

If there would be no dependency at all between red light violation and gender, then there would be 42 males respecting the traffic signals, 18 males violating the traffic signals, 28 females respecting the traffic signals and 12 females violating the traffic signals.

However, the behaviour observations generated the following results:

	Respecting traffic signal	Violating traffic signal	Total
Males	50	10	60
Females	20	20	40
Total	70	30	100

Table 3: example chi square test observed values

Out of 60 males, 50 males respected the traffic signals and 10 violated the traffic signals. Out of 40 females, 20 respected the traffic signals and 20 violated the traffic signals. Intuitively, there are reasons to doubt the null hypothesis of independency between gender and red light violation. In this case, females seem to be more likely to violate the traffic signals. Half of them walked against red, while only 16,67% of the men in the sample violated traffic signals.

The chi-square test is based on a comparison between expected values for each cell and the values in the sample.

$$X^2 = \frac{\Sigma(Oij - \hat{E}\,ij)^2}{\hat{E}ij}$$

Equation 2: Chi-Square test

- where O_{ij} is the observed value in row i and column j
- where $\hat{E}_{ij}$ is the expected value in row i and column j

$$X^2 = \frac{[n_{11} - \hat{E}(n_{11})]^2}{\hat{E}(n_{11})} + \frac{[n_{12} - \hat{E}(n_{12})]^2}{\hat{E}(n_{12})} + \frac{[n_{21} - \hat{E}(n_{21})]^2}{\hat{E}(n_{21})} + \frac{[n_{22} - \hat{E}(n_{22})]^2}{\hat{E}(n_{22})}$$

$$X^2 = \frac{[50 - 42]^2}{42} + \frac{[10 - 18]^2}{18} + \frac{[20 - 28]^2}{28} + \frac{[20 - 12]^2}{12} = 12{,}698$$

High X^2-values indicate that the values in the sample are quite different from the expected values. If this X^2-value is higher than the critical X^2-value which can be consulted in a table, then the hypothesis of independency is rejected. There are several critical values, but most frequently used is the value where ($p \leq 0,05$). This value is written as $X^2_{0,05}$

The critical X^2-value is based on the degrees of freedom (number of rows-1)*(number of columns-1), in this case (2-1)*(2-1)=1. In this case, the critical chi-square value is 3,841.

As $X^{2>}$ $X^2_{0,05}$ (12,698>3,841), the null hypothesis has to be rejected (Mc Clave et al., 2006). This means that there is statistical evidence for an association between gender and red light violation.

In the next chapter, a lot of analyses have been conducted with the chi-square test.

5.6.2 Chi-square test with combined categories

In some cases, it is desirable to narrow the analysis. In the behavioural observations, there have been collected data about age. There are three age categories for motorized road users and four age categories for pedestrians. However, when conducting a chi-square test with the variables age and for example red light violation, then it is not possible to conclude whether eventual dependent relationships are due to a high amount of youth violations, or whether adults are most likely to violate red signals. In this case, it can be chosen to alter the categories, based on for example hypotheses about relationships found in literature. For example, older persons can be distinguished from the other age categories. In this case, the number of categories decreases from four to two. In the analyses for this research project, a chi-square test with combined categories has been used.

Example 3

The yielding behaviour of males and females have been observed on a pedestrian crossing.

	Yielding early	Yielding late	Not yielding	Total
Males	47	4	4	55
Females	30	7	8	45
Total	77	11	12	100

Table 4: example observed values yielding and gender

The largest group of car drivers is yielding early. There are only a few car drivers yielding late or not yielding at all. However, pedestrians tend to react and take evasive action both if car drivers yield late and if they do not yield at all. Therefore, both situations are unwanted. As there are so few observations in the categories "yielding late" and "not yielding", the chi-square test breaks down. As both "yielding late" and "not yielding" are unwanted traffic behaviours, we are interested in "yielding early" or "not yielding early". We group together the second and third categories and end up with the following table:

	Yielding early	Not yielding early	Total
Males	47	8	55
Females	30	15	45
Total	77	23	100

Table 5: example observed values partial chi square test

In this case, the expected values of each cell are more than 5 and thus, Pearson Chi Square can be used. In this example, there is a significant association between gender and yielding behaviour. $X^{2}> X^{2}_{0,05}$ (4.954>3.841), using the same computation method as above.

5.6.3 Cramér's V

The chi-square test can be used to test whether there is association between two categorical variables. However, the strength of the association is not addressed by this statistical test. Chi-square values will increase when the sample size increases. That is why this value should be standardized in order to eliminate the effect of sample size. In case of binary variables, the Cramér's V coefficient can be used to compute the strength of the association between these variables. This value ranges from 0 to 1 (Crewson, 2006).

Cramér's V= $\sqrt{X^2/N(k-1)}$

- where k is the lowest value of number of row or the number of columns.

Example 4

Let us assume that all men in the sample respected traffic signal and all women violated traffic signal.

	Respecting traffic signal	Violating traffic signal	Total
Males	50	0	50
Females	0	50	50
Total	50	50	100

Table 6: Table with extreme dependency

Under the assumption of independence, one should expect 25 males respecting and 25 males violating traffic signal, and the same numbers for females. This value gives the highest possible chi-square value, which equals

$$X^2 = \frac{[50-25]^2}{25} + \frac{[0-25]^2}{25} + \frac{[0-25]^2}{25} + \frac{[50-25]^2}{25} = 100$$

Cramér's V equals √100/100(2-1)=1

However, if the row totals and column totals are not equal, the maximum Cramér's V cannot be 1, but somewhat lower than 1.

Example 5

	Respecting traffic signal	Violating traffic signal	Total
Males	25	25	50
Females	25	25	50
Total	50	50	100

Table 7: Table with extremely independent values

In this situation, the observations are distributed equally among the different cells. The observed values equal the expected values.

$$X^2 = \frac{[25-25]^2}{25} + \frac{[25-25]^2}{25} + \frac{[25-25]^2}{25} + \frac{[25-25]^2}{25} = 0$$

Cramér's V equals √0/100(2-1)=0.

In most occasions, the Cramér's V will take a value somewhere between these extreme values. By comparing two Cramér's V values, the strength of the association of different variables can be compared .

Mostly, the Cramér's V has a value between these extreme values. For example, in example 2, the chi-square test statistic equals 12.698. Cramér's V then equals √12.698/100(2-1)=0.356.

The practical threshold for substantial association is often set to a Cramér's V of 0.10. Above 0.5, there is high association. Between 0.3 and 0.5, there is a moderate association. Between 0.1 and 0.3, there is a low association (Crewson, 2006).

5.6.4 Fisher's exact test

In case that one or more expected values is less than 5, it is not possible to use Chi Square tests in order to test for association. Instead, we must use another test that computes exact p-values instead of asymptotic p-values. For all possible tables, the probabilities can be computed by making use of the following equation:

$$P(n11) = \binom{row\ total\ 1st\ row}{n_{11}} \binom{row\ total\ 2nd\ row}{column\ total\ 1st\ column - n_{11}} / \binom{total}{column\ total\ 1st\ column}$$

Equation 3: Computation of exact p-values

- where n_{11} is the number of observations in the first row and the first column

The hyper geometric distribution is used for computing the chance for every possible contingency table. Equation 3 explains that the exact p-values are computed by taking into account the number of ways that a certain combination of values can be obtained in relation to the total number of different possibilities to construct a certain table.

When having a fixed row total and a fixed column total, the value of one cell in a table with two binary variables determines the value of all other cells. For example, in case of a column total of 4 in both columns and a row total of 4 in both rows, in case one knows that the first cell equals 3, one can determine the values of all other cells. The second cell will be 1 to obtain a row total of 4. The third cell will be 1 to obtain a column total of 4 in the first column. The fourth cell will be 3 to obtain a row total of 4 in the second row and a column total of 4 in the second column.

The chances of all possible contingency tables together sum up to 1 (Agresti, 2007).

<u>Example 6</u>

A scientist thinks that, when violating traffic lights, males are more likely to yield for oncoming vehicles than females. However, there are not so many cases where pedestrians violating traffic signals interact with conflicting vehicles. That is why it is not possible to use Pearson Chi-Square, but Fisher's Exact test is used instead.

In this example, we start with the observed values and compute the chance for obtaining this table. After that, all other possible tables are deduced by making use of the fact that one value in the table determines all other values, if there is a fixed row total and a fixed column total.

After behavioural observations, there are 9 cases where a pedestrian violated red light and got involved in a traffic interaction with a motorized vehicle. There are 4 men and 5 women. Out of 4 persons yielding, 3 were men. 1 female are yielding, 1 male is not yielding and 4 females are not yielding.

	Yielding	Not yielding	Total
Males	3	1	4
Females	1	4	5
Total	4	5	9

Table 8: Observed values example Fisher's Exact Test

$$\boldsymbol{P(n11)} = \binom{\mathbf{4}}{\mathbf{3}}\binom{\mathbf{5}}{\mathbf{1}}/\binom{\mathbf{9}}{\mathbf{4}}$$

Where $\binom{4}{3}$**=4!/(3! *1!)=**(4*3*2*1)/((1*2*3)(1)=4 or in general

$$\binom{N}{n} = \frac{N!}{n! * (N-n)!}$$

This equation indicates in how many ways n can be selected out of N.

P(n11)=0.159

We can construct similar tables in case that 0, 1, 2 and 4 males are yielding.

0 males yielding:

	Yielding	Not yielding	Total
Males	0	4	4
Females	4	1	5
Total	4	5	9

Table 9: Table with 0 males yielding

$$\boldsymbol{P(n11)} = \binom{\mathbf{4}}{\mathbf{0}}\binom{\mathbf{5}}{\mathbf{4}}/\binom{\mathbf{9}}{\mathbf{4}}$$

0 males yielding: P(n11)=0.040.

1 male yielding:

	Yielding	Not yielding	Total
Males	1	3	4
Females	3	2	5
Total	4	5	9

Table 10: Table with 1 male yielding

$$\boldsymbol{P(n11)} = \binom{\mathbf{4}}{\mathbf{1}}\binom{\mathbf{5}}{\mathbf{3}}/\binom{\mathbf{9}}{\mathbf{4}}$$

P(n11)=0.317

2 males yielding:

	Yielding	Not yielding	Total
Males	2	2	4
Females	2	3	5
Total	4	5	9

Table 11: Table with 2 males yielding

$$P(n11) = \binom{4}{2}\binom{5}{2} / \binom{9}{4}$$

P(n11)=0.476

4 males yielding:

	Yielding	Not yielding	Total
Males	4	0	4
Females	0	5	5
Total	4	5	9

Table 12: Table with 4 males yielding

$$P(n11) = \binom{4}{4}\binom{5}{0} / \binom{9}{4}$$

P(n11)=0.008

Now all possible contingency tables have been set up. The probabilities of all possible values for the first cell sum up to 1.

We can combine the probabilities of those cases where the number of males yielding is equal to or higher than the observed values. In this case, we add up 0.159 and 0.008 and this results in a Fisher's Exact value of 0.167. This means that the chance to observe 3 or 4 yielding males, out of four males, equals 16.7%. The conclusion is that there tend to be more men yielding than women do, but this difference is not statistically significant on a 95% confidence level (Agresti, 2007).

5.6.5 Residuals

By using Pearson's chi-square test, there is a test for association between an independent variable and a dependent variable. An example is the association between gender and red signal violation. However, when the chi-square test concludes that there is an association between two variables, the direction of the association can be unclear.

That is why it is useful to study residuals. For each cell, residuals can be computed to get a standardized value in order to estimate whether values are much higher or much lower than expected in case of independence. For large samples, the sample distribution of residual follows a standard normal distribution. Residuals with an absolute value which exceeds 1.96 indicate that for that specific cell, there is a significant difference between the observed value and the observed value under the assumption of independence (Agresti, 2007).

Residuals can be computed as follows:

$$Oij - Eij/\sqrt{Eij}((1-(row\ total/total))(1-(column\ total/total)))$$

Equation 4: Adjusted residuals

Referring back to example 2, the null hypothesis of independency between gender and red signal violation has been rejected. By analysing residuals, there is more information available about the nature of the association. These residuals indicate for each cell whether there is a significantly higher or significantly lower value than expected.

	Respecting traffic signal	Violating traffic signal	Total
Males	42	18	60
Females	28	12	40
Total	70	30	100

Table 13: Expected values

	Respecting traffic signal	Violating traffic signal	Total
Males	50	10	60
Females	20	20	40
Total	70	30	100

Table 14: Observed values

$$50-42/\sqrt{42}((1-(70/100))(1-(60/100)))=3.563$$

	Respecting traffic signal	Violating traffic signal
Males	3.563	-3.563
Females	-3.563	3.563

Table 15: Residual table

In this case, it has been proven that males are more likely to respect traffic signals than females (Agresti, 2007).

5.6.6 Odds ratio

Odds ratio is a measure that takes into account the odds of success of two different groups. This measure is computed by dividing the chance of success by the chance of failure in each of the two groups and then dividing the odds of success of group 1 by the odds of success of group 2.

$$\theta = \frac{\pi 1/(1-\pi 1)}{\pi 2/(1-\pi 2)}$$

Equation 5: Odds ratio

This odds ratio compares the odds of success of group 1 and group 2. If the odds of success of group 1 are much larger than the odds of success of group 2, then the odds ratio has a large positive number (much larger than 1). If the odds of success of group 2 are much larger than the odds of success of group 1, then the odds ratio has a small positive number (much smaller than 1, but still positive).

Referring back to example 2, we retake the table with observed values:

	Respecting traffic signal	Violating traffic signal	Total
Males	50	10	60
Females	20	20	40
Total	70	30	100

Table 16: Observed values for odds ratio

$$\theta = \frac{(50/60)/(10/60)}{(20/40)/(20/40)} = 5$$

In this example, the odds for males to respect traffic signals are 5 times the odds for females to respect traffic signals (Agresti, 2007).

5.6.7 Confounding factors

Some variables will mediate the relationship between two other variables. For instance, there could be a significant association between the country and red signal compliance. However, the question is whether this association can be explained by other variables. There could be more young people in the Swedish sample than in the Belgian sample and young people tend to commit red light violations more frequently. That is why both the association between country and red signal compliance and the association between age and red signal compliance should be analysed. By using logistic regression models, the effects of different factors can be taken into account simultaneously.

Logistic regression models

Logistic regression models are regression models that try to explain the probability of a certain outcome by one or more explanatory variables. As the probability only can take a value between 0 and 1, linear regression models can give problems. In some cases, there might be probabilities of over 100 per cent or even negative probabilities. The logit-link transforms possible outcomes between minus infinity and plus infinity to outcomes between 0 and 1.

$$logit(\pi(x)) = log\frac{\pi(x)}{1-\pi(x)} = \beta 0 + \beta 1x1 \,(+ \beta..x..)$$

Equation 6: Formula logistic regression model 1

The probability of a certain outcome x can be computed using the following formula:

$$\pi(x) = \frac{\exp(\beta 0 + \beta 1x1 + \beta..x..)}{1 + \exp(\beta 0 + \beta 1x1 + \beta..x..)}$$

Equation 7: Formula logistic regression model 2

If a parameter has a positive value, the presence of this parameter value has a positive effect on the outcome variable. If a parameter has a negative value, the presence of this parameter value has a negative effect on the outcome variable.

Fitting the model can be done by a statistical software package like SPSS that is used in this case.

Interpretation of logistic regression models

Each parameter gets a certain parameter value. In the case of binary variables, this means that the presence of a certain parameter value has a certain effect on the outcome variable. In the case of variables with more than two values, k-1 dummies are needed (Agresti, 2007).

<u>Example 7</u>

In a logistic regression model predicting red signal violation by gender and age, the intercept variable has a value of -1.05, gender has a value of 0.89 and age has values of -0.60, 1.15 and 0.35.

Gender has the values 1 (men) and 0 (women)

Age has the values 1 (children), 2 (young people), 3 (people between 30 and 65 years old) and 0 (older people).

Women and older people are reference categories.

The logistic regression model takes the following form:

$$logit(\pi(x)) = log\frac{\pi(x)}{1-\pi(x)} = \beta 0 + \beta 1men + \beta 2child + \beta 3young + \beta 4middle$$

Inserting the values described above, the formula looks as follows:

$$logit(\pi(x)) = log\frac{\pi(x)}{1-\pi(x)} = -1.05 + 0.89man + -0.60child + 1.15young + 0.35middle$$

If we compare men with women, we see that men will have a log odds ratio that is 0.89 higher than women. If we take the exponent of this value, we end up with the odds ratio that we are interested in. $\frac{\pi(x)}{1-\pi(x)}$ equals 2.435. This means that in this example, men have an odds ratio that is 2.435 higher than women to violate the traffic signal.

Software packages can provide standard errors, Wald statistics, Deviance, Pearson Chi Square tests and AIC Values to compare different models and test the goodness of fit.

- Wald statistics check whether a specific parameter is statistically significant by dividing the parameter values by their standard errors. These values have a standard normal distribution
- Deviance and Pearson Chi Square statistics test the Goodness of Fit of logistic regression models. A statistically significant Deviance or Pearson Chi Square statistic indicates a lack of fit. These statistics have a Chi Squared distribution
- AIC Values can be used to compare different models. This AIC value takes into account both the information that a specific model provides and the number of parameters. In this way, the best model is not necessarily the model with most parameters because there has been a correction for the complexity of models. The lower the absolute AIC value, the better.
- The deviance divided to the number of degrees of freedom is a value for estimating overdispersion. This value should be approximately 1. If this value is much higher than 1, there is an indication of overdispersion. Overdispersion means that the true variance, derived from the observed values, is higher than the assumed variance following the Bernouilli distribution that is equal to $(1-\pi)$.
- Type 3 tests estimate whether a categorical variable is significant as a whole. Categorical variables in other cases indicate a significant association of a certain category with regard to a reference category. For example, one can test whether young people violate the traffic signal more often than old people. Type 3 tests indicate the significance of a categorical variable without comparing to a certain reference category (Agresti, 2007).

5.6.8 Conclusion

When analysing categorical data in this research project, the following steps have been executed in order to get insight in the associations between variables.

1. Testing whether there is an association (chi-square test)
2. Testing the strength of the association (Cramér’s V)
3. Testing the direction of the association in each cell (residuals)
4. Testing the odds ratio
5. Testing for confounding factors by using logistic regression models

If there is no statistical evidence for association between variables, there is no need to test the strength of the association and the direction of the association. However, if the null hypothesis is rejected in the first step i.e. there is an association, then the other steps must be executed as well.

6 Data description

6.1 Speed measurement

The speed of 100 cars has been measured using a radar speed gun at both the intersection in Lund and the intersection in Hasselt in order to get an idea of the speed behaviour at both intersections. The speed has been measured for vehicles driving straight on on the major road, at the pedestrian crossing behind the intersection, in order to catch the highest speeds. It is not feasible to measure all cars in a queue, so only the speed of vehicles in free flow has been measured. This means that vehicles closely following other vehicles are not included in the measurements. No distinction has been made between vehicles starting from stationary and vehicles approaching the intersection during green time because of the very different way the traffic light installations work. The intersection in Belgian has no detection loops and a rather long green time, while the intersection in Sweden is a variable signalized intersection which has very different characteristics.

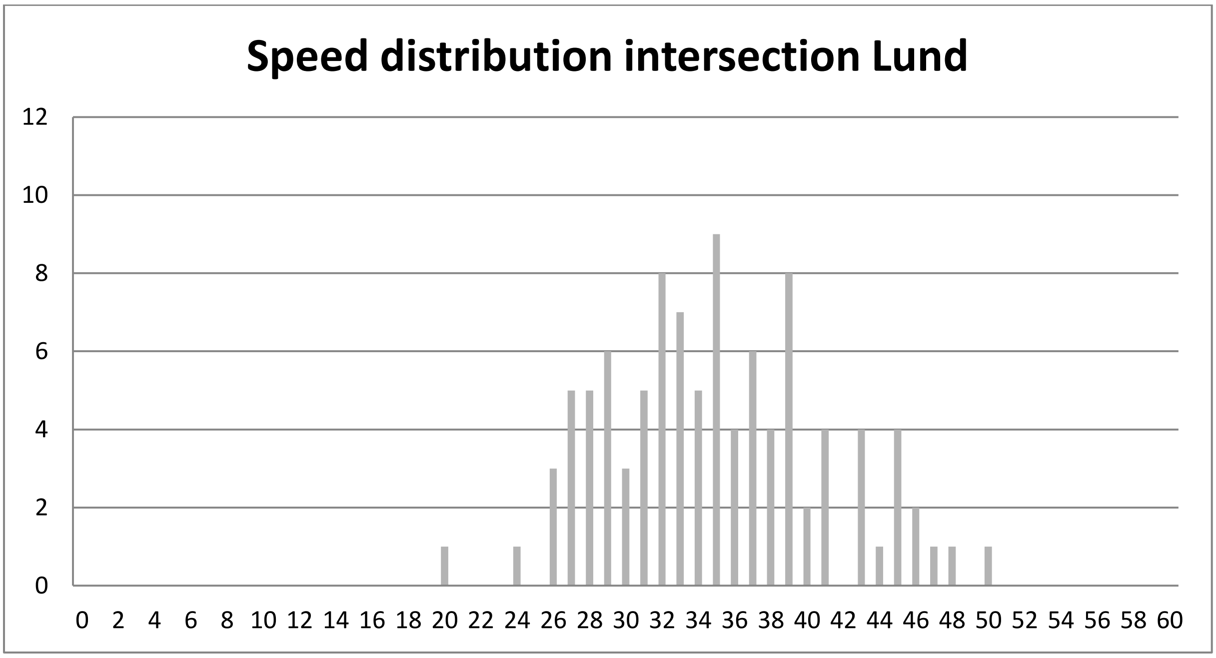

Table 17: Speed distribution intersection Tunavägen-Ole Römersväg, Lund (S)

The measured speed of the motorized vehicles driving straight on on the Tunavägen ranges from 20 to 55 kilometre an hour. The mean speed equals 35 km/h (SD=6.12 km/h). The speed that is not exceeded by 85 per cent of the vehicles (the V85) equals 41 km/h.

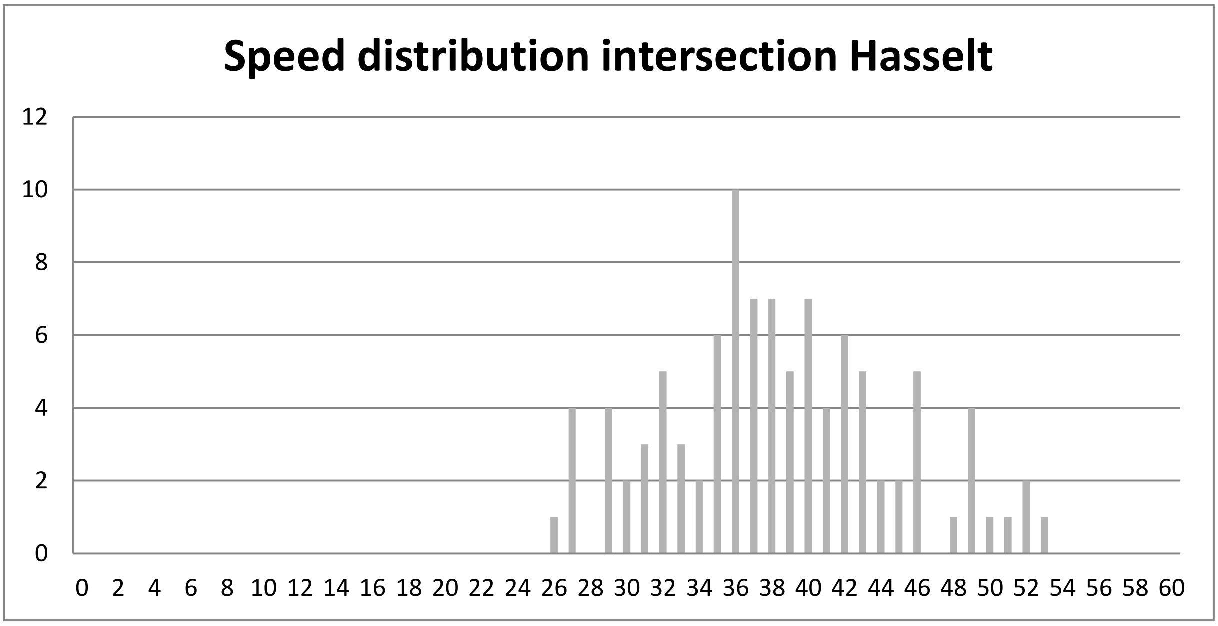

Table 18: Speed distribution intersection Diestersteenweg-Koorstraat/Kermtstraat, Hasselt (B)

The measured speed of the motorized vehicles driving straight on on the Diestersteenweg ranges from 26 to 53 kilometre an hour. The mean speed equals 38.41 km/h (SD=6.27 km/h). V85 equals 45,85 kilometre an hour.

The mean speed of the vehicles at the intersection in Hasselt seems to be somewhat higher than the mean speed of the vehicles at the intersection in Lund. Also the V85 seems to be higher.

To test the equality of means of two samples, the independent samples t-test can be used (McClave et al., 2006).

$$H_0: (\mu 1 - \mu 2) = 0$$

$$z = \frac{((\bar{x}1 - \bar{x}\,2) - 0)}{\sigma_{(\bar{x}1 - \bar{x}2)}}$$

Where: $\sigma_{(\bar{x}1-\bar{x}2)} = \sqrt{(\frac{\sigma_1^2}{n1} + \frac{\sigma_2^2}{n2})}$

If the absolute value of z exceeds 1.96, then the two means are significantly different on a 95 percent confidence level.

A confidence interval can be formed using the following equation:

$$\bar{x}1 - \bar{x}\,2 \pm 1.96 * \sigma_{(\bar{x}1 - \bar{x}2)}$$

The t-test for testing equality of means is performed using the statistical software package SPSS.

It has been proven that the mean speed at the signalized intersection in Lund is significantly lower than the mean speed at the signalized intersection in Hasselt, with a 95 per cent confidence interval of [-5,14;-1,68].

This means that vehicles driving straight on on the major road tend to approach the pedestrian crossing at a somewhat higher speed at the intersection in Hasselt than at the intersection in Lund.

6.2 Data exploration

In total, 594 traffic situations have been observed. In 172 situations, there was a traffic interaction between one or more pedestrians and a motorized road user.

In the sample, there are 194 groups of pedestrians, existing of two or more pedestrians, and 400 individual pedestrians. In the sample, there are 217 women (54,25%) and 183 men (45,75%). There are 34 children (8,5%), 151 young people (37,75%) , 115 people between 31 and 65 years old (28,75%) and 100 old people (25%) in the sample. 54 of the 172 motorized road users were female (31,4%), while 118 car drivers were male (68,6%). Out of the car drivers, 29 were young, 113 were between 30 and 65 years old and 30 were older than 65 (see table 19).

Variable	Descriptive stat
# Pedestrians	individual pedestrians=400, group = 194
Gender pedestrians	mals=217, female=183
Age pedestrians	children=34, young=151, middle=115, old=100
Gender car drivers	male=118, female=54
Age car drivers	young=29, middle=113, old=30

Table 19: Descriptive statistics

	One pedestrian	More than one pedestrian	Total
Lund	140	85	225
Hasselt	115	56	171
Leuven	145	53	198
Total	400	194	594

Table 20: Distribution of individual pedestrians and groups over the three locations

At the intersection in Lund, 140 individual pedestrians and 85 groups of pedestrians have been observed. In Hasselt, 115 individual pedestrians and 56 groups have been observed and in Leuven, 145 individual pedestrians and 53 groups have been observed (see table 24). It is important to note that, due to the high number of pedestrians at the intersection in Lund, one leg has been observed at a time. The observation period has been divided by 4 blocks of two hours, one block for each leg.

	No traffic interaction	Traffic interaction	Total
Lund	177	48	225
Hasselt	123	48	171
Leuven	122	76	198
Total	422	172	594

Table 21: Distribution of traffic interactions

There were in total 172 traffic interactions; 48 at the intersection in Lund, 48 at the intersection in Hasselt and 76 at the intersection in Leuven. In 177, 123 respectively 122 cases there were only pedestrians (see table 25). Again, the observations in Lund have been performed at one leg at the time. The observations in Hasselt and Leuven have been performed for the four legs simultaneously because of the lower number of pedestrians at these intersections compared to the intersection in Lund.

6.3 Accident data

6.3.1 Intersection Tunavägen-Ole Römersväg/Warholmsväg, Lund (Sweden)

For the intersection in Lund, detailed accident data is available via STRADA (Swedish Traffic Accident Data Acquisition). This database exists of both police data and hospital data. Between 1999 and 2011, 8 injury crashes have been reported. All of the traffic crashes resulted in slight injuries. One traffic crash was a single vehicle crash, there was one single bicycle accident during icy weather conditions. One accidents happened with a roller-skater and a car driver and one with a pedestrian falling down the road without others involved. In one situation, a bicyclist and pedestrians are involved. In three cases, there was an accident between a bicyclist and a car driver. On figure 27, there is an overview of the different traffic accidents. There is some uncertainty about the exact location of the traffic accidents. However, the total number of involved bicyclists, pedestrians and motorized road users is reported.

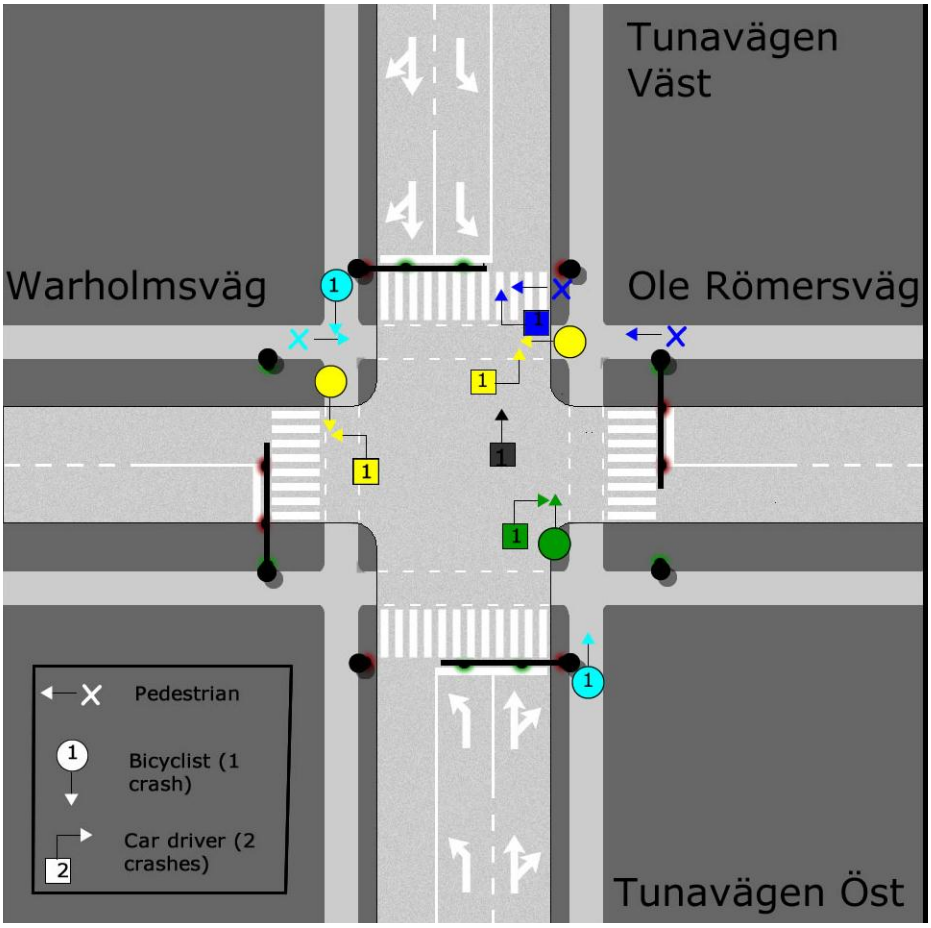

Figure 27: Overview traffic accidents Lund

Despite the fact that accident data always is underreported, the accident data at the intersection in Lund show that out of six reported injury crashes involving motorized road users, three traffic accidents occurred between car drivers and bicyclists. Bicyclist conflicts were also the most prevalent traffic conflicts at this intersection.

6.3.2 Intersection Diestersteenweg-Kermstraat/Koorstraat, Hasselt (Belgium)

For the intersection in Hasselt, police accident data from the police station in Hasselt was available from 2008. Between 2008 and 2011, 4 accidents have been reported. 2 crashes were injury crashes. In no traffic crash, vulnerable road users were involved. There were 2 single vehicle crashes and 2 crashes happened while one of the cars was violating the red signal.

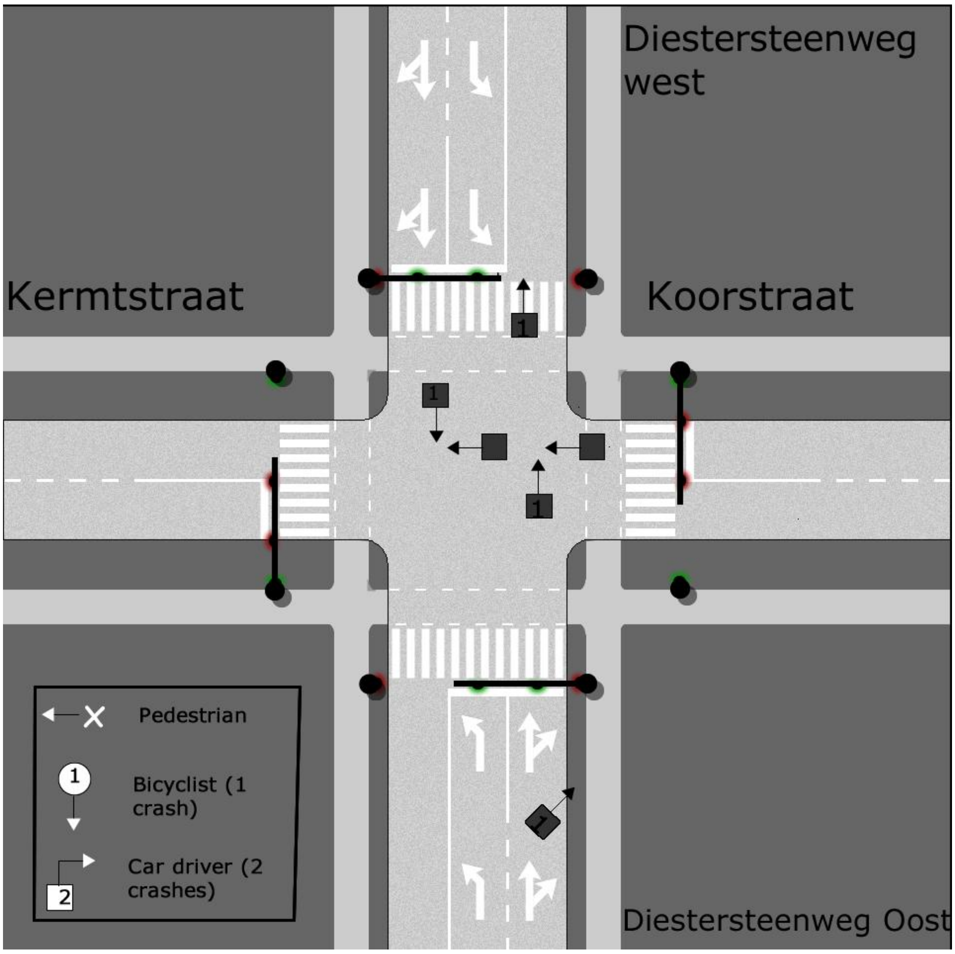

Figure 28: Overview traffic accidents Hasselt

Remarkable is the fact that all crashes happened during non-peak hours. Three out of four crashes happened during night.

7 Results

7.1 Conflict observations

During the conflict observations in Lund and Hasselt, 48 traffic conflicts have been observed. In this chapter, all traffic conflicts will be discussed briefly. After this first part, the focus will be on traffic conflicts involving pedestrians. Traffic conflicts with pedestrians will be discussed more in detail because of the focus of traffic conflicts between pedestrians and motorized road users in this research project.

For both the Swedish and the Belgian intersection, data has been collected about red light violation, head movement, yielding and use of directional lights. In this paragraph, the process leading to each traffic conflict between a pedestrian and a motorized road user will be analysed. What are the circumstances under which these traffic conflicts occur? Are those circumstances also present at normal traffic interactions, or are these circumstances different, thus leading to dangerous situations?

In a few examples concerning traffic conflicts between pedestrians and motorized road users, the pedestrians are already in the conflict zone. The motorized road user sometimes has a higher time to accident value. According to the Swedish Traffic Conflict Technique, the least severe time to accident value should be taken. However, for traffic conflicts between pedestrians and motorized road users, the validity of traffic conflicts increases if the most severe time to accident value is taken instead (Shbeeb, 2000), as described in chapter 4. All traffic conflicts that are severe according to Shbeebs method are taken into consideration.

7.1.1 Traffic conflicts at the Swedish intersection

There have been conflict observations at the Swedish intersection (Tunavägen-Ole Römersväg/Warholmsväg) during 30 hours between October 5th and October 12th. In total, 35 traffic conflicts have been observed. Of these traffic conflicts, there were 9 traffic conflicts involving pedestrians. In this paragraph, a general image of the traffic conflicts will be described first. After that, a more detailed analysis of the traffic conflicts with pedestrians will follow.

On figure 29, there is an overview of all traffic conflicts where at least one motorized road user was involved. Most traffic conflicts happen when motorized road users turn to the right (13 traffic conflicts) or turn to the left (5 traffic conflicts) from Tunavägen to Warholmsväg or Ole Römersväg. There were four traffic conflicts with pedestrians and vehicles driving straight on.

Car-bicyclist conflicts

Of the 35 traffic conflicts that happened during the 30 hour observation period at the intersection Tunavägen-Ole Römersväg/Warholmsväg, 16 traffic conflict occurred between bicyclists and motorized road users. Frequently, the bicyclist is located behind the motorized road user waiting for the traffic signal (see figure 29). At the moment the car driver turns to the right, the bicyclist passes the car driver and the two road users are on a collision course. In most situations, it is the car driver that takes evasive action.

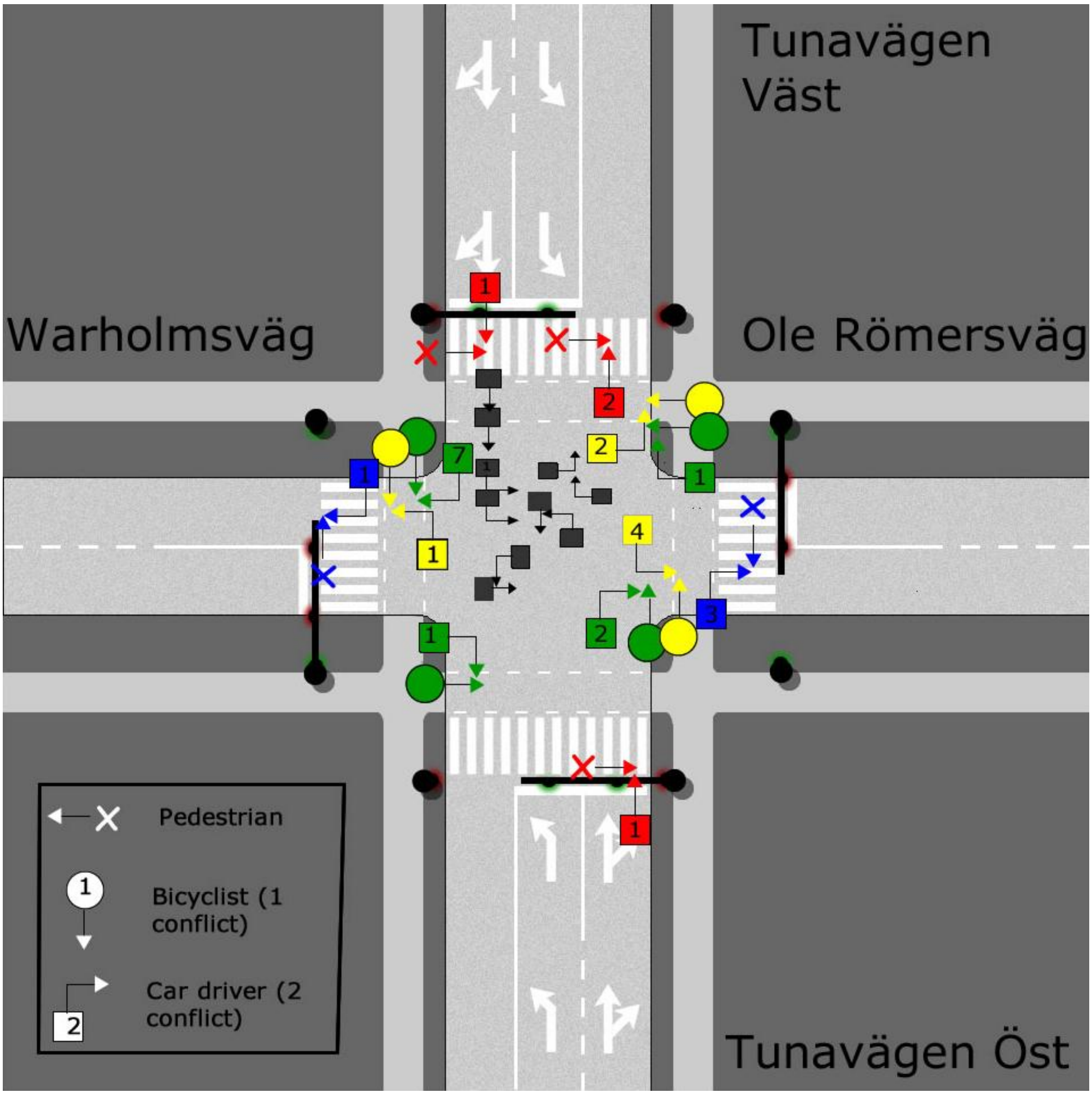

Figure 29: Overview of traffic conflicts intersection Lund

Car-car conflicts

Five traffic conflicts that happened during the observation period at the intersection Tunavägen-Ole Römersväg/Warholmsväg occurred between two motorized vehicles (car-car, car-bus or car-lorry). All traffic conflicts between motorized road users occur when one of the vehicles is turning to the left or to the right. Further, there is no clear pattern in these conflicts (see figure 29). In one of the conflict situations, there is a secondary involved bicyclist for whom the first car brakes. The second car is following the first car and has to brake suddenly.

Conflicts between vulnerable road users

The remaining five traffic conflicts occur between two bicyclists or between a bicyclist and a pedestrian. Mostly there is lack of communication, the pedestrian tends not to see the bicyclist approaching and moves unexpectedly. The bicyclist tends to have certain expectations of the pedestrian’s behaviour. If these expectations do not come out, there will be a potentially dangerous situation.

Traffic conflicts involving pedestrians

The traffic conflicts involving pedestrians are discussed more in detail. Each traffic conflict is discussed in the following way: first, there is a standard table with information about the circumstances under which the traffic conflict occurs. Second, there is a sketch of the intersection where the position of both road users is indicated. Third, there is a short discussion about special behavioural factors of both road users that occurred prior to or during the traffic conflict.

1. Tunavägen Öst-Ole Römersväg

	Road user 1	Road user 2
Type	Car	Pedestrian
Manoeuvre	Turning right	Crossing
Evasive action	Braking	None
Conflict speed	20 km/h	NA
Conflict distance	4 m	NA
TA	0.7 s	NA
Relevant road user	X	
Seriousness	Serious conflict	Serious conflict
Signal phase	Green	Green
View	Obstructed by car ahead	Good
Arrival at the conflict zone	2nd	1st
Communication	Directional light	Making eye contact with driver
Location of the pedestrian		On the pedestrian crossing
Gender pedestrian		Male
Age pedestrian		Young

Table 22: Description conflicts Lund conflict 1

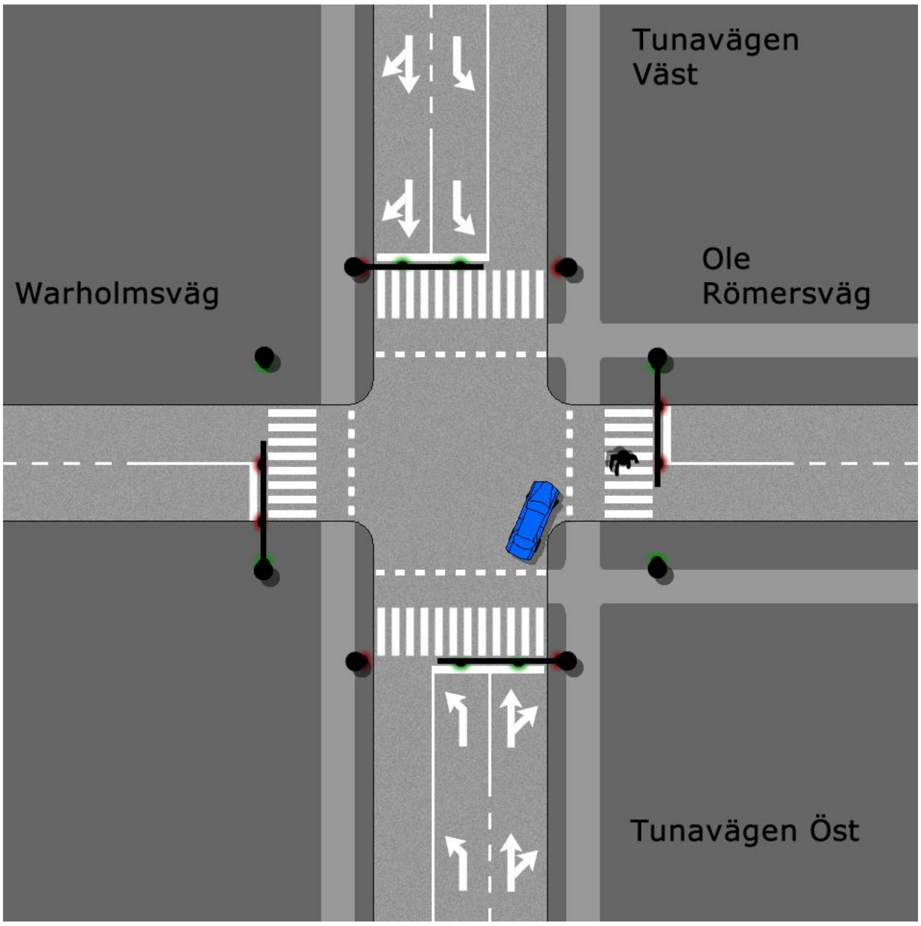

Figure 30: Situational sketch Lund conflict 1

Behavioural characteristics

Both the pedestrian and the car driver had green light. The pedestrian departed somewhat earlier than the car drivers. Because the pedestrian was crossing from west to east, he had a good sight on the oncoming vehicles. However, the car driver turning to the right was obstructed in his view on the pedestrian crossing because he was the second car in a queue. The first car was a larger 4x4 car driving straight on. Nevertheless, he accelerates and does not recognize the pedestrian before turning to the right. He stops accelerating and brakes somewhat in order to avoid a crash. The traffic situation was quiet, there was a small queue existing of three vehicles waiting for the traffic signals.

After the conflict, the car passed just after the pedestrian. There was a very limited time margin. The pedestrian looks to the right on the moment that the car turns to the right. The car driver used his directional lights.

The pedestrian entered the pedestrian crossing long before the car driver did. It is likely that the pedestrian expected to cross safely.

2. Tunavägen Öst

	Road user 1	Road user 2
Type	Car	Pedestrian
Manoeuvre	Straight on	Crossing
Evasive action	Braking	Braking
Conflict speed	10 km/h	5 km/h
Conflict distance	1 m	2 m
TA	0.4 s	1.4 s
Relevant road user	x	
Seriousness	Serious conflict	Slight conflict
Signal phase	Green	Red
View	Good	Good
Arrival at the conflict zone	2nd	1st
Communication	None	None
Location of the pedestrian		On the pedestrian crossing
Gender pedestrian		Male
Age pedestrian		Middle

Table 23: Description conflicts Lund conflict 2

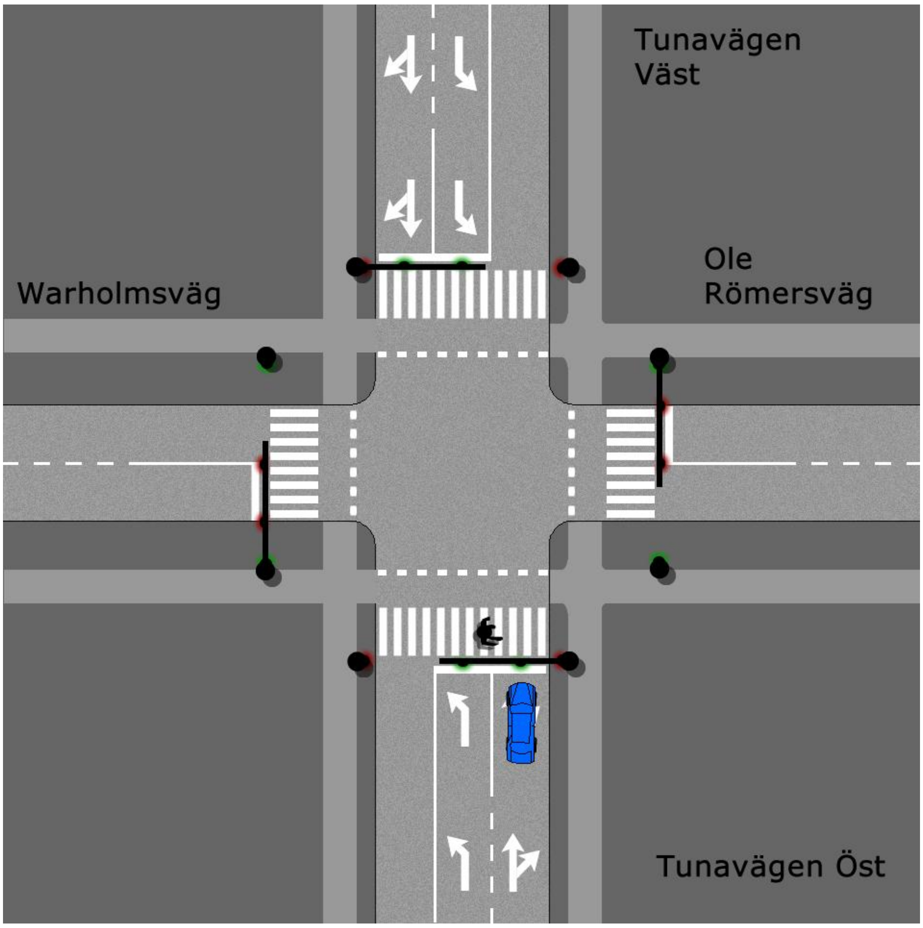

Figure 31: Situational sketch Lund conflict 2

Behavioural factors

This traffic conflict is caused by red light violation. The pedestrian expects to be able to cross in time, but then, all of a sudden the traffic light for the oncoming vehicle turns green. The car driver cancelled his acceleration. This means that he did not recognize the presence of the pedestrian before accelerating, or he did not expect the pedestrian to continue his crossing.

This traffic situation is an example of lack of communication between the car driver and the pedestrian in that sense that there is a lot of uncertainty about the other's intentions. The car driver is interacting with the traffic signal. The pedestrian does not interact with the traffic signal. He does not even look at the traffic signals of the conflicting road, but only focuses on the stationary car. Notwithstanding the fact that the pedestrian violated red signals, the car driver let him cross first.

3. Tunavägen Väst

	Road user 1	Road user 2
Type	Car	Pedestrian
Manoeuvre	Straight on	Crossing
Evasive action	Braking	Braking
Conflict speed	35 km/h	7 km/h
Conflict distance	5 m	2 m
TA	0.4 s	1.1 s
Relevant road user	x	
Seriousness	Serious conflict	Slight conflict
Signal phase	Green	Red
View	Good	Good
Arrival at the conflict zone	2nd	1st
Communication	None	Looking at the oncoming car
Location of the pedestrian		In front of the pedestrian crossing
Gender pedestrian		Male
Age pedestrian		Middle

Table 24: Description conflicts Lund conflict 3

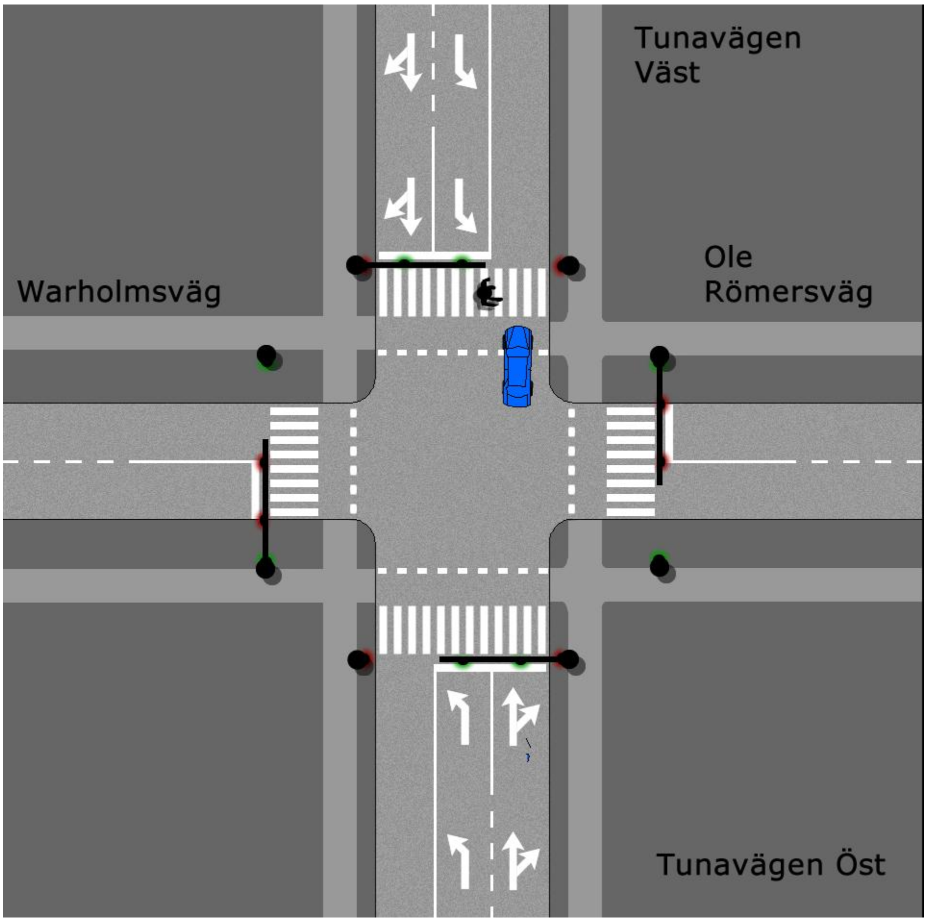

Figure 32: Situational sketch Lund conflict 3

Behavioural factors

This traffic conflict is caused by the fact that the pedestrian was violating the traffic signal. Although this is no serious conflict, there is still an unwanted situation. The car driver is not aware about the behaviour of the pedestrian. The use of the vehicle horn is an indicator of the fact that the situation was not expected by the car driver. Seen from the perspective of the pedestrian, it looks like the crossing is quite well-planned. The pedestrian was constantly looking to both directions prior to crossing the street. It looks like he intended to stop for the oncoming vehicle.

4. Tunavägen Väst

	Road user 1	Road user 2
Type	Car	Pedestrian
Manoeuvre	Straight on	Crossing
Evasive action	Braking	None
Conflict speed	30 km/h	NA
Conflict distance	10 m	NA
TA	1.2 s	NA
Relevant road user	x	
Seriousness	Serious conflict	Serious conflict
Signal phase	Green	Red (Green when starting)
View	Good	Looking to the ground
Arrival at the conflict zone	2nd	1st
Communication	None	None
Location of the pedestrian		On the pedestrian crossing
Gender pedestrian		Female
Age pedestrian		Old

Table 25: Description conflicts Lund conflict 4

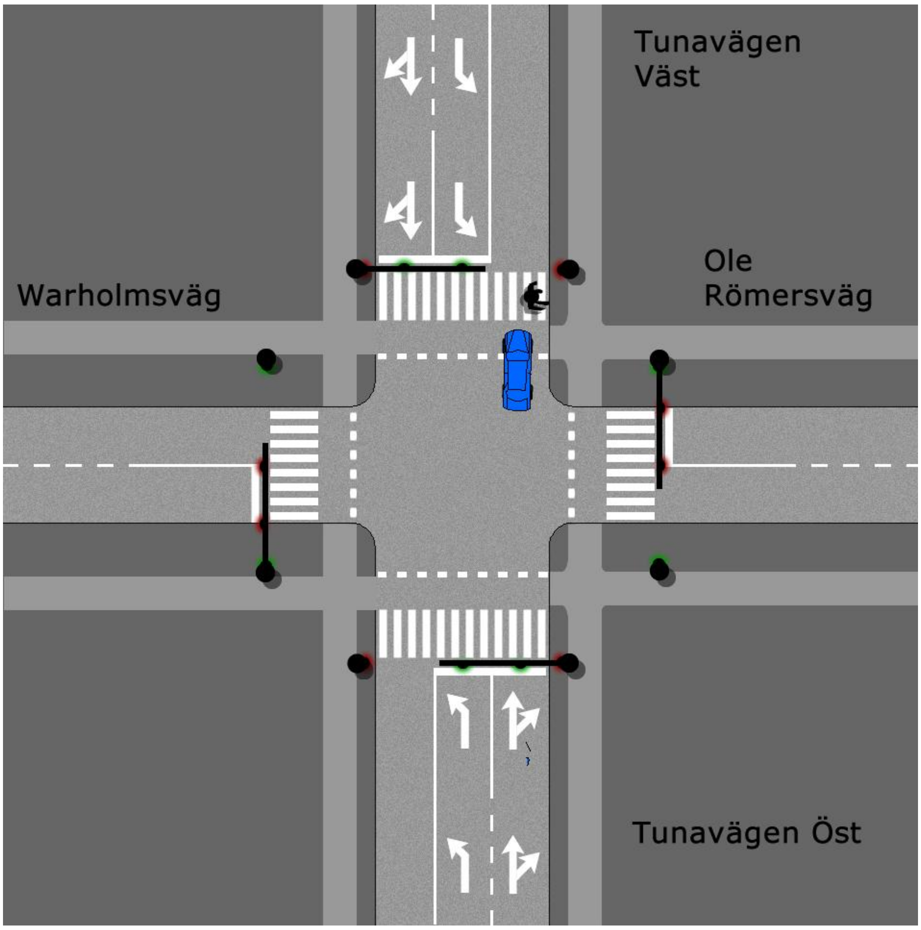

Figure 33: Situational sketch Lund conflict 4

Behavioural factors

The woman starts crossing at green signal. However, because she walks slowly, the signal turns red and the conflicting direction gets green light. For the car driver, the presence of the crossing pedestrian is not expected. The pedestrian looked to the ground when crossing and she did not observe the oncoming vehicle. In this case, the traffic green time for the pedestrian was too short for her to manage the crossing.

5. Warholmsväg

Strictly speaking, there is no collision course so there is no traffic conflict. However, in this situation, there is a low post-encroachment time.

	Road user 1	Road user 2
Type	Car	Pedestrian
Manoeuvre	Turning to the right	Crossing
Evasive action	None	None
Conflict speed	NA	NA
Conflict distance	NA	NA
TA	NA	NA
Post Encroachment Time	0.8 s	
Relevant road user	x	
Seriousness	Serious conflict	Serious conflict
Signal phase	Green	Green
View	Good	Looking to the ground
Arrival at the conflict zone	2nd	1st
Communication	None	None
Location of the pedestrian		On the pedestrian crossing
Gender pedestrian		Female
Age pedestrian		Old

Table 26: Description conflicts Lund conflict 5

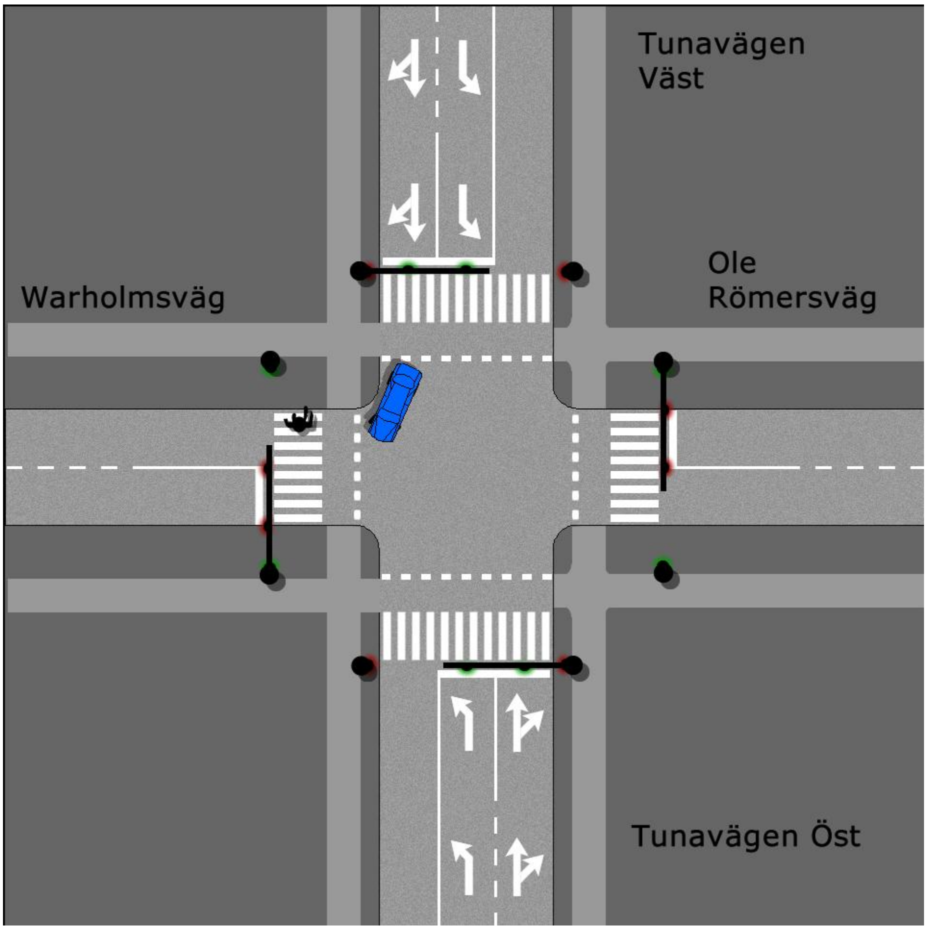

Figure 34: Situational sketch Lund conflict 5

Behavioural factors

The approach speed of the car is quite high. As there is such a low post-encroachment time, it looks as if the car driver did not see the pedestrian before turning to the right. The woman turned her head just prior to crossing. However, while crossing, she looked down to the ground. If she would have observed the oncoming car while crossing, then she might have increased her walking speed. The car used directional lights, so it would have been possible anticipate on the fast approaching car.

6. Tunavägen Öst

	Road user 1	Road user 2
Type	Car	Pedestrians (2)
Manoeuvre	Turning to the left	Crossing
Evasive action	None	Braking
Conflict speed	NA	5 km/h
Conflict distance	NA	1 m
TA	NA	0.7 s
Relevant road user		x
Seriousness	Serious conflict	Serious conflict
Signal phase	Green	Green
View	Good	Good
Arrival at the conflict zone	2nd	1st
Communication	None	Making eye contact
Location of the pedestrian		On the pedestrian crossing
Gender pedestrian		Male
Age pedestrian		Young

Table 27: Description conflicts Lund conflict 6

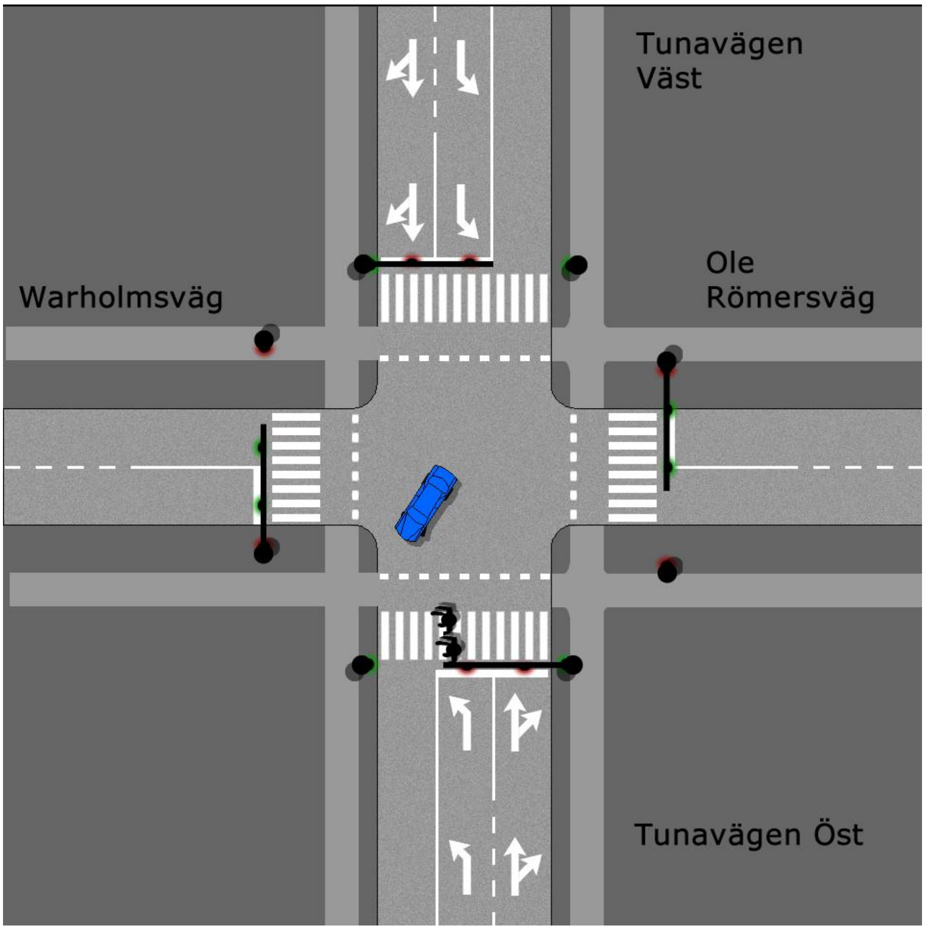

Figure 35: Situational sketch Lund conflict 6

Behavioural factors

The car has a relatively high speed when making its manoeuver. As the car driver passes the pedestrians on the right side, he has probably observed them but deliberately not given priority. The pedestrians have observed the car first when the car has overtaken them. They started crossing earlier than the car and the situation was surprising the pedestrians, although one of the pedestrians was looking around while walking on the first half of the pedestrian crossing. As the car driver did not perform any evasive action, this could have led to a dangerous situation.

7. Tunavägen Väst

	Road user 1	Road user 2
Type	Car	Pedestrian
Manoeuvre	Straight on	Crossing
Evasive action	Braking	None
Conflict speed	40 km/h	NA
Conflict distance	12 m	NA
TA	1.1 s	NA
Relevant road user	x	
Seriousness	Serious conflict	Serious conflict
Signal phase	Green	Red
View	Good	Good
Arrival at the conflict zone	2nd	1st
Communication	None	Making eye contact
Location of the pedestrian		On the pedestrian crossing
Gender pedestrian		Male
Age pedestrian		Young

Table 28: Description conflicts Lund conflict 7

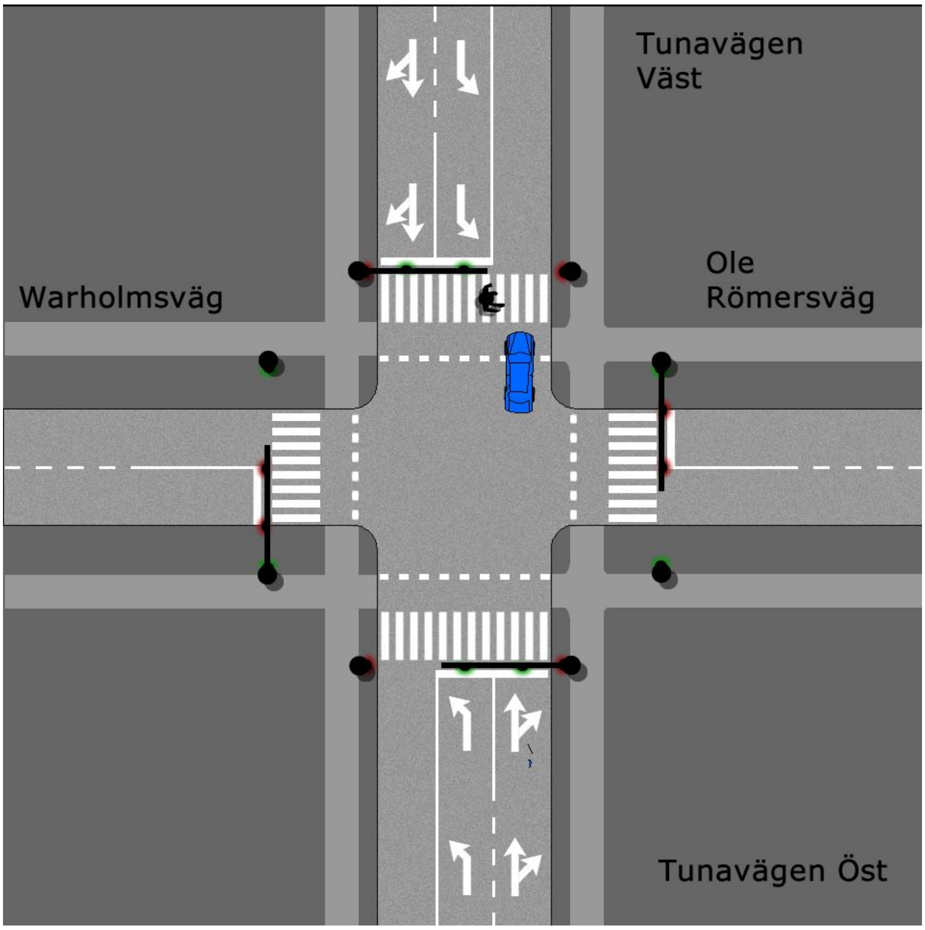

Figure 36: Situational sketch Lund conflict 7

Behavioural factors

The pedestrian is violating the red signal. The car driving is approaching the intersection at a relatively high speed, although not exceeding the maximum allowed speed. As the car driver has green light, he does clearly not expect crossing pedestrians. He brakes slightly after having accelerated in front of the intersection when getting green. Nevertheless, he reaches the conflict zone within 1 second after the moment the pedestrian reached the pavement.

8. Ole Römersväg

	Road user 1	Road user 2
Type	Bus	Pedestrian
Manoeuvre	Turning to the right	Crossing
Evasive action	Braking	Accelerating
Conflict speed	10 km/h	5 km/h
Conflict distance	4 m	0 m
TA	1.4 s	0 s
Relevant road user	x	
Seriousness	Slight conflict	Serious conflict
Signal phase	Green	Green
View	Good	Good
Arrival at the conflict zone	2nd	1st
Communication	Directional light	None
Location of the pedestrian		On the pedestrian crossing
Gender pedestrian		Check
Age pedestrian		Check

Table 29: Description conflicts Lund conflict 8

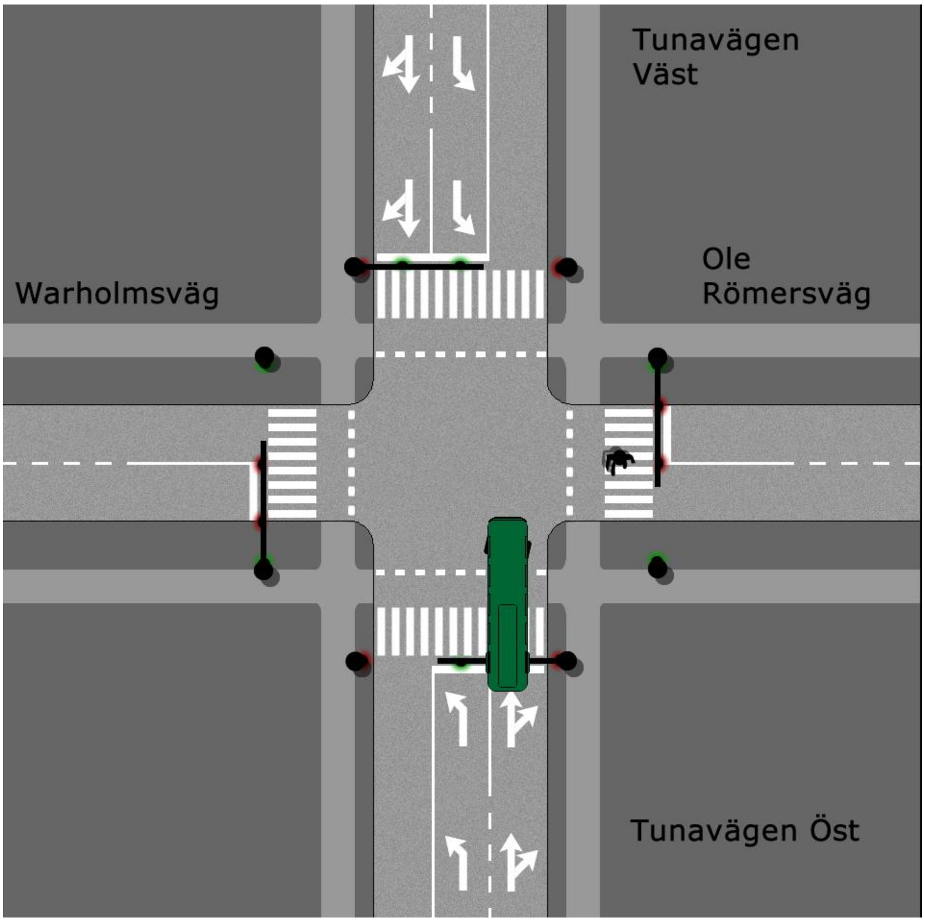

Figure 37: Situational sketch Lund conflict 8

Behavioural factors

Both the pedestrian and the bus driver have green signal. However, the bus driver turns to the right before the pedestrian has reached the pavement. There is lack of communication between the bus driver and the pedestrian, because the pedestrian suddenly accelerates and runs to the pavement. The bus driver could have planned to first turn to the right and then brake for the pedestrian. For the pedestrian, however, this is not clear. He starts to accelerate for his safety.

9. Ole Römersväg

	Road user 1	Road user 2
Type	Bus	Pedestrian
Manoeuvre	Turning to the right	Crossing
Evasive action	Braking	Braking
Conflict speed	5 km/h	5 km/h
Conflict distance	0.5 m	0.5 m
TA	0.4 s	0.4 s
Relevant road user	x	x
Seriousness	Serious conflict	Serious conflict
Signal phase	Green	Green
View	Good	Good
Start	1^{st}	2nd
Communication	Directional light	None
Location of the pedestrian		In front of the pedestrian crossing
Gender pedestrian		Female
Age pedestrian		Young

Table 30: Description conflicts Lund conflict 9

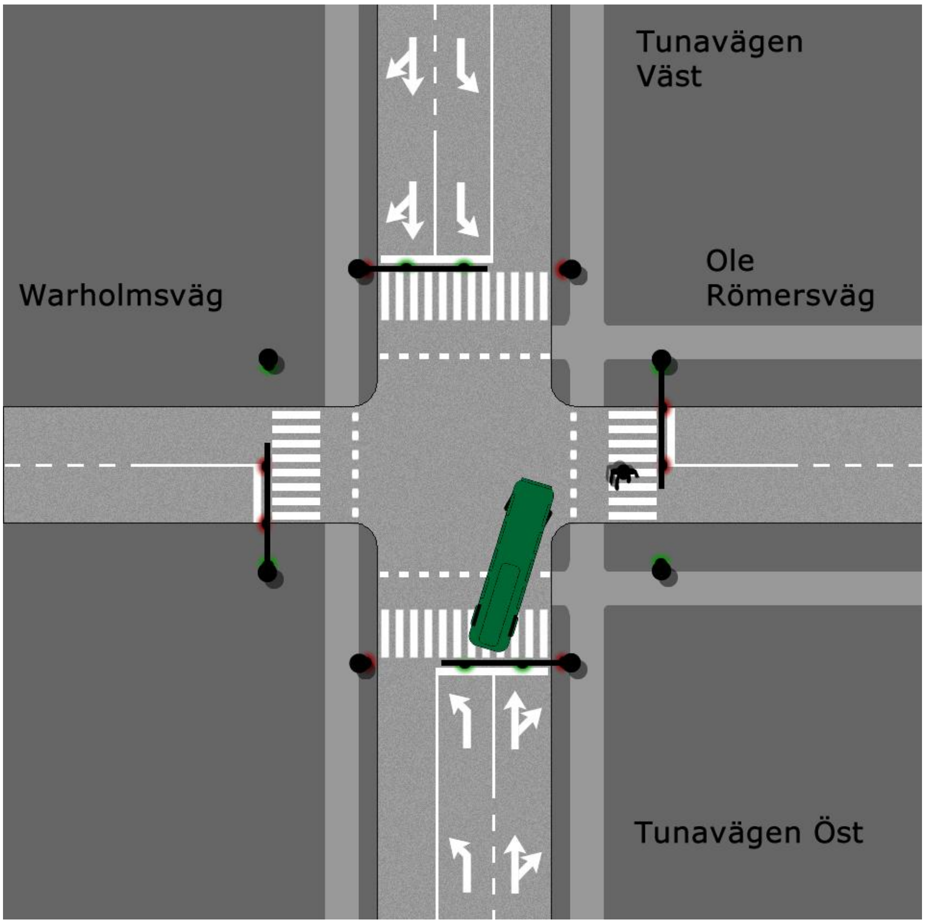

Figure 38: Situational sketch Lund conflict 9

Behavioural factors

Both the bus driver and the pedestrian are respecting the traffic signals. However, because the traffic signal for the pedestrians is still red when the bus driver faces green light, he doesn't expect crossing pedestrians. At the moment he starts turning, the pedestrian signal turns green and the pedestrian starts crossing. On that moment, both the pedestrian and the bus driver observe each other and decelerate. The bus driver uses directional lights. As the pedestrian walks from the Ole Römersväg, she has seen the bus standing still at the traffic lights before actually crossing. This could be a reason why she also reacts quickly. The looking behaviour of the bus driver is not optimal, given the presence of a second traffic conflict involving a bicyclist. Before accelerating, the bus driver did not make sure that there was no other road user crossing the intersection. The bus driver accelerates and brakes abruptly again.

Traffic light installation

An important issue to emphasize on are the traffic signals. The traffic lights turn green for bicyclists and motorized traffic simultaneously. Pedestrians need to push a button in order to get green. There are occasions where the car driver observes a red signal for the pedestrians prior to turning to the right, but where the pedestrians reach the crossing, push the button and get green a few seconds later. The green time is also not always long enough. People crossing slowly are not able to reach the end before the signal has turned red. When crossing during the second half of the green phase, the conflicting direction already gets green light. In conflict 4 and conflict 9, the traffic light installation plays an important role.

7.1.2 Traffic conflicts Hasselt

In this section, the traffic conflicts that happened at the intersection in Hasselt are discussed. The conflicts between bicyclists and cars and between two motorized vehicles are discussed shortly, and after that the traffic conflicts involving pedestrians are discussed more in detail.

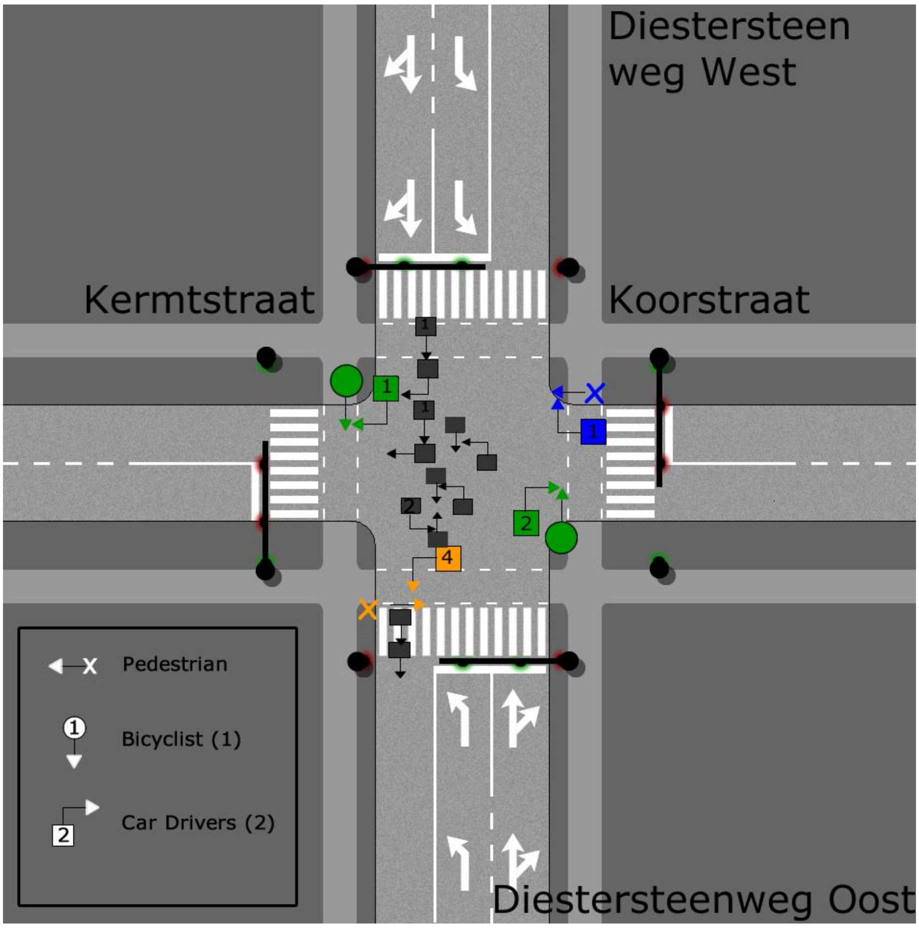

Figure 39: Traffic conflicts intersection Hasselt

On Figure 39, there is an overview of all traffic conflicts at the intersection in Hasselt. There is no clear concentration of traffic conflicts, although it is remarkable that 4 out of 5 traffic conflicts with pedestrians happen on the pedestrian crossing of the intersection leg Diestersteenweg Oost.

Car-bicyclist conflicts

During the 30 hour observation period at the intersection Diestersteenweg-Koorstraat/Kermtstraat, 3 traffic conflicts with bicyclists occurred. All traffic conflicts occurred when a car was turning to the right.

Car-car conflicts

Six traffic conflicts that happened during the observation period at the intersection Diestersteenweg-Koorstraat/Kermtstraat occurred between two motorized vehicles. The situations were very diverse, although the most frequent situation was a car turning to the left and choosing a too small gap, so that the car from the conflicting direction has to brake (see Figure 39). Beside these traffic conflicts, there were 27 situations with a low post-encroachment time. All of these situations occurred when a car was turning to the left.

Conflicts between car drivers and pedestrians

In this section, just like in the previous section about the Swedish intersection, each traffic conflict is discussed in detail. A standard table summarizes the circumstances under which the traffic conflict occurs. A sketch is added to locate the traffic conflict and at the end, the behavioural processes prior to and during the traffic conflict are shortly discussed.

1. Diestersteenweg Oost

	Road user 1	Road user 2
Type	Car	Pedestrian
Manoeuvre	Turning to the left	Crossing
Evasive action	Braking	None
Conflict speed	25 km/h	NA
Conflict distance	5 m	NA
TA	0.7 s	NA
Relevant road user	x	
Seriousness	Serious conflict	
Signal phase	Green	Green
View	Good	Good
Arrival at the conflict zone	2nd	1st
Communication	Directional lights	None
Location of the pedestrian		Pedestrian crossing
Gender pedestrian		Male
Age pedestrian		Old

Table 31: Description conflicts Hasselt conflict 1

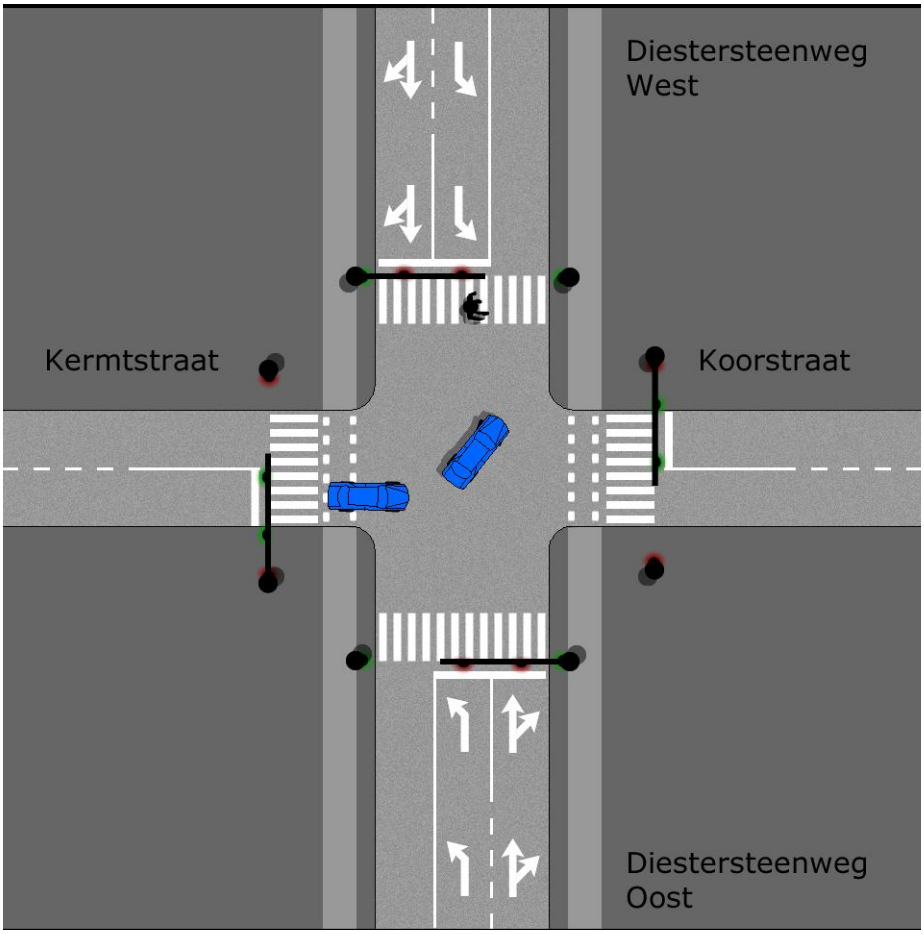

Figure 40: Situational sketch Hasselt conflict 1

Behavioural factors

Both the pedestrian and the car driver have green signal. The pedestrian looks to the ground and starts his evasive action first after the car driver has braked. The car driver first observes the pedestrian after having passed him horizontally. At that moment, he has already started turning to the left. The car driver did use his directional lights. After the car has taken evasive action, the pedestrian starts to accelerate.

2. Diestersteenweg Oost

	Road user 1	Road user 2
Type	Car	Pedestrian
Manoeuvre	Turning to the left	Crossing
Evasive action	Braking	Accelerating
Conflict speed	20 km/h	6 km/h
Conflict distance	5 m	0 m
TA	0.9 s	0 s
Relevant road user	x	
Seriousness	Serious conflict	Serious conflict
Signal phase	Green	Green
View	Good	Good
Arrival at the conflict zone	2nd	1st
Communication	Directional lights	None
Location of the pedestrian		Pedestrian crossing
Gender pedestrian		Male
Age pedestrian		Young

Table 32: Description conflicts Hasselt conflict 2

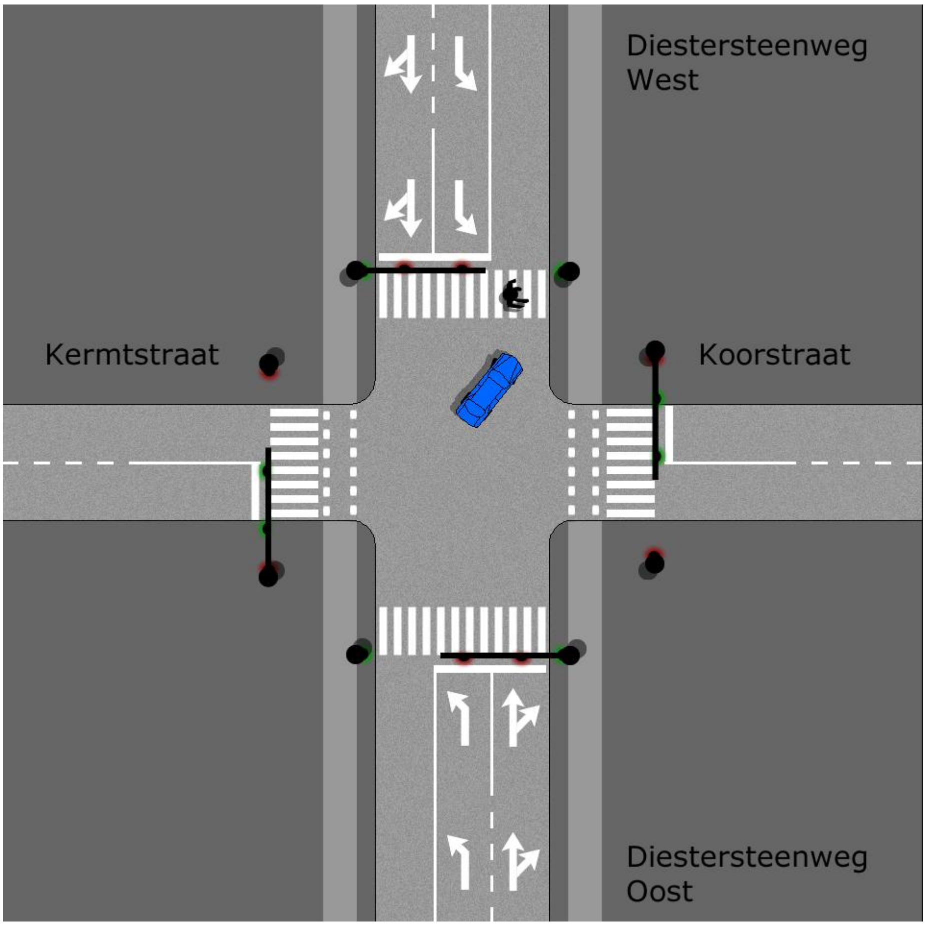

Figure 41: Situational sketch Hasselt conflict 2

Behavioural factors

Both the pedestrian and the car driver respected traffic signals and crossed at green signal. The pedestrian started crossing before the car driver did so. The car driver brakes after having passed the pedestrian on the right hand. The car driver already started to turn to the left. The pedestrian observes the car driver when he is already in the conflict zone and increases his speed.

3. Diestersteenweg Oost

	Road user 1	Road user 2
Type	Car	Pedestrian
Manoeuvre	Turning to the left	Crossing
Evasive action	Braking	None
Conflict speed	20 km/h	NA
Conflict distance	4 m	NA
TA	0.7 s	NA
Relevant road user	X	
Seriousness	Serious conflict	Serious conflict
Signal phase	Green	Green
View	Good	Good
Start	2nd	1st
Communication	Directional lights	None
Location of the pedestrian		Pedestrian crossing
Gender pedestrian		Female
Age pedestrian		Old

Table 33: Description conflicts Hasselt conflict 3

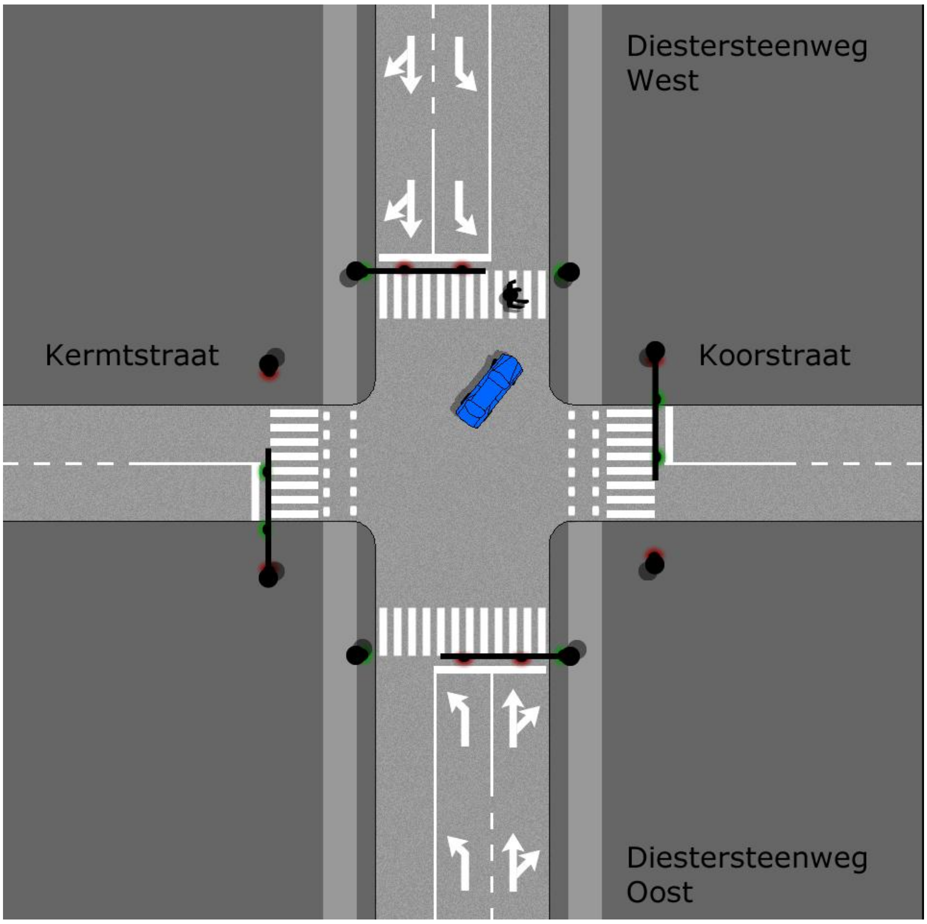

Figure 42: Situational sketch Hasselt conflict 3

Behavioural factors

Both the pedestrian and the car driver respected traffic signals and crossed at green signal. The pedestrian started crossing before the car driver did so. The car driver brakes after having passed the pedestrian on the right hand. The pedestrian doesn't take evasive action and looked down at the ground.

4. Diestersteenweg West

	Road user 1	Road user 2
Type	Car	Pedestrian
Manoeuvre	Turning to the right	Crossing
Evasive action	Braking	Braking
Conflict speed	20 km/h	5 km/h
Conflict distance	4 m	0 m
TA	0.7 s	0 s
Relevant road user	x	
Seriousness	Serious conflict	Serious conflict
Signal phase	Green	Green
View	Good	Good
Arrival at the conflict zone	2nd	1st
Communication	Directional lights	None
Location of the pedestrian		Pedestrian crossing
Gender pedestrian		Male
Age pedestrian		Young

Table 34: Description conflicts Hasselt conflict 4

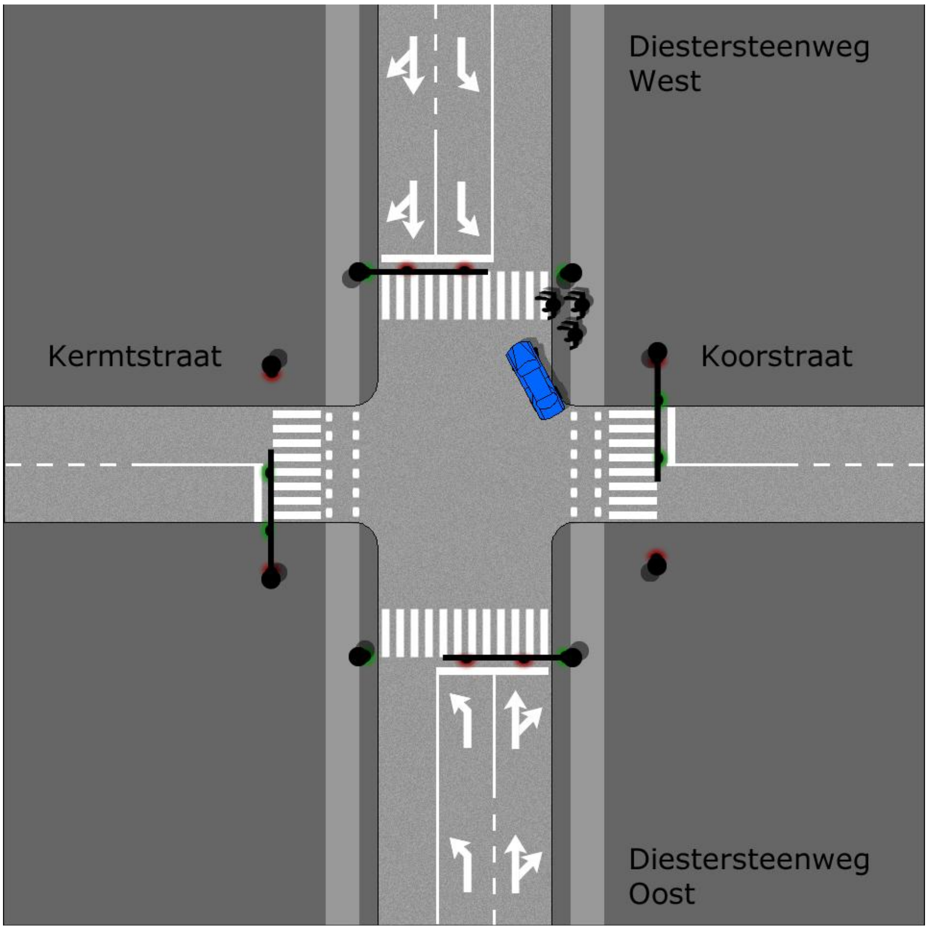

Figure 43: Situational sketch Hasselt conflict 4

Behavioural factors

A group of pedestrians intends to cross the street. The first pedestrian starts crossing, but the other pedestrians observe a vehicle (4x4) turning to the right and they wait at the kerb. The pedestrian who already started crossing observes the oncoming vehicle, brakes abruptly notwithstanding the fact that he is already in the conflict zone and continues crossing when he is sure that the car has stopped. The car turning to the red approach quite fast and although the car driver already had to brake for making his manoeuvre, he brakes more abruptly when observing the group of pedestrians.

Both the pedestrians and the car driver had green traffic light. However, the speed of the car driver was quite high. He already started decelerating in the curve and discovered that he had to come to a full stop because of the pedestrians. The first pedestrian scanned the road on the right hand but failed to do so on the left. First after entering the conflict zone, he looked to the left. Maybe he was warned by his accompany. At the moment just prior to the traffic conflict, there is one oncoming vehicle driving straight on from the Koorstraat to the Kermtstraat. There are no secondary involved vehicles.

5. Diestersteenweg West

	Road user 1	Road user 2
Type	Lorry	Pedestrian
Manoeuvre	Turning to the left	Crossing
Evasive action	Braking	Braking
Conflict speed	15 km/h	5 km/h
Conflict distance	5 m	0.5 m
TA	1.2 s	0.4 s
Relevant road user	x	
Seriousness	Slight conflict	Serious conflict
Signal phase	Green	Green
View	Good	Good
Start	2nd	1st
Communication	Directional lights	None
Location of the pedestrian		Pedestrian crossing
Gender pedestrian		Male
Age pedestrian		Young

Table 35: Description conflicts Hasselt conflict 5

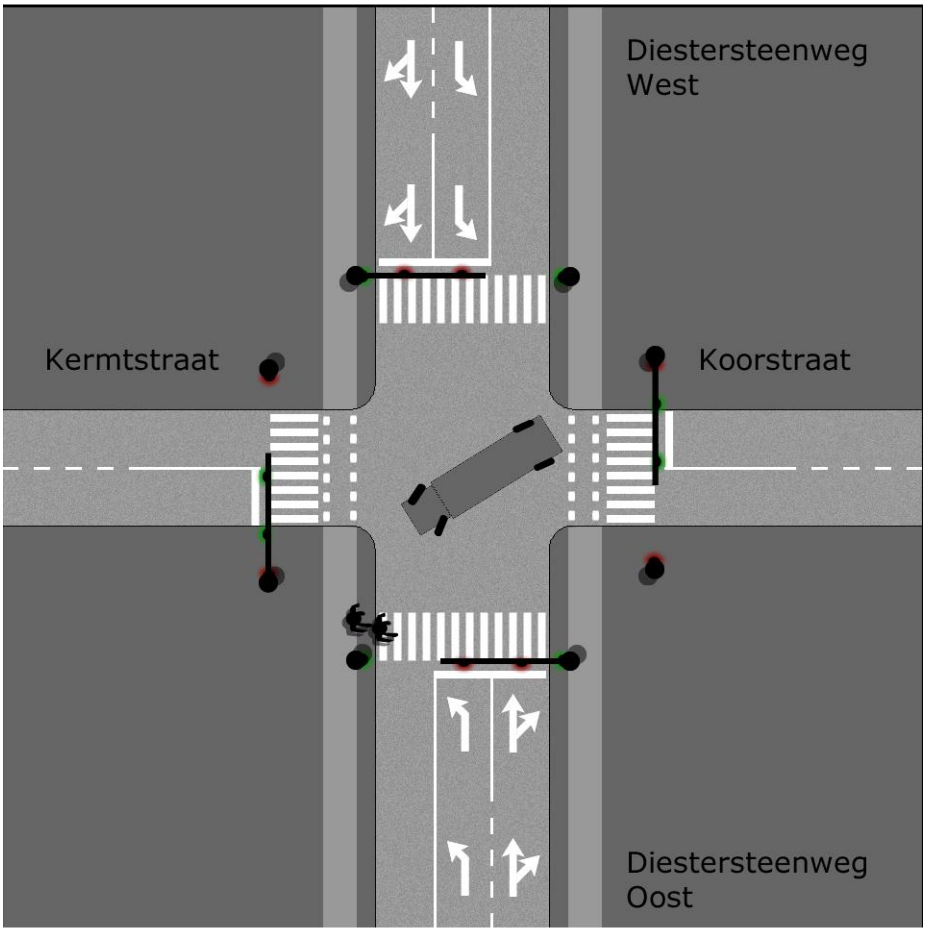

Figure 44: Situational sketch Hasselt conflict 5

Behavioural factors

Two pedestrians intend to cross the Diestersteenweg, when a lorry turns to the left. The pedestrians brake just before entering the conflict zone. One of the pedestrians does not see the lorry and the other pedestrian warns her and stops her just when she intends to start crossing. The lorry driver also brakes simultaneously. At the moment the lorry starts driving from the traffic lights, the pedestrians have not yet reached the pedestrian crossing. This is why the situation is unexpected for the lorry driver.

Both the lorry driver and the pedestrians have green light. The lorry driver uses directional lights. Nevertheless, one of the pedestrians starts crossing despite the fact that there is an approaching lorry. The crossing pedestrian is not observing the situation and is stopped by the other pedestrian. The lorry driver starts braking as soon as the pedestrians approach the pedestrian crossing. However, the braking distance of the lorry is relatively high.

7.1.3 Synthesis

The types of traffic conflicts in Hasselt are different from those in Lund. When considering traffic conflicts with pedestrians, it is clear that at the intersection in Hasselt, there are more traffic conflicts with motorized road users turning left. At the intersection in Lund, pedestrians violating the red signal are involved in four out of nine traffic conflicts. Most traffic conflicts have relatively low conflict speeds. This is probably because of a low speed of vehicles turning left or right.

In many cases, pedestrians have a higher time to accident value than car drivers. This is because of their low speed. Even at a low distance to the conflict point, time to accident values tend to be relatively high.

Regarding the link between traffic conflicts data and accident data at the intersections in Lund and Hasselt, there is no clear link. Especially in Hasselt, there was no single police-reported crash between a motorized road user and a pedestrian between 2008 and 2011, while there were some traffic conflicts. In Lund, there was only one crash between a motorized road user and a roller-skater. However, as the total number of crashes at both sites is very low, it is not possible to draw any conclusions about the safety state at those locations.

7.2 Behavioural observations

In this chapter, first the data will be explored. After that, it will be tested in which way the behavioural factors differ according to the location using the Chi-Square test or Fisher's Exact test, Phi-association measure and multiple logistic regression to control for confounding factors.

7.2.1 Descriptive statistics

As described in chapter 6, there are 594 observations in total. Out of these 594 observations, there were 194 traffic interactions and 400 pedestrians or groups of pedestrians without a traffic interaction with a motorized road user.

Signal compliance pedestrians

Most pedestrians complied to the traffic signals. Of all pedestrians observed in total, 78% complied to red signal. 18% violated red signal and 4% violated red signal while the bicycle light in the corresponding direction was green. This situation could only occur at the intersection in Lund (see figure 45).

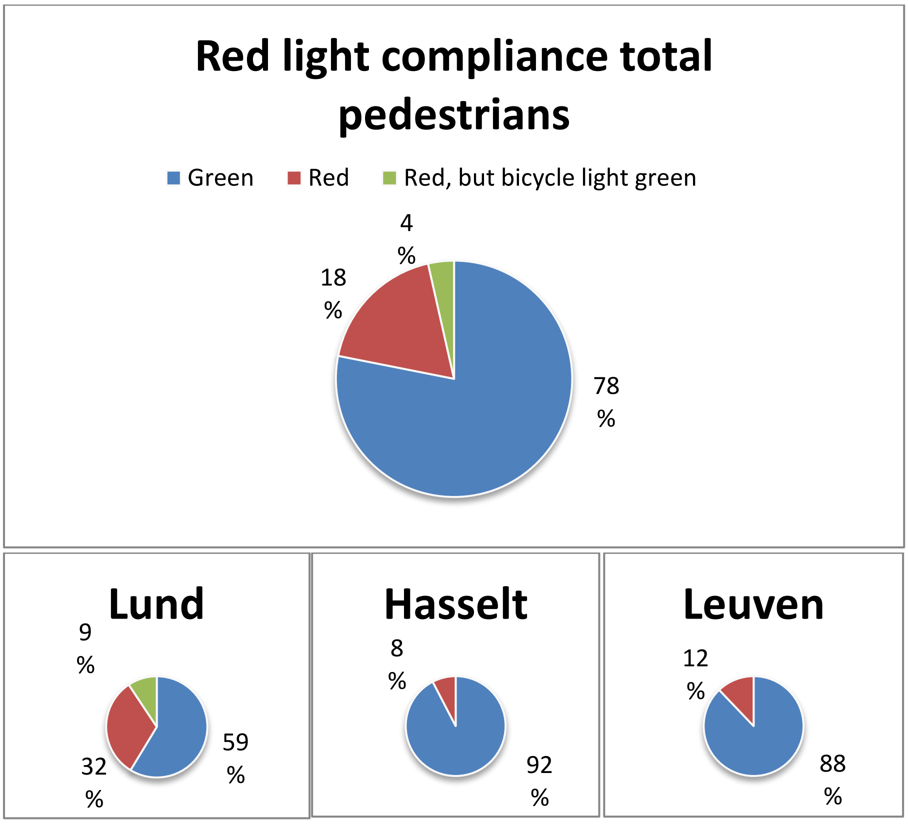

Figure 45: Red signal compliance pedestrians

It is remarkable that red signal compliance is much worse at the intersection in Lund, compared to the intersections in Hasselt and Leuven. Approximately one third of all pedestrians did not respect the traffic signal. In Hasselt, this is 8 percent and in Leuven, this is 12 percent.

Signal compliance motor vehicles

All motor vehicles that encountered pedestrians during the behavioural observations complied with the traffic signals.

Looking behaviour pedestrians

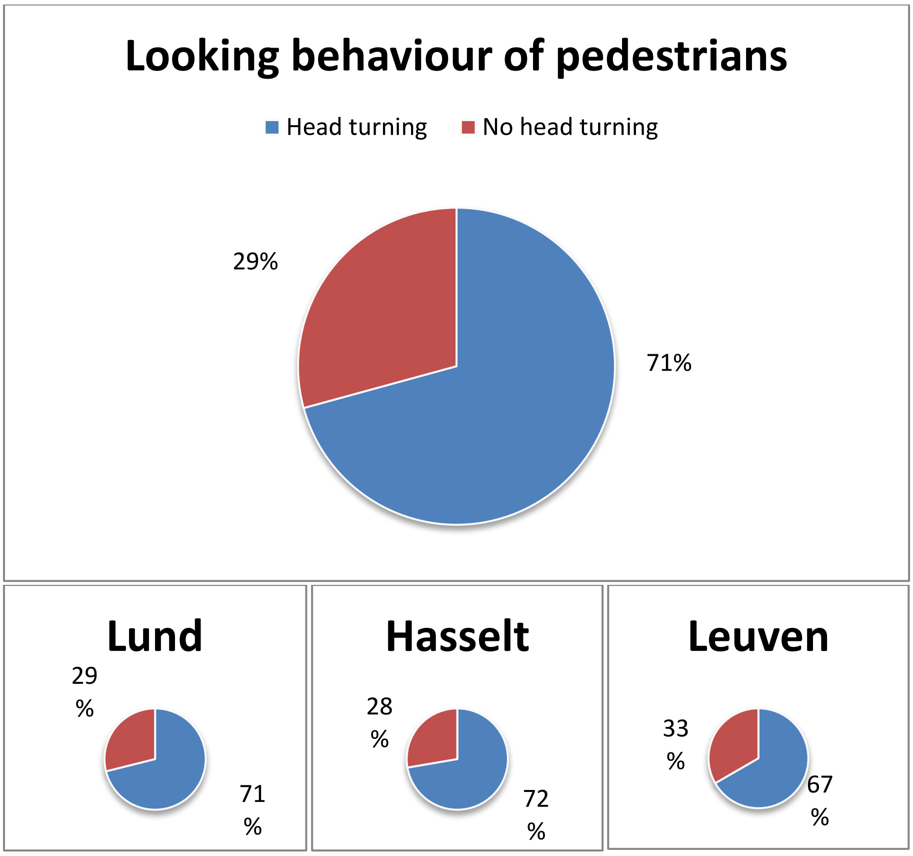

Figure 46: Looking behaviour pedestrians

71% of the pedestrians turned their head prior to crossing in order to make sure that there are no approaching cars that could form a danger to the pedestrian. 29% of the pedestrians did not turn their head before crossing. In most situations these pedestrians looked down at the ground.

Looking behaviour car drivers

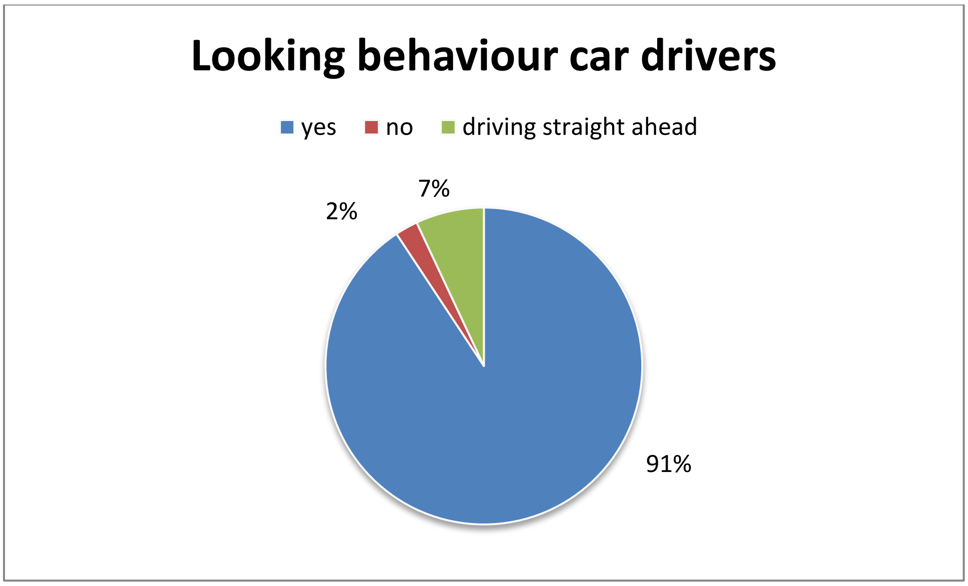

Figure 47: Looking behaviour car drivers

For the car drivers, the distribution is different. 92 % of the motorized road users turned their head before approaching the pedestrian crossing. 2% failed to do so. However, in 6% of the situations, the car driver is driving straight on. In this kind of traffic interactions, the pedestrians violate the red signal. In most situations where the car driver was driving straight on, he did not turn his head in order to scan the traffic situation at the left and the right side of the intersection. The number of car drivers that are not turning their heads before turning to the left or to the right is too low to make a useful comparison among the different intersections possible.

Use of directional lights

Another issue related to communication is the use of directional lights.

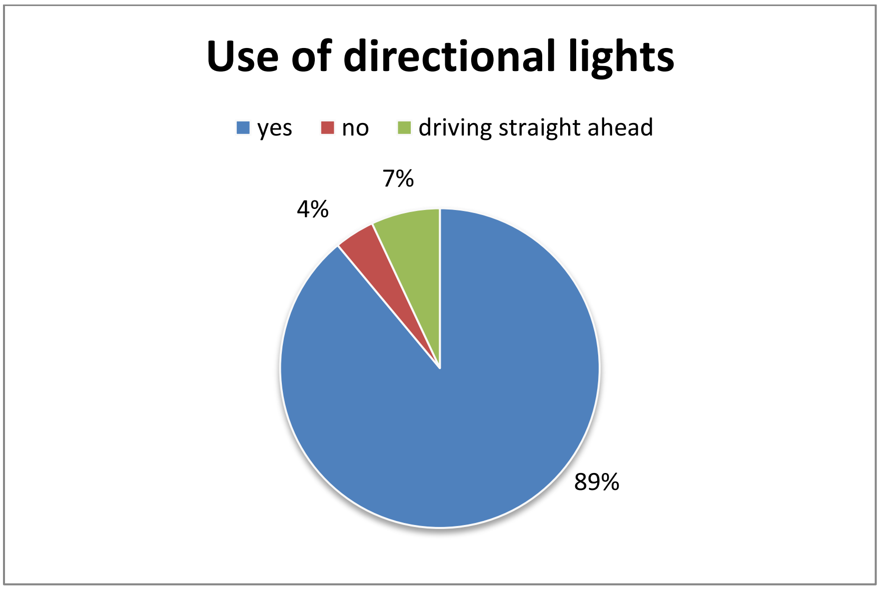

Figure 48: Use of directional lights car drivers

Of all motorized road users that interacted with pedestrians, 89 per cent used directional lights. 4 per cent did not use directional lights although turning. In 7 per cent of the cases the car driver drove straight on. Again, the number of car drivers not using their directional lights is too low to make a useful comparison among the different intersections possible.

Yielding behaviour

According to traffic law in both Sweden and Belgium, turning vehicles should yield to pedestrians walking straight on. However, if pedestrians would violate the traffic signal, interacting cars have priority. Pedestrians should yield in this case.

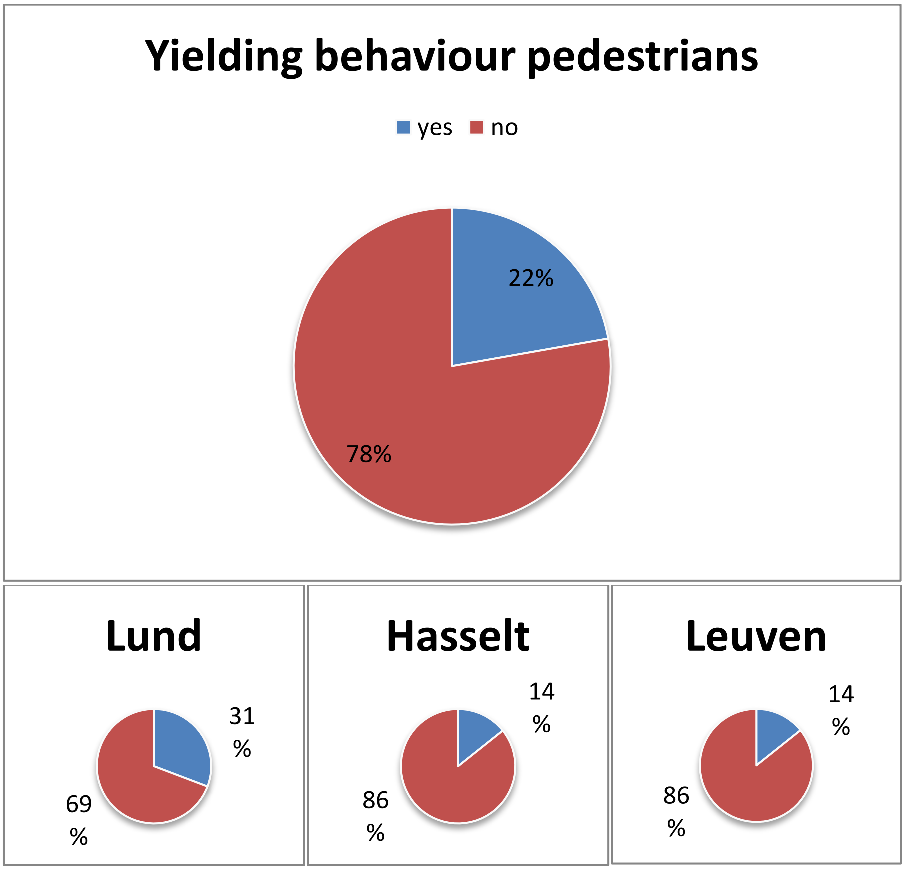

Figure 49: Yielding behaviour pedestrians

Pedestrians are not yielding when they violate the red signal. In 27 cases there was a pedestrian violating red signal and being involved in a traffic interaction with a motorized road user. 78% of the cases (21 cases), the pedestrian did not yield to the motorized road user. In 6 cases, the pedestrian did yield. In Hasselt and Leuven, only 1 pedestrian out of 7 yielded. In Lund, 4 out of 13 pedestrians yielded.

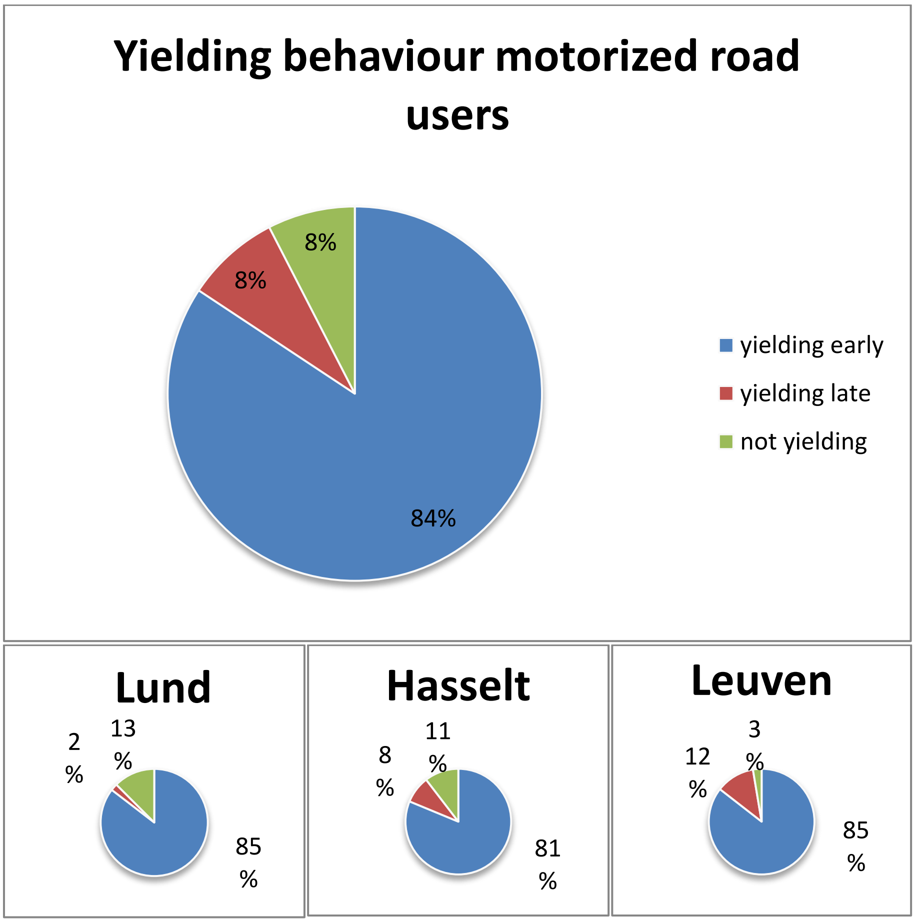

Figure 50: Yielding behaviour motorized road users

The yielding behaviour of the car drivers is more favourable. 84 per cent of the car drivers interacting with pedestrians did yield early and was not disturbing the pedestrian while crossing the road. 8 per cent yield late and caused an evasive action for the pedestrian. Another 8 per cent did not yield at all and passed before the pedestrian.

7.2.2 Statistical tests

Above, some general descriptive statistics have been shown in order to get a picture about general pedestrian behaviour and traffic interactions between pedestrians and motorized road users. In this section there will be focused on certain aspects that coincide with behavioural factors.

7.2.2.1 Red signal violation

Overall, 18 per cent of all observed pedestrians violated red signal. In this paragraph there will be looked to gender of the pedestrian, age of the pedestrian, whether the pedestrian is alone or walking in a group, the presence of a car and country in order to investigate which factors are associated with red light violation among pedestrians. Finally, a multiple logistic regression model will be discussed. This regression model includes all of those factors simultaneously and can account for confounding factors.

Gender

Gender	Green	Red	Red (bicycles green)	Total
Woman	174	34	9	217
Man	134	45	4	183
Total	308	79	13	400

Table 36: Gender and red light violation

There is a small group of pedestrians violating the traffic signal when the bicycle signal was green. This situation only occurred at the intersection in Lund. Because of the low number of observations, this data is taken out of further analyses.

The Chi-Square statistic equals 5,801 and has a p-value of 0.055. With a 95 per cent confidence level, this result is not statistically significant. However, there is still an indication that men tend to be more prone to violate traffic signals than women, significant at a 90 per cent confidence level.

		Green	Red	Total
Man	Frequency	134	45	179
	Residual	-2,1	2,1	
Woman	Frequency	174	34	208
	Residual	2,1	-2,1	
Total		308	79	387

Table 37: Cross table gender and signal compliance

	Value	p-value
Pearsons Chi Square	4.579	0.032
Cramér's V	0.109	
Odds ratio	0.582	

Table 38: Statistical tests gender and signal compliance

When deleting the pedestrians in the small, third group, the Chi-Square statistic equals 4.579 with a corresponding p-value of 0.032. This gives a statistically significant association between gender and signal compliance. Phi association measure gives a result of 0.109. This means a rather weak association.

When studying residuals, women have a positive residual for compliance of 2.1 and a negative residual for red signal violation of -2.1. Men have a negative residual for compliance of 2.1 and a positive residual for red signal violation of 2.1. This means that men are more likely to violate the traffic signal than women.

The same pattern occurs when studying odds ratio values. Men have an odds ratio for complying with the traffic signal of 0.582. We can turn around the situation and look at red light violation instead. The odds ratio for men for violating the traffic signal is the inverse of the odds for men for complying with the traffic signal. 1/0.582=1.719. This means that for men, the odds of *violating* the traffic signal are 71,86% higher than the odds for women of violating the traffic signal.

Age of the pedestrian

There is a small group of pedestrians violating traffic signal while the bicycle signals are green. This group has been taken out of this analysis because of the low number of observations in each age group.

		Green	Red	Total
Children	Frequency	30	4	34
	%	88%	12%	1
	Residual	1,3	-1,3	
Young	Frequency	97,0	46,0	143
	%	68%	32%	1
	Residual	-4,4	4,4	
Middle	Frequency	91,0	21,0	112
	%	81%	19%	1
	Residual	0,5	-0,5	
Old	Frequency	90,0	8,0	98
	%	92%	8%	1
	Residual	3,5	-3,5	

Table 39: Cross table and residuals age group and red light violation

	Value	p-value
Pearsons Chi Square	22.970	0.000
Cramér's V	0.244	
Odds ratio child*	1.499	0.531
Odds ratio young*	5.333	0.000
Odds ratio middle*	2.596	0.031

Table 40: Statistical tests age group and red light violation

*=as compared to older people by using a single logistic regression model

Out of 34 children, 4 children (11,8%) violated traffic signals. Out of 143 young people, 46 (32,2%) violated traffic signals. Out of 112 people between around 31 and 65 years old, 21 (18,8%) violated traffic signals and out of 98 older people, 8 (8.2%) violated traffic signals (see Table 39).

The value of Pearson Chi-Square statistic is 22,970, resulting in a p-value of 0,000. There is, according to the observed data, evidence for a statistically significant association between age and red signal compliance. The Phi-value equals 0.244, resulting in a stronger association than was the case with the analysis of gender in combination with red signal compliance.

The residuals for red signal compliance are 1.3 for children, -4.4 for young people, 0.5 for people between 31 and 65 and 3.5 for older people. This means that *young* people are significantly *less well complying* with traffic signals and *older* people are significantly *better complying* with traffic signals. For children and people between 31 and 65 years old, there is no significant difference between the observed values and the expected values.

The odds ratio values, compared to old people, of children, young people and people between 31 and 65 years old, equal 1.499 (p-value: 0.531), 5.333 (p-value: 0.000) and 2.596 (p-value: 0.031) respectively. These odds ratio values are derived from a fitted logistic regression model, on the contrary to the other odds ratio values that are derived from observed data. Young people tend to have an odds ratio to violate traffic signals that is more than 5 times higher than old people. People between 31 and 65 years old have an odds ratio to violate traffic signals that is 2.596 time higher than old people. For children, the odds ratio is not statistically significant.

Location

In this section it will be analysed whether or not there are differences in traffic signal compliance among the different locations.

		Green	Red	Total
Lund	Frequency	78	49	127
	Residual	-6.2	6.2	
Hasselt	Frequency	104	11	115
	Residual	3.4	-3.4	
Leuven	Frequency	126	19	145
	Residual	2.8	-2.8	
Total		308	79	387

Table 41: location and red light violation

	Value	p-value
Pearsons Chi Square	38.906	0.000
Cramér's V	0.318	
Odds ratio	n.a.	

Table 42: Statistical test location and red light violation

Of all pedestrians walking alone, 79.6% comply with the traffic signal and 20.4% violate the traffic signal. However, in Lund the situation is very different. The Pearson's Chi-Square value is very significant (p-value = 0.000), indicating significant difference between the locations. In Leuven there tends to be somewhat more red light violation than in Hasselt. However, when only taking into account the intersections in Leuven and

Hasselt, the Pearson's Chi-Square value is not statistically siginificant (p-value = 0,375), so we can conclude that the traffic behaviour of pedestrians regarding traffic signal compliance is not significantly different in Hasselt than in Leuven.

	Value	p-value
Pearsons Chi Square	0.787	0.375
Cramér's V	0.055	
Odds ratio	1.426	

Table 43: Statistical tests Belgian locations and red light violation

This implies that we can combine the observations in Hasselt and Leuven to form a Belgian group and take the observations in Lund as a Swedish group for the next analyses. The observations have no generalizing value for all signalized intersections in Belgium and Sweden but are only an indication valid at the intersections where the observations have taken place.

At the intersection in Sweden, 61.4% (78 out of 127) of the individual pedestrians complied with traffic lights, while at the intersections in Belgium, 88.5% (230 out of 260) complied. This results in a Pearson's Chi-Square statistic equaling 38.411 with a corresponding p-value of 0,000. The Cramér's V equals 0.315. This means a rather strong association.

		Green	Red	Total
Swedish intersection	Frequency	78	49	127
	Residual	-6,2	6,2	
Belgian intersections	Frequency	230	30	260
	Residual	6,2	-6,2	
Total		308	79	387

Table 44: Cross table and residuals country and red light violation

	Value	p-value
Pearsons Chi Square	38,411	0
Cramér's V	0,315	
Odds ratio	0,208	

Table 45: Statistical tests country and red light violation

The residuals for red signal compliance in Sweden are -6.2 and in Belgium 6.2. For red signal violation, these residuals equal 6.2 in Sweden and -6.2 in Belgium. This means that pedestrians at the Swedish intersection are much more likely to violate the traffic signal than pedestrians at the Belgian intersections.

The odds of violating traffic lights in Sweden equal 4.816, compared to the odds of violating traffic lights in Belgium. This again indicates that red violation is much more likely at the Swedish intersection than at the Belgian intersections.

Individuals versus groups

		Green	Red	Total
One pedestrian	Frequency	308	79	387
	%	79.6%	20.4%	100%
	Residuals	-1.2	1.2	
More than one pedestrian	Frequency	156	30	186
	%	83.9%	16.1%	100%
	Residual	1.2	-1.2	
Total	Count	464	109	573
	%	81.0%	19.0%	100%

Table 46: Cross table number of pedestrians and red light violation

	Value	p-value
Pearsons Chi Square	1.497	0.221

Table 47: Pearson Chi Square test number of pedestrians and red light violation

There seems to be somewhat higher red light compliance when pedestrians are walking together when we look at the percentages. However, this difference is not statistically significant (Pearson's Chi-Square = 1,497 with a p-value of 0,221). Therefore, the Cramér's V and odds ratio values are not shown.

Presence of a car

		Green	Red	Total
Presence of a car	Count	140	31	171
	% within car	81.9%	18.1%	100%
	Residual	0.4	-0.4	
No car	Count	324	78	402
	% within car	80.6%	19.4%	100%
	Residual	-0.4	0.4	
Total	Count	464	109	573
	% within car	81%	19%	100%

Table 48: Crosstable presence of a car and red light violation

	Value	p-value
Pearsons Chi Square	0.126	0.722

Table 49: Pearson Chi Square test presence of a car and red light violation

Out of the result, there is no indication that pedestrians comply better with the traffic signal if there is a traffic interaction. The percentages are nearly equal and the corresponding Pearson's Chi-Square value is 0,126 (p-value of 0,722). We also see residuals with a very low absolute value.

Confounding factors

Gender, age and country were all factors that correlate with red signal compliance. However, if these variables are interrelated, then it is not clear which factors have a real influence.

		Children	Young	Middle	Old	Total
Sweden	Count	4	84	28	11	127
	%	0,031	0,661	0,22	0,087	1
Belgium	Count	30	59	84	87	260
	%	0,115	0,227	0,323	0,335	1
Total	Count	34	143	112	98	387
	%	0,088	0,37	0,289	0,253	1

Table 50: Crosstable country and age

In the Swedish sample, 3.1 % is child, 66.1% is young, 22.0% is middle aged and 8.7% is old. In the Belgian sample, 11.5% is child, 22.7% is young, 32.3% is middle aged and 33.5% is old. As old people are significantly less violating the traffic signals and young people are significantly more violating traffic signals, the question is what is measured in this case.

Gender and age are also correlated with more young males and more middle aged females. However, this association is not statistically significant (Pearson's Chi-Square equals 6.023 with a corresponding p-value of 0.11).

		Child	Young	Middle	Old	Total
Man	Frequency	14	73	42	50	179
	%	7,8%	40,8%	23,5%	27,9%	100,0%
	Residual	-,6	1,4	-2,2	1,1	
Woman	Frequency	20	70	70	48	208
	%	9,6%	33,7%	33,7%	23,1%	100,0%
	Residual	,6	-1,4	2,2	-1,1	
Total	Frequency	34	143	112	98	387
	%	8,8%	37,0%	28,9%	25,3%	100,0%

Table 51: Crosstable gender and age

	Value	**p-value**
Pearsons Chi Square	6.023	0.11

Table 52: Pearson Chi Square test gender and age

A multiple logistic regression model has been used to account for these confounding factors. The probability of violating the red signal has been modeled as a function of gender, age and country. Only main effects have been taken into account and after the full model including country, gender and age, backward elimination has been used to get a final model with all explanatory variables having a statistically significant parameter.

Parameter	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	degrees of freedom	p-value
(Intercept)	-2,643	0,3804	-3,389	-1,898	48,275	1	0
child	0,407	0,6575	-0,881	1,696	0,384	1	0,535
young	1,077	0,4383	0,218	1,936	6,033	1	0,014
middle	0,765	0,4514	-0,12	1,649	2,87	1	0,09
old	0a	.	.	.	.	.	.
Sweden	1,27	0,2915	0,698	1,841	18,972	1	0
Belgium	0a	.	.	.	.	.	.
(Scale)	1b						

Dependent Variable: Red light compliance

Model: (Intercept), age of the pedestrian, country (Swedish intersection versus the two Belgian intersections)

a. Set to zero because this parameter is redundant.

b. Fixed at the displayed value.

Table 53: Output logistic regression model age/country-red light violation

The final model takes into account the age of the pedestrian and the country. The categories "old" at age and "Belgium" at country are reference categories and there are no parameters to estimate for these categories. The other categories have parameters that are based on the reference categories.

According to Equation 6:

$$logit\big(\pi(x)\big) = log\,\frac{\pi(x)}{1-\pi(x)} = \beta0 + \ \beta1x1\ (+\ \beta..x..)$$

The formula can be filled in like this:

$$logit(P(red\ signal\ violation)) = -2.643 + 0.407 * child + 1.077 * young + 0.765 * middle + 1.270 * Sweden$$

The chance of violating the red signal can be computed according to Equation 7:

$$\pi(x) = \frac{\exp(\beta0 + \beta1x1 + \beta..x..)}{1 + \exp(\beta0 + \beta1x1 + \beta..x..)}$$

$$P(red\ signal\ violation) = exp\,(-2.643 + 0.407 * child + 1.077 * young + 0.765 * middle + 1.270 * Sweden)/(1 + (\,exp\,(-2.643 + 0.407 * child + 1.077 * young + 0.765 * middle + 1.270 * Sweden))$$

Of the age categories, only young and middle were statistically significant on a 90% significance level. However, it is clear that both age and country play a role.

Likelihood Ratio Chi-Square	Degrees of freedom	p-value
43,397	4	0.000

a. Compares the fitted model against the intercept-only model.

Table 54: Likelihood Ratio Chi-Square of the logistic regression model

The Likelihood Ratio Chi-Square statistic equals 43,397 and is statistically significant with a p-value of 0.000. This means that this logistic regression model explains significantly more of the variability than an intercept-only model.

	Wald Chi-Square	df	Sig.
(Intercept)	61,576	1	,000
Age pedestrian	6,451	3	,092
Country	18,972	1	,000

Table 55: Type 3 statistics

In Table 556, it is shown that both the age of the pedestrian and the country do have an influence on a 90 per cent confidence level.

Goodness of fit measures	Value	Degrees of freedom	Value/df
Deviance	2,949	3	0,983
Pearson Chi-Square	2,867	3	0,956
Akaike's Information Criterion (AIC)	358,309		

Table 56: Goodness of fit of the logistic regression model

The Pearson Chi-Square value of 2.867 does not indicate a lack of fit. The Deviance divided by the number of degrees of freedom equals 0.983 and indicates no overdispersion problems, because this value is very close to 1.

7.2.2.2 Communication

Pedestrians turning their head and gender

		Head turning	No head turning	Total
Man	Frequency	139	69	208
	%	66,8	33,2	100
	Residual	-2	2	
Woman	Frequency	136	43	179
	%	76	24	100
	Residual	2	2	
Total		275	112	387
		71,1	28,9	100

Table 57: Cross table and residuals gender and head turning pedestrians

	Value	p-value
Pearsons Chi Square	3,917	0,048
Cramér's V	0,101	
Odds ratio	0,637	

Table 58: Statistical tests gender and head turning pedestrians

Men are significantly more frequently turning their head prior to crossing the road than women. 66.8% of the women in the sample turned their head, while 76% of the men in the sample performed this action.

The Pearson Chi-Square equals 3.917 with a corresponding p-value of 0.048. The phi measure of association equals 0.101. This means a rather weak association, but statistically significant with a confidence level of 95 per cent.

The odds for crossing the street without turning the head for women are 1.57 times higher than for men.

Age and head turning

		Head turning	No head turning	Total
Children	Frequency	25	9	34
	%	73.5%	26.5%	100.0%
	Residual	0.3	-0.3	
Young	Frequency	106	37	143
	%	74.1%	25.9%	100.0%
	Residual	1.0	-1.0	
Middle	Frequency	81	31	112
	%	72.3%	27.7%	100.0%
	Residual	0.3	-0.3	
Old	Frequency	63	35	98
	%	64.3%	35.7%	100.0%
	Residual	-1.7	1.7	
Total	Frequency	275	112	387
	%	71.1%	28.9%	100.0%

Table 59: Age and head turning pedestrians

	Value	p-value
Pearsons Chi Square	0.088	0.378

Table 60: Pearson Chi Square age and head turning pedestrians

There is no significant association between age and head turning. The Pearson Chi-Square value equals 0.088, resulting in a p-value of 0.378. All residuals also have absolute values less than 2.

Pedestrians turning their head and presence of a car

		Head turning	No head turning	Total
Car	Frequency	85	29	114
	%	74,6%	25,4%	100,0%
	Residual	1,1	-1,1	
No car	Frequency	198	88	286
	%	69,2%	30,8%	100,0%
	Residual	-1,1	1,1	
Total	Frequency	283	117	400
	%	70,8%	29,3%	100,0%

Table 61: Cross table and residuals presence of a car and head turning pedestrians

	Value	p-value
Pearsons Chi Square	1,119	0,29

Table 62: Pearson Chi Square presence of a car and head turning pedestrians

This association is not statistically significant. The Pearson Chi-Square value equals 1.119 with a corresponding p-value of 0.29.

Pedestrians turning head and country

		Head turning	No head turning	Total
Sweden	Frequency	102	38	140
	%	73	27	1
	Residual	0,7	-0,7	
Belgium	Frequency	181	79	260
	%	70	30	1
	Residual	-0,7	0,7	
Total	Frequency	283	117	400
	%	71	29	1

Table 63: Crosstable and residuals country and head turning pedestrians

This association is not statistically significant. The Pearson Chi-Square value equals 0.803 with a corresponding p-value of 0.370.

Red light violation and head turning

Pedestrians violating traffic signals are fortunately turning their head significantly more often than pedestrians complying with red signals.

		Head turning	No head turning	Total
Green	Frequency	200	108	308
	%	64.9	35.1	100
	Residual	-5.2	5.2	
Red	Frequency	75	4	79
	%	94.9	5.1	100
	Residual	5.2	-5.2	
Total	Frequency	275	112	387
	%	71.1	28.9	100

Table 64: Traffic light and head turning pedestrians

	Value	**p-value**
Pearsons Chi Square	27.519	0.000
Cramér's V	0.267	
Odds ratio	0.099	

Table 65: Statistical outputs traffic light and head turning pedestrians

Out of 79 individual pedestrians violating traffic signals, only 4 did not turn their head prior to crossing. For the pedestrians complying with traffic signals, 108 or 35.1 % did not turn their head. Pearson Chi-Square statistic equals 27,519, leading to a p-value of 0.000. The residuals are highly significant and equal 5.2 for pedestrians not turning their head and complying with traffic signals and -5.2 for pedestrians not turning their head and violating traffic signals. Phi association value equals 0.267 and is a moderate association. The odds ratio for not looking while having red light is 0.099. This means that pedestrians are much more likely to turn their heads when violating the traffic signal.

Motorized road users turning head and using directional lights

Practically all motorized road users turned their head prior to entering the intersection and used their directional lights. Due to the low number of car drivers not performing these steps, no conclusions can be drawn on this topic in combination with any other topic.

Regarding head turning, there is only a significant association between red light violation and head turning. Therefore, no logistic regression model has been estimated.

7.2.2.3 Yielding behaviour

Yielding by car drivers and age of pedestrians

The age of pedestrians does play a role. As the number of car drivers not yielding or yielding late is relatively small, Pearson Chi Square statistic cannot be used to discover associations. In this case, a Fisher's Exact Test has to be used. Fisher's Exact value equals 15,184 with a corresponding p-value of 0.006. This means that there is a statistically significant association between yielding behaviour and age of the pedestrian.

		Yielding early	Yielding late	Not yielding	Total
Child	Frequency	10	5	0	15
	%	66.7	33.3	0	100
	Residual	-1,9	3,9	-1,3	
Young	Frequency	26	2	5	33
	%	78.8	6.1	15.2	100
	Residual	-0,8	-0,5	1,5	
Middle	Frequency	36	0	4	40
	%	90	0	10	100
	Residual	1,4	-2,3	0,3	
Old	Frequency	23	2	1	26
	%	88.5	7.7	3.8	100
	Residual	0,8	0	-1	
Total	Frequency	95	9	10	114
	%	83.3	7.9	8.8	100

Table 66: Age pedestrian and yielding behaviour car driver

	Value	p-value
Fisher's Exact Test	15.184	0.006
Cramér's V	0.297	

Table 67: Statistical tests age pedestrian and yielding behaviour car driver

For middle aged and older persons, car drivers seem to be more inclined to yield early when looking at percentages. However, studying residuals, there is no clear message about where this difference is situated.

The yielding behaviour of car drivers does not depend on gender or age of those car drivers. Fisher's exact p-values equal 0.158 respectively 0.554. There is a tendency for women to be more inclined to yield early. The residual for women yielding early equals 2.0. However, this difference can be due to coincidence. On the other hand, we see that out of 27 people not yielding early, 23 were men. The number of males in the sample is higher than the number of females, but still nearly all females did yield.

		Yielding early	Yielding late	Not yielding	Total
Man	Frequency	95	12	11	118
	%	0,805	0,102	0,093	1
	Residual	-2	1,4	1,3	
Woman	Frequency	50	2	2	54
	%	0,926	0,037	0,037	1
	Residual	2	-1,4	-1,3	
Total	Frequency	145	14	13	172
	%	0,843	0,081	0,076	1

Table 68: Crosstable and residuals gender and yielding behaviour car drivers

	Value	p-value
Fisher's Exact Test	3.736	0.158
Cramér's V	0.108	

Table 69: Statistical tests gender and yielding behaviour car drivers

When combining yielding late and not yielding to one category that is compared to the category of yielding early, there is somewhat more data to rely on. For pedestrians, yielding late and not yielding caused either slight or even serious conflicts. In the case of yielding late, the evasive action is taken by either the pedestrian or the motorized road user, or both of them. In the case of not yielding, the pedestrian has to take evasive action.

This test is a Pearson Square Test that relies on differences between one category and the aggregate of all other categories.

In this case, the residuals equal 2.0 respectively -2.0. Pearson Chi-Square statistic shows a significant association between yielding behaviour and gender of the car driver.

		Yielding early	Yielding late/not yielding	Total
Man	Frequency	95	23	118
	%	80,5	19,5	100
	Residual	-2	2	
Woman	Frequency	50	4	54
	%	92,6	7,4	100
	Residual	2	-2	
Total	Frequency	145	27	172
	%	84,3	15,7	100

Table 70: Cross table and residuals gender and yielding early versus not early (car driver)

	Value	p-value
Pearsons Chi Square	4.088	0.043
Cramér's V	0.154	
Odds ratio	0.330	

Table 71: Statistical tests gender and yielding early versus not early (car driver)

Yielding and red light violation

		Yielding	Not yielding	Total
Green	Frequency	120	20	140
	%	85,7	14,3	1
	Residual	1,1	-1,1	
Red	Frequency	24	7	31
	%	77,4	22,6	1
	Residual	-1,1	1,1	
Total	Frequency	144	27	171
	%	84,2	15,8	1

Table 72: Cross table and residuals traffic light pedestrians and yielding behaviour car drivers

	Value	**p-value**
Pearsons Chi Square	1.313	0.188

Table 73: Pearsons Chi Square (1 sided test)

The yielding behaviour of car drivers does not depend on whether the pedestrian is violating red signals. The car driver is yielding early somewhat more often when the traffic light is green, but this difference is not statistically significant (p-value: 0.188).

7.2.3 Summary of the behavioural observations

According to the tests that have been performed with the data of the behavioural observations in Lund, Hasselt and Leuven, the following results can be summarized:

7.2.3.1 Red light violation

- Men are more inclined to violate traffic signals than women. This is in accordance with other behavioural studies at signalized intersections
- Young people are more inclined to violate traffic signals. This is also in accordance with other behavioural studies at signalized intersections
- At the Swedish intersection, red light were violated significantly more frequently than at the Belgian intersections
- A logistic regression model indicates that both age and country had a significant association with red light violation when both variables are included in the model
- There is no evidence for an association between red signal compliance and whether pedestrians are walking individually or in group
- There is no evidence for an association between red signal compliance and whether there is a traffic interaction between a pedestrian and a motorized road user

7.2.3.2 Communication

- Men turn their head prior to crossing more frequently than women
- There seems to be no age effect regarding to head turning
- Pedestrians do not seem to turn their head more often if there is an interaction with a motorized road user
- There seems to be no difference regarding head turning between the Swedish intersection on the one hand and the Belgian intersections on the other hand
- Practically all motorized road users turned their head before turning to the left or to the right and used their directional lights

7.2.3.3 Yielding

- Car drivers yield early more often for older pedestrians than for younger pedestrians
- Female car drivers yield early more often than male car drivers
- There is no evidence that car drivers yield early more often for pedestrians complying with traffic signals than for pedestrians violating traffic signals

8 Discussion

8.1 Behavioural Sequence Model and traffic conflicts

Above, the Behavioural Sequence Model has been discussed. This model can be used to describe interactions between pedestrians and motorized road users in six sequential steps. Every step must be performed properly and in time in order to have a safe interaction. The steps are searching, detection, evaluation, decision and action for both road users and the reaction of the vehicle for the motorized road user as a sixth step. If there is an error in one of these steps or if one of these steps is not performed in time, the process breaks down and there is a possibly dangerous situation. However, the pedestrian can compensate errors of the motorized road user and vice versa (Snyder and Knoblauch, 1971).

The traffic conflicts involving a pedestrian can also be described in this way. The traffic conflicts can be divided in some groups according to specific characteristics.

1. The first group can be seen as conflicts where one of the persons involved is violating the traffic signal. In the conflict data, there are only pedestrians violating the traffic signal. They scan the road and detect the presence of a car. However, they evaluate the situation incorrectly and decide to cross. By doing so, they enter themselves on a collision course. The car driver on the other hand is often not prepared to observe these pedestrians, is therefore not scanning those parts of the intersection where the pedestrian is coming from, and detects the pedestrian in a late stadium. The result is a late reaction and a traffic conflict.
2. The second group of traffic conflicts exists of conflicts where the car driver does not search for pedestrians when turning to the right or to the left. The consequence is a late detection of the pedestrian. The pedestrian on the other hand could have avoided a traffic conflict if he would have scanned the road before crossing. Because neither the car driver nor the pedestrian did detect the other in time, the evaluation of the situation, decision and action are performed in a late stadium and a traffic conflict occurs.
3. The third group of traffic conflicts exists of conflicts where the car driver does not detect the pedestrian in time. The pedestrian does detect the car driver in time, but he is already on the pedestrian crossing before the car driver makes his turning. This is typically the case when pedestrians meet right-turning car drivers on their right hand, or when pedestrians meet left-turning car drivers turning on their left hand. The car drivers do not detect the pedestrian in time.

The pedestrian observes the car driver in time and expects that the car driver has also detected him.

In the next paragraph, behavioural aspects will be discussed that seem to have a relation with the traffic conflicts that occurred between pedestrians and motorized road users.

8.2 Traffic conflicts and traffic behaviour

8.2.1 Traffic conflicts with pedestrians violating red signals

At the intersection in Lund, four out of nine traffic conflicts happened while the pedestrian was violating red signals. As pedestrians crossing the street while having red signal are not expected, car drivers often do not search in the areas alongside the road and do not detect the pedestrians. The consequence is a late detection of the pedestrian and a need to brake abruptly. On the other hand, the pedestrians violating red signals and involved in traffic conflicts did look and did detect the car in time. However, they made a wrong evaluation of the speed and distance of the oncoming car and decided to cross while there is no time.

Violating red signals is occurring frequently at the Swedish intersection. Out of 204 observed pedestrians or groups of pedestrians, 72 violated red signals. If we assume that the traffic behaviour of pedestrians in the conflict observation period is the same as in the behavioural observation period, then we can estimate the probability of getting involved in a traffic conflict when violating and when obeying traffic signals.

During 8 hours of observation, there were 72 cases where one or more pedestrians violated traffic signals (or 9 pedestrians/hour). During 30 hours of conflict observations, there were 4 pedestrian conflicts while pedestrians were violating traffic signals (or 0,133 conflicts/hour). This means that, on average, there was a serious traffic conflict for every 68^{th} pedestrian. There were 132 cases where one or more pedestrians complied with traffic signals (or 14,667 pedestrians/hour). During 30 hours of conflict observations, there were 5 pedestrian conflicts while pedestrians were complying with traffic signals (or 0,167 conflict/hour). This means that, on average, there was a traffic conflict for every 88^{th} pedestrian. At the Swedish intersection, pedestrians seem to be involved in a traffic conflict 30% more frequently if they are walking against red light.

If only focusing on traffic interactions, the image gets still more clear. This is not surprising, because traffic conflicts always occur in case of a traffic interaction. In this case, we look at all pedestrians interacting with a motorized road user. 31 pedestrians or groups of pedestrians complied with traffic signals while interacting with a car (or 3,875 pedestrians/hour). 16 pedestrians or groups of pedestrians violated red signals while interacting with a car (or 2 pedestrians/hour). This means that, on average, there was a traffic conflict for every 29th pedestrian complying with red signals and for every 12th pedestrian violating the traffic signals. In other words, pedestrians at this intersection seem to be involved in a traffic conflict 141% more frequently if they are violating the traffic signal.

Unfortunately, the numbers are very small and it is therefore not possible to get statistical evidence for this statement. However, it is an indication that, when violating red signals, pedestrians are not always crossing responsibly. They are not always making sure that they can cross safely without disrupting the oncoming car traffic. The fact that red light violation does not depend on the presence of a car seems to confirm this.

8.2.2 Traffic conflicts and pedestrians' looking behaviour

Most pedestrians that have been observed during the 24-hour observation periods did turn their heads before crossing and can make sure that there is no danger. However, when looking at the traffic conflicts, the image is very different. Out of 14 traffic conflicts, there are 8 conflicts where the pedestrian is not turning his head before crossing. In most occasions, the pedestrian looks to the ground. If we only look at traffic conflicts during green phase, there is an even higher percentage of the traffic conflicts occurring when the pedestrian is not looking properly.

The looking behaviour at the Swedish intersection is not very different from the looking behaviour at the Belgian intersections. When focusing on the intersections in Lund and Hasselt, we see that out of 255 pedestrians walking alone, 69 (27.1 percent) are not turning their head before crossing. The observation time at these intersections was 16 hours. This means an average of 4.3125 pedestrians not turning their heads per hour. Out of 14 traffic conflicts with pedestrians, there were 8 conflicts where the pedestrians did not turn their heads before crossing. The total observation time was 60 hours, resulting in an average of 0.1333 traffic conflicts per hour. When assuming that the pedestrians involved in traffic conflicts are not behaving differently from the pedestrians observed during the behavioural observations, we can assume 1 traffic conflict for every 32nd pedestrian. 186 pedestrians did turn their heads before crossing, resulting in an average of 11.625 pedestrians per hour. In 6 traffic conflicts, the pedestrians were turning their heads prior to crossing. The total observation time was 60 hours, resulting in an average of 0.1 traffic conflicts per hour. 1 traffic conflict for every 116th pedestrian is assumed. In other words, pedestrians at these intersections seem to be involved in traffic conflicts 263% more frequently if they are not turning their heads before crossing.

Therefore, pedestrian looking behaviour could play an important role in the occurrence of traffic conflicts. Again, there are a lot of assumptions that have been made and the number of traffic conflicts is very low, but there is an indication that looking behaviour could play an important role.

When only considering those cases where there was a traffic interaction, the image gets still more clear because all traffic conflicts only occur in case of a traffic interaction. There are 60 cases with individual pedestrians interacting with car drivers. Out of these 60 pedestrians, 13 did not turn their heads (0.8125 per hour). This means 1 traffic conflict for each 6th pedestrian not turning his head. 47 pedestrians did turn their heads (2.9375 per hour). This means 1 traffic conflict for each 30th pedestrian turning his head. This indicates pedestrians not turning their heads to be 5 times more likely to get involved in a traffic conflict.

It is important to emphasize the uncertainty associated with this analysis, because the pedestrians involved in traffic conflicts are not necessarily the same pedestrians as the pedestrians observed in the behavioural observation periods. However, the number of traffic conflicts with pedestrians not turning their heads is higher than one might expect based on the percentage of pedestrians not turning their heads under the assumption of independence.

8.2.3 Yielding and traffic conflicts

In all traffic conflicts, either the pedestrian or the car driver did not yield early. We see that, out of 172 traffic interactions, there were 145 traffic interactions (84.3%) where the car driver gave priority early. Pedestrians get priority in most of the cases, but not always. The consequence is that pedestrians do expect to get priority. However, in 15.7 per cent of the cases, the pedestrian did not get priority early. In 7.6 per cent of the cases, the car driver went first and the pedestrian had to take evasive action. These situations do not always end up in a traffic conflict. Pedestrians can compensate for the failures that this group of drivers apparently makes. However, if pedestrians do not compensate for these failures, the situation ends up with a traffic conflict.

8.2.4 Age and gender pedestrians

Notwithstanding the fact that there is a very limited number of traffic conflicts, it is remarkable that, in 10 out of a total of 14 conflicts, the pedestrian is male (71.4%). In 8 of the cases the pedestrian is young (57%). These percentages are high in comparison with the total rate of males (54%) and young persons (38%) observed at these intersections. The chance for getting involved in a traffic crash is also higher for males and young persons, so this higher chance seems to be reflected in traffic conflict data as well.

8.3 Traffic volume and traffic conflicts

The traffic volume at the intersection in Lund is quite different from the traffic volume at the intersection in Hasselt. There is more motorized traffic and less bicycle and pedestrian traffic at the intersection in Belgium. Research has shown that traffic accidents involving pedestrians with left-turns are much more likely to occur in case there is a high traffic volume (Leden, 2002 & Yan and Radwan, 2007). The reason for this could be that there are only small gaps in the traffic flow. The car driver is mostly looking at car traffic and does not concentrate on pedestrian traffic.

Despite the low numbers of traffic conflicts between pedestrians and motorized road users, this pattern is also recognizable at the intersections in Lund and Hasselt. At the intersection in Hasselt, out of five traffic conflicts with pedestrians, in four traffic conflicts a left turning car was involved. At the intersection in Lund, only one traffic conflict out of nine was happening when a car was turning to the left. The traffic volume of motorized traffic in Hasselt was much higher than in Lund. That is why the traffic volume seems to have an influence on the nature of traffic conflicts between pedestrians and motorized traffic.

At the intersection in Lund, there were 48 traffic interactions measured during the observation period. At the intersection in Hasselt, there were also 48 traffic interactions. However, in Lund, only one leg was observed at the time. The observation period was divided in four blocks of 2 hours. This means that we could assume the total number of traffic interactions to be approximately 4 times higher in Lund than in Hasselt. The number of traffic conflicts in Lund was higher than the number of traffic conflicts in Hasselt (9 traffic conflicts in Lund, while 5 traffic conflicts in Hasselt). However, if we take into account this higher number of traffic interactions, there are more traffic conflicts for each traffic interaction in Hasselt than in Lund. This result conforms to former research that stated that the risk per pedestrian at signalized intersections decreases with a growing number of pedestrians (Leden, 2002).

8.4 Country and red light violation

At the Swedish intersection, people are much more likely to violate the traffic lights than at the Belgian intersections. It has been shown that there are more young people at the Swedish intersection and that young people are more likely to violate the traffic lights. However, there is still an effect of country as well. Both age and country were statistically significant.

The question is why people at the Swedish intersection tend to violate the traffic lights so much more frequently than people at both Belgian intersections. There are different possible reasons for that:

- If the intersections in Lund and Hasselt are representative for all urban intersections with a similar layout, then there could be a difference in traffic culture. Pedestrians who feel safer could take more risks (Ibrahim et al., 2011). In some cases, the car drivers yield for pedestrians even when they violate the traffic signal. Nevertheless, if we look at the total pedestrian fatality rate in Belgium and Sweden, Sweden performs nearly twice as well as Belgium (European Commission, 2012) which does not seem to confirm this hypothesis.
- Differences between red signal compliance could be due to differences in the probability of getting a fine when violating the red signal. In Sweden, it is illegal to violate the traffic signal for pedestrians. However, there is no fine for doing so if not causing a traffic accident. Police officers do not give penalties to pedestrians violating the traffic light (Vägverket, 2012).
- The traffic volume is very different. At the Swedish intersection, there is much less motorized traffic than at the Belgian intersections. The number of vulnerable road users is sometimes even higher than the number of motor vehicles. This difference in traffic volume could imply that pedestrians feel safer to move around and cross, also outside the safe periods. Sometimes, there is no traffic, so then it is safe to cross. However, the analysis above shows that the likeliness to violate the traffic signal is not dependent on whether there is a traffic interaction. On the other hand, there could be differences in traffic interactions between one pedestrian and one car, and between a pedestrian and a long queue of oncoming motor vehicles. The link between traffic volume and red light violation should be studied on a larger scale to draw clearer conclusions.
- As discussed above, pedestrians are more likely to violate the traffic signal if the waiting time increases (Thorson et al., 2003 & Kennedy and Sexton, 2009). However, the average waiting time at the intersection in Lund was much smaller than the average waiting time at the intersection in Hasselt and Leuven.

8.5 Further research

This explorative research project has been conducted on a very small scale. There are some results that are remarkable and that could be studied on a larger scale, perhaps using video processing techniques. The following hypotheses that arose from this explorative study can be tested:

1. At Swedish intersections, red light violation is more prevalent than at Belgian intersections OR Red light violation is more prevalent in case of low motorized volume or high pedestrian volume
2. Red light violation by pedestrians does not depend on whether there are oncoming vehicles
3. Pedestrians neglecting the traffic signal are more likely to be involved in traffic conflicts than pedestrians respecting the traffic signal
4. Pedestrians not turning their heads before crossing are more likely to be involved in traffic conflicts than pedestrians turning their heads before crossing

In this research project, the conflict observations have been separated from the behavioural observations. This is because of the fact that there was only one observer. If there would be more observers, the same data could have been used for both the conflict observations and the behavioural observations. In further studies, this can be used to enhance the link between normal traffic interactions and traffic conflicts. The prevalence of certain behavioural aspects can then be linked directly to the prevalence of certain types of traffic conflicts. In this research project, the assumption has been made that the nature of traffic interactions is similar during the conflict observation periods and during the behavioural observation periods.

In order to generalize the results of behavioural observations, it is necessary to increase the number of locations. The scope of this research could also be extended to other types of intersections and other types of traffic interactions.

On a national scale, the traffic safety of pedestrians in Sweden is much better than in Belgium. However, at the signalized intersection in Lund, less favourable pedestrian behaviour has been observed. Despite the lower waiting time, red light violation was much more prevalent at the intersection in Lund than at the intersections in Hasselt and Leuven. The conflict observations indicated a higher probability of being involved in a traffic conflict when violating the traffic signal. According to Kennedy and Sexton (2009), 60 per cent of all pedestrian fatalities happen when the pedestrian was violating the traffic signal. The combination of drivers' expectations and relatively high speeds could explain this figure.

Finally, in further research, the influence of speed behaviour by car drivers could be analysed. Using video processing techniques, the speed of approaching vehicles can be measured continuously. Any patterns in speed behaviour prior to traffic conflicts, other than deceleration, could give some more information. Is there a connection between the speed of vehicles when turning to the left or to the right and the prevalence of traffic conflicts? Or does the approach speed before the intersection is reached play a role?

8.6 Shortcomings of the current research

In order to make a cross-national comparison of behavioural aspects and traffic conflicts as a traffic safety outcome, the number of locations should be much higher than was possible for this research project. Therefore, the focus in this research project is on the relationship between normal traffic behaviour and traffic conflicts. Still, to draw conclusions with a higher confidence level, there should be more data available: more traffic interactions and most important, more traffic conflicts.

Despite an extensive trial to find an intersection in Belgium that is as similar as possible to the selected intersection in Sweden, the traffic volumes are very different. However, there has been chosen to study those intersections because the layout is very similar. The result is that it is not clear whether differences in traffic behaviour are due to the fact that the traffic volume is different or due to the fact that the intersections are located in different countries.

Due to the low number of traffic interactions, traffic conflicts and traffic crashes, it is not possible to test the validity of traffic behaviour as a proxy for traffic conflicts or traffic conflicts as a proxy for traffic crashes. Nevertheless, by describing the behavioural aspects occurring prior to and during a traffic conflict, an attempt has been made to link normal traffic behaviour and traffic interactions to traffic conflicts. Beside this, the results of the observations are mostly in accordance with earlier research about traffic behaviour, traffic conflicts and traffic crashes and do have theoretical underpinnings in the Behavioural Sequence Model (Snyder and Knoblauch, 1971).

Because of the fact that the behavioural observations and the conflict observations have been conducted by a single observer, reliability of the behavioural data and conflict data can be questioned. However, by videotaping all observations at the intersections in Lund and Hasselt, it was possible to look back at all traffic conflicts and enhance the conflict descriptions.

In later research containing cross-national observations, it could be more feasible to find similar intersections if non-signalized intersections would be studied. Signalized intersections are already specific intersections. It would be likely to be easier to find non-signalized intersections with a similar traffic volume and a similar layout. It was a very difficult task to find comparable intersections in Sweden and Belgium. The traffic system and the spatial planning in those countries are different and this could be reflected in the nature of the traffic interactions.

9 Conclusions

In this chapter, the results of this explorative research project will be summarized shortly.

- *How do pedestrians and motorized road users interact at signalized intersections?*

    - *To which degree do pedestrians violate the traffic signal when there is a traffic interaction?*

When there is a traffic interaction, 18.1 per cent of the pedestrians did violate the traffic signal. If we look at the Swedish intersection, 33 per cent of the pedestrians did violate the traffic signal when there was an oncoming car. At the Belgian intersections, this percentage is only 11 per cent.

- *To which degree do car drivers violate the traffic signal when there is a traffic interaction?*

During 24 hours of behavioural observations, there was no single car driver violating the traffic signal when there was a traffic interaction between a pedestrian and a car driver.

- *To which degree do car drivers yield to pedestrians when they cross the street at a signalized intersection having green light?*

Most car drivers did yield to pedestrians when they turned to the left or to the right. Still, there was a group of 16 per cent that did not yield early. 8 per cent of the car drives did not yield at all.

- *To which degree do pedestrians yield to car drivers when they cross the street at a signalized intersection having red light?*

Only 22 per cent of the pedestrians did yield to car drivers when having red light, although they should not hinder the car drivers.

- *To which degree do car drivers look before turning at a signalized intersection?*

Most car drivers did look before turning to the left or to the right. Only 2 per cent of the car drivers failed to do so. However,

- *To which degree do pedestrians turn their heads before crossing the street at a signalized intersection?*

71 per cent of the pedestrians did turn their heads before crossing the street at a signalized intersection.

- *To which degree do car drivers use their directional lights at signalized intersections?*

96 per cent of the car drivers interacting with pedestrians did use their directional lights.

- *Are there differences in red light compliance, yielding behaviour, looking behaviour and use of directional lights between males and females?*

Males violate traffic lights more frequently than women. Males tend to turn their heads more frequently than females. There are no differences in the looking behaviour of car drivers. The use of directional lights is also not dependent on gender. However, yielding behaviour seems to depend on gender: females yield early more often than males.

- *Are there differences in red light compliance, yielding behaviour, looking behaviour and use of directional lights between different age groups?*

Young pedestrians do violate the traffic signal much more frequently than all other age groups. Older people do comply more frequently. There seems to be no age effect of head turning and yielding.

- *Are there differences in red light compliance, yielding behaviour, looking behaviour and use of directional lights between a Swedish intersection and the Belgian intersections observed?*

At the Swedish intersection, red light violation is much more prevalent than at the Belgian intersections. It is remarkable that the pattern is not really different at the intersection in Hasselt and the intersection in Leuven.

- *What kinds of traffic conflicts do occur at urban signalized intersections?*

During the conflict observations, there are several types of traffic conflicts that occurred. At the intersection in Lund, there were some traffic conflicts that occurred when the pedestrian was violating the traffic signal. Most traffic conflicts happen when the motorized road user turns to the left or to the right. There is an indication that traffic conflicts with left-turning vehicles are more prevalent at intersections with high traffic volumes, because at the intersection in Hasselt, nearly all traffic conflicts with pedestrians occurred with left turning vehicles.

- *Which behavioural characteristics in interactions between pedestrians and motorized road users at signalized intersections tend to be related to traffic conflicts?*

- *Are traffic conflicts more likely to occur when violating the traffic signal?*

Although the behavioural observations and the conflict observations have not been conducted simultaneously, the assumption has been made that the circumstances of normal traffic interactions are not fundamentally different from the circumstances under which traffic conflicts at the same intersections occur. Derived from the data, it can be shown that there is a higher probability to get involved in a traffic conflict when pedestrians are violating the red signal. However, this result should be interpreted with great uncertainty regarding the non-simultaneous data collection and the low number of traffic interactions and, more important, the low number of traffic conflicts.

- *Are traffic conflicts more likely to occur when not looking?*

Pedestrians not turning their heads seem to be at a substantially higher risk for getting involved in a traffic conflict. However, this result should be interpreted with great uncertainty regarding the non-simultaneous data collection and the low number of traffic interactions and, more important, the low number of traffic conflicts.

- *Are traffic conflicts more likely to occur when not using the directional lights?*

There are no traffic conflicts where the directional lights were not used. Therefore, it is not possible to indicate whether or not there is a higher risk if car drivers would not use their directional lights.

- *Do the processes that lead to traffic conflicts differ between the Belgian and the Swedish intersection?*

Based on the traffic conflicts that occurred at the intersections in Sweden and Belgium, there are several facts that are remarkable and interesting for further studies. At the intersection in Sweden, red light violation played a role in 4 out of 9 traffic conflicts. As red light violation seems to be much more prevalent at the Swedish intersection, it is logical that there are to be expected more traffic conflicts with pedestrians violating the red signals. Another remarkable fact is the occurrence of traffic conflicts with left turning traffic. Most of the traffic conflicts (4 out of 5) at the Belgian intersection, occurred when the car driver turned to the left. At the Swedish intersection, 8 out of 9 traffic conflicts involving pedestrians and car drivers happened when the car driver turned to the right or was driving straight on. A possible reason for this difference could be the traffic volume which is much higher at the intersection in Hasselt than at the intersection in Lund.

A last remark is the conflict speed. At the Belgian intersection, the conflict speed tends to be somewhat higher than at the Swedish intersection. This result is in accordance with the mean speeds of traffic during normal condition which is also somewhat higher at the Swedish intersection than at the Belgian intersection.

The results of this explorative behavioural and conflict study are not to be generalized to other signalized intersections, nor can the intersections that have been studied be generalized to the whole countries of Sweden and Belgium. However, in further research, the topics studied here could be studied more extensively, using more different locations and possibly automated video processing techniques.

10 References

Agresti, A. (2007). *An Introduction to Categorical Data Analysis* (2nd ed.). Wiley-Interscience.

Antov, D., & Sööt, S. (2002). Toward Improved Traffic Safety: Road Use Perception and Behavior in Estonia. *Transportation Research Record*, *1818*(1), 1–6. doi:10.3141/1818-01

Autey, J., & Sayed, T. (2012). Operational performance comparison of four unconventional intersection designs using micro-simulation. *Journal of Advanced Transportation*.

Autey, J., Sayed, T., & El Esawey, M. (2012). Operational performance comparison of four unconventional intersection designs using micro-simulation. *Journal of Advanced Transportation*. doi:10.1002/atr.181

Berntman, M. (1994). Metoder för insamling av uppgifter om svårt trafikskadade : några källor och tekniker. Lunds tekniska högskola, instutionen för teknik och samhälle, trafik och väg.

BIVV. (nd). BIVV fiche Snelheid. BIVV.

Brewer, M., Fitzpatrick, K., Whitacre, J., & Lord, D. (2006). Exploration of Pedestrian Gap-Acceptance Behavior at Selected Locations. *Transportation Research Record: Journal of the Transportation Research Board*, *1982*(-1), 132–140. doi:10.3141/1982-18

Brüde, U., & Larsson, J. (1992). *Trafiksaakerhet i taatortskorsningar*.

Chin, H.-C., & Quek, S.-T. (1997). Measurement of traffic conflicts. *Safety Science*, *26*(3), 169–186.

Crewson, P. (2006). Coefficients for Measuring Association. Retrieved from http://www.acastat.com/Statbook/chisqassoc.htm

Das, S., Manski, C. F., & Manuszak, M. D. (2005). Walk or wait? An empirical analysis of street crossing decisions. *Journal of Applied Econometrics*, *20*(4), 529–548. doi:10.1002/jae.791

De Ceunynck, T. (2012, March 12). *Surrogate Safety Measures*. Lecture presented at the Lecture Impact Infrastructure, Diepenbeek.

Dumbaugh, E., & Li, W. (2011). Designing for the Safety of Pedestrians, Cyclists and Motorists in Urban Environments. *Journal of the American Planning Association*, (77), 69–88.

Ekman, L. (1988). *Fotgängares risker på markeret övergångsställe jämfört med andra korsningspunkter.* (No. Bulletin 76/3000). Institutionen för trafikteknik, LTH.

Ekman, L. (1996). *On the treatment of flow in traffic safety analysis, a non-parametric approach*. Lund: Institutionen för trafikteknik, LTH.

Ekman, L. (1997, May 23). Fotgängares situation vid övergångsställe. Institutionen för trafikteknik, LTH.

Ekman, L., & Hydén, C. (1999). Pedestrian Safety in Sweden. FHWA.

El-Basyouny, & Sayed, T. (in review). Safety Performance Functions using Traffic Conflicts. *Safety Science*.

Elvik, R., Borger Mysen, A., & Vaa, T. (1997). *Trafikksikkerhetshåndbok : oversikt over virkninger, kostnader og offentlige ansvarsforhold for 124 trafikksikkerhetstiltak*. Oslo: Transportøkonomisk Institutt.

Elvik, R., & Hoye, A. (2009). *The Handbook of Road Safety Measures*. Bingley: Emerald Group Publishing.

Esma, G. (2010). Cultural values and governance quality as correlates of road traffic fatalities: A nation level analysis. *Accident Analysis & Prevention*, *42*(6), 1894–1901. doi:10.1016/j.aap.2010.05.010

European Commission. (2012). Road accidents in the European Union using a Geographical Information System (GIS). *European Commission Road Safety*. Retrieved May 20, 2012, from http://ec.europa.eu/transport/road_safety/specialist/statistics/gis/index_en.htm

Evans, L. (2004). *Traffic Safety*. Science Serving Society.

Ewadh, H. A., & Neham, S. S. (2011). Conflict to study safety at four leg-signalised intersections. *Proceedings of the ICE-Transport*, (164).

Fehlig Mitman, M., Cooper, D., DuBose, B., & Pande, S. (2010). Driver/Pedestrian Behavior at Marked and Unmarked Crosswalks in the Tahoe Basin. University of California.

Gaygısız, E. (2010). Cultural values and governance quality as correlates of road traffic fatalities: A nation level analysis. *Accident Analysis & Prevention*, *42*(6), 1894–1901.

Green, M. (2000). “How long does it take to stop?” Methodological Analysis of Driver Perception-Brake Times. *Transportation Human Factors*, *2*(3), 195–216.

Harkey, D. L., Srinivasan, R., & Baek, J. (2008). Accident Modification Factors for Traffic Engineering and ITS Improvements. National Cooperative Highway Research Program.

Hauer, E. (1971). Accidents, overtaking and speed control. *Accident Analysis & Prevention*, *3*, 1–13.

Hauer, E., & Garder, P. (1986). Research into the validity of the traffic conflicts technique. *Accident Analysis & Prevention*, *18*(6), 471–481. doi:10.1016/0001-4575(86)90020-5

Hawkins, R. K. (1988). Motorway Traffic Behaviour in Reduced Visibility Conditions. Presented at the Vision in Vehicles II. Second International Conference on Vision in Vehicles. Retrieved from http://trid.trb.org/view.aspx?id=926202

Holmberg, B., & Hydén, C. (2005). *Trafiken i samhället*. Lund: Studentlitteratur.

Hunter, W. W., Stutts, J. C., Pein, W. E., & Cox, C. L. (1995). Pedestrian and bicycle crash types of the early 1990’s. Federal Highway Administration.

Ibrahim, J. M., Day, H., Hirshon, J. M., & El-Setouhy, M. (2011). Road risk-perception and pedestrian injuries among students at Ain Shams University, Cairo, Egypt. *Journal of injury & violence research*. doi:10.5249/jivr.v4i2.112

Kennedy, J., & Sexton, B. (2009). Literature review of road safety at traffic signals and signalised crossings. TRL.

Knoblauch, R. L., Nitzburg, N., & Seifert, R. L. (2001). Pedestrian Crosswalk Case. Studies: Richmond, Virginia;. Buffalo, New York; Stillwater,. Minnesota. Center for Applied Research for the Federal Highway Administration.

Knoblauch, R. L., Pietrucha, M. T., & Nitzburg, N. (1996). Field studies of pedestrian walking speed and start-up time. *Transportation Research Record*, (1538), 27–38.

Kraay, J. H., Horst, A. R. A. van der, & Oppe, S. (1986). *Handleiding voor de conflictobservatietechniek DOCTOR (Dutch Objective Conflict Technique for Operation and Research).* Leidschendam: Stichting Wetenschappelijk Onderzoek Verkeersveiligheid.

Lascala, E. A., Gerber, D., & Gruenewald, P. J. (2000). Demographic and environmental correlates of pedestrian injury collisions: a spatial analysis. *Accident; Analysis and Prevention*, *32*(5), 651–658.

Laureshyn, A. (2010). *Application of automated video analysis to road user behaviour (PhD Dissertation)*. Lund: Lund University Department of Technology and society Traffic Engineering.

Leden, L. (2002). Pedestrian risk decrease with pedestrian flow. A case study based on data from signalized intersections in Hamilton, Ontario. *Accident Analysis & Prevention*, *34*(4), 457–464.

Lord, D. (1995). Pedestrian conflicts and Left-Turning Traffic at Signalized Intersections. Université de Montréal-Ecole Polytechnique.

Lord, D., Smiley, A., & Haroun, A. (1998). Pedestrian accidents with left-turning traffic at signalized intersections: characteristics, human factors and unconsidered issues.

McClave, J. T., George Benson, P., & Sincich, T. (2006). *Statistiek Een inleiding voor het hoger onderwijs*. Amsterdam: Pearson Prentice Hall.

Melinder, K. (2007a). Socio-cultural characteristics of high versus low risk societies regarding road traffic safety. *Safety Science*, *45*(3), 397–414.

Melinder, K. (2007b). Socio-cultural characteristics of high versus low risk societies regarding road traffic safety. *Safety Science*, *45*(3), 397–414. doi:10.1016/j.ssci.2006.07.004

Mitra, S., & Washington, S. (2007). On the nature of over-dispersion in motor vehicle crash prediction models. *Accident Analysis & Prevention*, *39*(3), 459–468. doi:10.1016/j.aap.2006.08.002

Muhlrad, N. (1993). Integration and evaluation of safety measures: scientific and institutional requirements. Proceedings of the Asian Road Safety Conference, Kuala-Lumpur.

Nilsson, G. (2000). *Hastighetsförändringar och trafiksäkerhetseffekter. "Potensmodellen".* (No. VTI notat 76-2000). Statens väg- och forksningsinstitut.

Nordfjærn, T., Jørgensen, S., & Rundmo, T. (2011). A cross-cultural comparison of road traffic risk perceptions, attitudes towards traffic safety and driver behaviour. *Journal of Risk Research*, *14*(6), 657–684. doi:10.1080/13669877.2010.547259

Oxley, J. A., Ihsen, E., Fildes, B. N., Charlton, J. L., & Day, R. H. (2005). Crossing roads safely: An experimental study of age differences in gap selection by pedestrians. *Accident Analysis & Prevention*, *37*(5), 962–971. doi:10.1016/j.aap.2005.04.017

Özkan, T. (2006). *The regional differences between countries in traffic safety: A cross-cultural study and Turkish Case*.

Perkins, S. R., & Harris, J. I. (1967). Traffic conflict characteristics: Accident potential at intersections. Highway Research Board Washington.

Persson, H. (1987). Kommunikation mellan fotgängare och bilförare. Institutionen för trafikteknik, LTH.

Poch, M., & Mannering, F. (1996). Negative binomial analysis of intersection accident frequencies. *Journal of Transportation Engineering*, 5, (122), 105–113.

Reinhardt-Rutland, A. H. (1991). NOTE ON RISK-HOMEOSTASIS AND NIGHT-TIME PEDESTRIAN CASUALTIES. *Perceptual and Motor Skills*, *73*(1), 50–50. doi:10.2466/pms.1991.73.1.50

Roper, V. J., & Howard, E. A. (1938). Seeing with motor car headlamps. *Transactions Illuminating Engineering Society*, *33*(5), 417–438.

Rosén, E., & Sander, U. (2009). Pedestrian fatality risk as a function of car impact speed. *Accident Analysis & Prevention*, *41*(3), 536–542. doi:10.1016/j.aap.2009.02.002

Rosenbloom, T., Nemrodov, D., & Barkan, H. (2004). For heaven’s sake follow the rules: pedestrians’ behavior in an ultra-orthodox and a non-orthodox city. *Transportation Research Part F: Traffic Psychology and Behaviour*, *7*(6), 395–404. doi:10.1016/j.trf.2004.10.004

Rune, E. (2009). *Handbook of Road Safety Measures*. (E. Rune, Ed.) (2nd Revised ed.). Emerald Group Publishing Limited.

Schmidt, S., & Färber, B. (2009). Pedestrians at the kerb – Recognising the action intentions of humans. *Transportation Research Part F: Traffic Psychology and Behaviour*, *12*(4), 300–310. doi:10.1016/j.trf.2009.02.003

Seim, R. (1994). *Analyse av kryssulykker i Akershus fylke 1990-93. Hovedoppgave i samferdselsteknikk høsten 1994.* Trondheim: Norges Tekniske Høgskole, Institutt for samferdselsteknikk.

Shbeeb, L. (2000). *Development of a traffic conflicts technique for different environments. A comparative study of pedestrian conflicts in Sweden and Jordan (PhD Dissertation)*. Lund Institute of Technology Department of Technology and Society Traffic and Road Lund University.

Shinar, D. (2007). *Traffic Safety and Human Behavior*. Amsterdam: Elsevier.

Sisiopiku V.P., & Akin D. (2003). Pedestrian behaviors at and perceptions towards various pedestrian facilities: an examination based on observation and survey data. *Transportation Research Part F: Traffic Psychology and Behaviour*, *6*(4), 249–274. doi:10.1016/j.trf.2003.06.001

Snyder, M. G., & Knoblauch, R. L. (1971). Pedestrian Safety: the identification of precipitating factors and possible countermeasures. National Highway Traffic Safety Administration.

Spek, A. C. E., Wieringa, P. A., & Janssen, W. H. (2006). Intersection approach speed and accident probability. *Transportation Research Part F: Traffic Psychology and Behaviour*, *9*(2), 155–171. doi:10.1016/j.trf.2005.10.001

Sullivan, J. M., & Flannagan, M. J. (2001). Characteristics of Pedestrian Risk in Darkness. University of Michigan Transportation Research Institute.

Svensson, Å. (1998). *A method for analysing the traffic process in a safety perspective*. Lund: University of Lund Lund Institute of Technology Department of Traffic Planning and Engineering.

Svensson, Å., & Hydén, C. (2006). Estimating the severity of safety related behaviour. *Accident Analysis & Prevention*, *38*(2), 379–385.

SWOV. (n.d.). SWOV-Factsheet Voetgangersveiligheid. *SWOV*. Retrieved May 20, 2012, from http://www.swov.nl/NL/Research/factsheets.htm#V

Thorson, O., Estevadeordal, J., Parés, J., & Thomsen, J. (2003). Pedestrian behaviour and want of discipline in traffic light controlled intersections in different towns in catalunya. Degree of discipline: pedestrians, motorists and car drivers. Walk21.

Tom, A., & Granié, M.-A. (2011). Gender differences in pedestrian rule compliance and visual search at signalized and unsignalized crossroads. *Accident Analysis & Prevention*, *43*(5), 1794–1801. doi:10.1016/j.aap.2011.04.012

Trafikvärket. (2012). Trafikregler. Frågor och svar. Trafikvärket. *Trafikvärket*. Retrieved April 3, 2012, from http://www22.vv.se/hitodit_templates/HD_Page____19243.aspx

Várhelyi, A. (1998). Drivers' speed behaviour at a zebra crossing: a case study. *Accident Analysis & Prevention*, *30*(6), 731–743. doi:10.1016/S0001-4575(98)00026-8

Várhelyi, A. (2011, August 15). *Traffic Conflict Course*. Lund.

Yan, X., & Radwan, E. (2007). Effect of Restricted Sight Distances on Driver Behaviors during Permitted Left-Turn Phase at Signalized Intersections. *Transportation Research Part F*, *10*(4), 330–344.

Zhu, M., Cummings, P., Chu, H., & Xiang, H. (2008). Urban and rural variation in walking patterns and pedestrian crashes. *Injury Prevention: Journal of the International Society for Child and Adolescent Injury Prevention*, *14*(6), 377–380. doi:10.1136/ip.2007.018234

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