ANALYZING INTERACTIONS BETWEEN PEDESTRIANS AND MOTOR VEHICLES AT TWO-PHASE SIGNALIZED INTERSECTIONS-AN EXPLORATIVE STUDY COMBINING TRAFFIC BEHAVIOUR AND TRAFFIC CONFLICT OBSERVATIONS IN A CROSS-NATIONAL CONTEXT

JORAM LANGBROEK[1], TIM DE CEUNYNCK[1], STIJN DANIELS[1], ÅSE SVENSSON[2], ALIAKSEI LAURESHYN[2], TOM BRIJS[1], GEERT WETS[1],

[1]TRANSPORTATION RESEARCH INSTITUTE, HASSELT UNIVERSITY, WETENSCHAPSPARK 5, BUS 6, BE-3590 DIEPENBEEK, BELGIUM
[2]TRAFFIC AND ROADS, DEPARTMENT OF TECHNOLOGY AND SOCIETY, FACULTY OF ENGINEERING LTH, LUND UNIVERSITY, BOX 118, 22100 LUND, SWEDEN

Abstract

Traffic safety has mainly been studied using crash data, which have some important shortcomings, including random variation because of the low number of crashes, underreporting and the limited availability of behavioural and situational aspects about the crashes. Therefore, there is a need for surrogate safety measures. Observational studies do not suffer from the aforementioned limitations, and can contribute to the understanding of the complex way road users interact.

This study explores the road safety at two-phase signalized intersections in a cross-national context by applying conflict and behavioural observations at three intersections in Sweden and Belgium. Variables collected are for instance the number of pedestrians, age and gender of involved road users and behavioural aspects like yielding behaviour and looking behaviour. Additionally, the Swedish Traffic Conflict Technique has been applied to collect information about traffic conflicts at one Belgian and one Swedish two-phase signalized intersection.

Generalizability of the results of this explorative research cannot be claimed. However, some interesting issues and hypotheses arose that should be analyzed into more detail. Red light violation was much more prevalent among the pedestrians at the Swedish intersection compared to the Belgian intersections. At the Swedish intersection, violating the red light is independent of the presence of a vehicle, which indicates that pedestrians do not only violate the red light when no vehicles are present. In addition, it has been found that pedestrians who do not look before they cross the signalized intersection have an increased risk to get involved in a traffic conflict.

Introduction

More than 1,2 million people die annually because of traffic accidents. Far more people get injured and the societal cost of traffic accidents is huge (Elvik et al, 2008). Traffic safety has mainly been studied using crash data. However, there are several shortcomings of accident analysis. Firstly, crashes are rare events and are therefore subject to random variation. The number of crashes at a specific location is often relatively low and highly variable

(Laureshyn, Svensson, & Hydén, 2010). Therefore, it will take a lot of time before it is possible to draw conclusions about traffic safety at that location (Hydén, 1987). Another problem of accident analysis is the fact that many crashes are not reported and different groups of road users are not equally represented in accident statistics (Berntman et al., 1994). Especially underrepresented are vulnerable road users like pedestrians and bicyclists (STRADA, 2012). Thirdly, the processes that lead to crashes are not taken into consideration because most often there is no information available about the behavioural and situational aspect of these crashes. This means that one cannot be sure about the circumstances under which crashes occur (Laureshyn et al., 2010).

Therefore, there is a need for surrogate safety measures (Chin & Quek, 1997; Svensson & Hydén, 2006). Behavioural studies are one of the methods to increase insight in the processes that lead to traffic accidents. As human behaviour plays a major role in traffic accidents, it is important to gain insight in human behaviour in traffic. Moreover, using traffic conflicts as a proxy for crashes, it is possible to gain more information about the traffic safety state at a specific location within a limited timeframe (Hydén, 1987).

Pedestrians are vulnerable road users and the consequences of traffic accidents with pedestrians tend to be severe, even at relatively low impact speeds. Many crashes with pedestrians occur at intersections in urban areas (Zhu et al., 2008). Therefore, a better insight in the interaction process between pedestrians and motorized road users at signalized intersections is required. This will contribute to the development of measures to reduce the occurrence and the severity of this type of crashes.

The aim of this explorative study is to investigate traffic behaviour between motorized road users and pedestrians at signalized intersections. This research has been conducted at signalized intersections in Sweden and Belgium in order to explore pedestrian behaviour in a cross-national context. The pedestrian risk of fatal accidents in Belgium is twice as large as in Sweden (European Commission, 2012) and therefore it is interesting to explore traffic behaviour in both countries.

Background

One of the main reasons to install traffic signals is to decrease the number of encounters between road users by separating traffic streams in time. For motorized road users, signalized intersections decrease the probability of getting involved in a side crash by 60 per cent. However, the probability of getting involved in a rear-end crash increases 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 are generally advantageous for car drivers (Evans, 2004). However, at traditional two-phase signalized intersections, a lot of potential interactions between turning motorized traffic and crossing pedestrians and bicyclists still remain.

Urban signalized intersections are locations where relatively many crashes with vulnerable road users occur. In Sweden, approximately 35 per cent of all traffic accidents between motor vehicles and pedestrians occur at signalized intersections. Pedestrians are reinforced to cross on pedestrian crossings, but accident risk is higher at pedestrian crossings than outside these crossings, even after accounting for exposure (Ekman, 1988). There are several possible influential factors. Behavioural aspects of pedestrians are important factors determining traffic safety (Taubman-Ben-Ari and Shay, 2012).

Red light violation among pedestrians is an important safety issue. According to research at different intersections in the Australian city Brisbane, the risk of being involved in a traffic accident when violating the red signal is 8.1 higher compared to the risk when obeying the traffic signal (95% CI [5.5;11.7]) (King et al., 2009). Nevertheless, a lot of pedestrians choose to violate the red signal rather than to wait. Red light violation depends on several personal, cultural, infrastructural factors and factors relating to enforcement. In some countries, red light violation is much more prevalent than in other countries (Kennedy and Sexton, 2009). Males are more prone to violate the red signal than females (Rosenbloom et al., 2004).

Pedestrians of different age groups have a different probability of getting involved in a traffic accident, but also the most prevalent behaviour playing a role in the process leading to a crash differs by age. While kids more often run into the street or enter the road between parked vehicles, teens are more likely to violate the traffic signals. Alcohol impairment is the most 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).

Another important issue is pedestrian looking behaviour, the behaviour regarding searching for conflicting road users. Pedestrian searching behaviour at signalized crossings is not extensive. Pedestrian searching behaviour failures are one of the most prevalent factor causing traffic accidents between pedestrians and motorized road users (Shinar, 1978). Pedestrian searching behaviour tends to be less extensive at pedestrian crossings compared to crossing outside pedestrian crossings and pedestrians tend to cross slower at pedestrian crossings (Fehlig Mitman et al., 2010). Visual contact between pedestrians and car drivers on pedestrian crossings is 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.

Methodology

Traffic Conflict Techniques

To select the most severe situations among observed vehicle-pedestrian interactions, the approach of the Swedish Traffic Conflict Technique was mainly used (Hyden, 1987). It has been shown that the number of events classified as serious conflicts according to the definition in this technique has a strong correlation with the number of police-reported accidents. In some cases (when the number of accidents is small), the serious conflicts can be even better estimators of the *expected number of accidents* than the actual accident statistics (Svensson, 1992)

A conflict is defined as a situation when two road users would have collided if not at least one of them had taken an *evasive action* (Hydén, 1987). An evasive action can be *braking, swerving and accelerating* or a combination of those. The time remaining to a collision at the moment the evasive action starts is called *Time-to-Accident* (TA-value). The speed of the road user at this moment is called *Conflicting Speed* (CS). These two parameters determine whether the conflict is classified as a serious or non-serious conflict.

One problematic issue is that in case of both road users taking evasive actions, the TA and CS values can be calculated for both of them. The "classical" approach described by Hyden, 1987, suggests that it is always just one road user suggesting the least severity who determines the conflict severity (called therefore the *relevant road user*). 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, i.e. the relevant road user. However, the correlation between the number of traffic conflicts and the number of fatal and injury crashes could increase if, in case of traffic conflicts between pedestrians and motorized road users at signalized intersections, the shortest time to accident, independent of who was taking evasive action, determines whether a traffic conflict is a serious conflict. This so-called *high definition* of a traffic conflict by Shbeeb could be an improvement of the technique. However, until now this high definition has not been validated. The number of registered conflicts will increase if instead of the conventional method, the method of Shbeeb is taken. Therefore, in this paper, both methods will be explored.

Other conflict techniques (for example, the Dutch technique DOCTOR - Kraay et al., 1986) consider also the situations with no collision course but very close to it. The motivation is that a small change in speed or planned trajectory may put the road users on a collision course and the risk of an accident suddenly becomes high (Laureshyn, 2010). Post-Encroachment Time (PET), defined as the time before the first road user leaving the conflict zone and the second one arriving to it, is a commonly used indicator for such situations. DOCTOR suggests that the situations with PET ≤ 1 sec. should also be considered as severe. Since this study is more of an explorative character, it was decided to include this type of situation in the analysis as well.

The validity of the traffic conflict technique has been discussed in many studies (e.g. Hauer and Gårder, 1986; Hydén, 1987; El-Basyouny, & Sayed, 2013). Most often, the validity is measured as the correlation between traffic conflicts and reported accidents. Another measure is whether there are stable conversion factors between the number of traffic conflicts and the number of injury accidents (Hauer and Gårder, 1986). The accident-to-conflict ratios differ for the different types of conflicts and different infrastructural characteristics. For example, the ratio for side conflicts is different from the ratio for rear-end conflicts (Svensson, 1998). It is worth mentioning that it is not the actual accidents, but the "expected number of accidents" that is the genuine measure of traffic (un)safety (Hauer, 1997), and the accident records being a subject for random variation, under-reporting, changes of the safety level during the observation time can also be considered as an indirect measure (Laureshyn, 2010).

The reliability of the traffic conflict technique depends on whether observers can distinguish traffic conflicts from other traffic interactions. This includes both recognition of the situation and its correct classification. The Swedish studies report that observers failed to judge 26%

of the traffic situations as traffic conflicts. The subjective estimates for speed and distance to the collision point seem to be quite accurate and consistent between the observers (Svensson, 1998). The average speed deviation of speed estimates was measured to be 3 km/h. Reliability can be further improved if the situations are video recorded and then (semi-) automatically processed to get more objective estimates of speeds, distances and time intervals (Laureshyn, 2010). Observations in this study have been executed by a certified within the Swedish Conflict Technique observer.

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 a traffic interaction 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 maneuvering through traffic.

Hydén (1987) placed traffic interactions, slight conflicts, serious conflicts and traffic accidents on a continuum. Traffic interactions, traffic conflicts and accidents are all situations with a collision course. What differs is the time to accident.

Interactions are 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. Traffic lights are intended to avoid or reduce the occurrence of certain interactions.

However, this chance is not eliminated because of red light violation. 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. Green (2000) found that the reaction time for unexpected behaviour tends to be higher. The result is that in case of unexpected traffic behaviour by the pedestrian, 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).

Field work

Traffic conflict observations according to the Swedish Traffic Conflict Technique and behavioural observations have been conducted at signalized intersections in Sweden and Belgium. For the conflict observations, one intersection in Sweden (Ole Römersväg/Warholmsväg-Tunavägen in Lund) and one intersection in Belgium (Kermtstraat/Koorstraat-Diestersteenweg in Hasselt) have been selected. For the behavioural observations, the observations have been conducted at the two intersections mentioned above and at another Belgian intersection (Rerum Novarumlaan/Borstelsstraat-Diestsesteenweg in Leuven) to increase the number of observations.

All roads at the three intersections have one lane in each direction and are situated in built-up areas of middle-sized municipalities (50.000-100.000 inhabitants).

For the behavioural observations, traffic interactions between pedestrians and motorized road users have been observed. The observations are pedestrian-driven, that means that the behaviour of all pedestrians has been observed regardless of the presence of a traffic interaction with a motorized road user.

The selection of the intersections is based on similar geometry. However, traffic volumes at the intersections differ. The number of pedestrians is much higher at the intersection in Lund, while the number of motorized road users is higher at the intersections in Hasselt and Leuven. It was not possible to find intersections that are similar both with regard to traffic flow and with regard to geometric characteristics. In table 1, the traffic flow at the three locations is shown. Passenger car equivalent take into account the fact that buses and lorries are counted twice because these vehicles are much larger than passenger cars.

	Lund	Hasselt	Leuven
Passenger car equivalent/h	522	2077	1681
Pedestrians/h	404	34	45
Bicyclists/h	220	33	107

Table 1: Traffic flow at the observation locations

At the two traffic conflict observation locations, 30 hours of conflict observations and 8 hours of behavioural observations have been conducted by a trained human observer. At the third location, 8 hours of behavioural observations have been conducted.

All observations were executed during daytime and in dry weather conditions. Most of the observations in Lund and Hasselt have been videotaped in order to be able to review traffic conflicts.

The following data have been collected for the behavioural observations using a standardized observation form: age and gender of car driver and pedestrian, red light violation by the pedestrian and by the motorized road user, which road user arrives first at the conflict zone, looking behaviour by the pedestrian and the car driver, use of directional lights, yielding by the pedestrian to the motorized road user in case of red light violation and yielding by the car driver when turning left or right.

The age of pedestrians was divided in broad categories: child (approximately 0-17 years), young (approximately 18-30 years), middle (approximately 31-64 years) and elderly (65 years and older). For car drivers, the last three categories were used. Red light violation has been defined as starting to cross when the pedestrian light is red. Situations where the light turns red while the pedestrian is crossing are not considered as red light violation. Nevertheless, side-conflicts with vehicles driving straight on are possible in these situations.

At the intersection in Lund, the behavioural observations were executed at one intersection leg at the time due to the high number of pedestrians. Subsequently, the observation time for each leg was 2 hours. At the intersections in Hasselt and Leuven, it was feasible to observe all intersection legs simultaneously due to the lower number of pedestrians. For groups of pedestrians, only some topics on the observation list could be filled in. Only red light violation, the presence of a car and the characteristics of the car driver were taken into consideration in case more than one pedestrian crossed an intersection leg simultaneously.

Data analysis

For the analysis of the behavioural observations, different methods of discrete data analysis are applied. Most of the data from the behavioural studies are dichotomous data. Pearson's chi-square tests, and Fisher's exact tests have been used to test whether two variables are related. Odds ratio and Cramér's V are used to investigate the strength and direction of the association of variables.

Pearson's chi-square test is used to investigate whether there is a significant association between two variables by comparing expected values (under the assumption of independence) with observed values. This test can be used when the following criteria are met: the sampling should be random, the expected cell count should be positive and exceed 5 in all cells (McClave et al., 2010). In case of small sample sizes, Fisher's exact test can be used. Fisher's exact test makes use of the exact probabilities using the hypergeometric distribution (Agresti, 2007).

Pearson's chi-square values will increase when the sample size increases. That is why this value should be standardized in order to be able to judge the strength of associations (Cools et al., 2010). In case of discrete dependent variables, the Cramér's V coefficient can be used to compute the strength of the association between these variables by standardizing. This value ranges from 0 to 1. Values between 0 and 0.2 imply a weak association, between 0.2 and 0.4 a moderate association, between 0.4 and 0.6 a relatively strong association and above 0.6 a strong association (Lea and Parker, 2012).

A measure to identify the strength and direction of an association is the odds ratio value. An odds ratio value of 1 indicates that the odds for success in group 1 equal the odds for success in group 2. The odds for success is the probability of success divided by the probability of failure. The more different the odds ratio value is from 1, the more distinct the odds for success in group 1 are compared to the odds for success in group 2 (Agresti, 2007).

Logistic regression models have been used in order to be able to test more variables simultaneously and to control the effects of confounding factors. Logistic regression can be used to fit binary data. In this case, red light violation was the dependent variable, while gender, age and country were the independent variables. In logistic regression, the logit-link is used. The logit-link transforms possible outcomes between minus infinity and plus infinity to outcomes between 0 and 1 and can be used to fit dichotomous dependent variables (Agresti, 2007).

If there is no statistical evidence for association between variables, the strength of the association and the direction of the association has not been investigated. However, if the null hypothesis is rejected in the first step i.e. in case there is an association, then the other steps have been executed as well.

Results

Results from the conflict observations

	1	2	3	4	5	6	7	8	9
Location (Lund/Hasselt)	L	L	L	L	L	H	H	H	H
Signal phase pedestrians (Green/Red)	G	R	G	R	G	G	G	G	G
Pedestrian looking (Yes/No)	Y	N	N	Y	Y	N	N	N	N
Arrival (Pedestrian first/Car first/Bus first)	P	P	P	P	B	P	P	P	P
Relevant road user (Pedestrian/Car/Bus)	C	C	-	C	P	C	C	C	C
Conflict speed (km/h)	20	30	-	40	5	25	20	20	20
Conflict distance (m)	4	10	-	12	0.5	5	5	4	4
Time to accident (s)	0.7	1.2	-	1.1	0.4	0.7	0.9	0.7	0.7
Maneuver car (Left turn, Right turn, Straight on)	R	S	R	S	R	L	L	L	R
Post encroachment time (s)			0.8						

Table 2: Overview of serious traffic conflicts

In total, nine serious conflicts have been observed, five of them at the intersection in Sweden and four at the intersection in Belgium. In table 2, some characteristics of the circumstances of these traffic conflicts are listed. Most traffic conflicts occurred with a rather low speed. This is because 7 out of 9 traffic conflicts occurred while the motorized road user was turning right or left. The speed range at turning movements was between 5 km/h and 25 km/h. The conflict speeds involving car drivers driving straight on and the pedestrian violating the traffic signal were 30 km/h and 40 km/h. The pedestrian did not look before crossing in 6 out of 9 serious conflicts.

Walking against red played a role in 2 out of 9 conflicts. In one case, an elderly woman complied with the traffic signal but failed to reach the other side of the road in time. In another case, a pedestrian was violating the traffic light deliberately.

In one case, no evasive action is taken and the road users are not on a collision course. However, the post-encroachment time is less than 1 second, so this traffic situation is also considered as a serious conflict.

Beside these 9 serious conflicts, there are 5 conflicts that could be considered following Shbeebs high definition of the relevant road user (Shbeeb, 2000). In case two road users take evasive action, the lowest time to accident value instead of the highest time to accident value defines whether the traffic conflict is a serious conflict. In two situations, there are pedestrians violating the traffic signal. In two cases, pedestrians encountered a heavy vehicle (a bus respectively a truck) and in one case, there is a car turning left driving at a relatively high speed not yielding to the pedestrian. According to the time to accident of the pedestrian, the conflict is not serious, but according to the time to accident of the vehicle, the conflict is serious.

	1	2	3	4	5
Location (Lund/Hasselt)	L	L	L	L	H
Signal phase pedestrians (Green/Red)	R	R	G	G	G
Pedestrian looking (Yes/No)	Y	Y	Y	N	N
Arrival (Pedestrian first/Car first/Bus first)	P	P	P	P	B
Relevant road user (Pedestrian/Car/Bus)	C	C	C	P	P
Conflict speed (km/h)	10	35	25	5	5
Conflict distance (m)	1	5	5	0	0.5
Time to accident (s)	0.4	0.4	0.7	0	0.4
Maneuver car (Left turn, Right turn, Straight on)	S	S	L	S	R

Table 3: Additional serious conflicts according to the high definition of the Relevant Road User

Results from the behavioural observations

Out of 594 observations, there were 400 individual pedestrians and 194 groups of pedestrians. There were 217 male pedestrians and 183 female pedestrians in the sample. There were 34 children, 151 young pedestrians, 115 middle aged pedestrians and 100 older pedestrians.

In 172 cases, there was a traffic interaction between pedestrians and a motorized road user. Out of 172 car drivers, there were 118 males and 54 females. There were 29 young car drivers, 113 middle aged car drivers and 30 older car drivers.

Variable	Descriptive statistics
# Pedestrians	individual pedestrians=400, group = 194
Gender pedestrians	males=217, females=183
Age individual 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
Traffic interaction	traffic interaction= 172 no traffic interaction=422
Red light violation pedestrian	green=465, red=109, missing=20
Red light violation car driver	green=172
Turning head pedestrian	yes=283, no=117
Turning head car driver	yes=141, no=4, driving straight ahead=27
Yielding pedestrian (when violating the traffic signal)	yes=6, no=21
Yielding car driver	yielding early=145 yielding late=14 not yielding=13

Table 4: Descriptive statistics behavioural studies

Red light violation is much more prevalent at the intersection in Lund than at the intersections in Hasselt and Leuven. At the intersection in Lund, approximately 35 per cent of the pedestrians violates the traffic signal, while at the intersections in Hasselt and Leuven, this is only around 10 per cent. This could be due to the higher number of pedestrians and the lower number of motorized road users at the Swedish intersection, but also due to differences in traffic mentality.

With regard to looking behaviour, 29 per cent of the pedestrians did not turn their heads before crossing in order to check if it is safe to cross the street. There are no remarkable differences between the looking behaviour of Swedish and Belgian pedestrians. The looking behaviour of most car drivers is different: only 2 per cent of the car drivers failed to turn his head before turning left or right.

A remarkable result from the behavioural observations is that pedestrians often do not yield when they violate the traffic signal, although they are at fault. In situations where there is a traffic interaction and the pedestrian light is red, only 22 per cent of the pedestrians does yield. In 78 per cent, the pedestrians cross first and the car driver has to take evasive action in order to prevent a traffic accident. There are no differences between the intersection in Sweden and the intersections in Belgium.

In situations where both the pedestrian and the car driver have green light, most car drivers yield early (84 per cent). Eight per cent of the car drivers yield late and eight per cent of the car drivers did not yield at all.

	Red light violation pedestrian	**Looking behaviour pedestrian**	**Yielding car driver**
Gender pedestrian			
X²	4.579	3,917	0.274
p-value	0.032**	0.017**	0.930°
Cramér's V	0.109	0.119	NA
Odds ratio (reference=males)	0.582	0.586	NA
Age pedestrian			
X²	22.970	4.376	15.184
p-value	0.000***	0.224°	0.006***
Cramér's V	0.244	NA	0.297
Odds ratio (reference=old)	child 1.499; young 5.333; middle 2.596	NA	NA
Gender car driver			
X²	NA	NA	4.088
p-value	NA	NA	0.043**
Cramér's V	NA	NA	0.154
Odds ratio (reference=males)	NA	NA	3.026
Age car driver			
X²	NA	NA	2.664
p-value	NA	NA	0.264°
Cramér's V	NA	NA	NA
Odds ratio	NA	Na	NA

	Red light violation pedestrian	Looking behaviour pedestrian	Yielding car driver
Individuals/groups			
X^2	1.497	NA	0.199
p-value	0.221°	NA	0.655°
Cramér's V	NA	NA	NA
Odds ratio	NA	NA	NA
Country			
X^2	38.411	0.803	0.157
p-value	0.000***	0.370°	0.692°
Cramér's V	0.315	NA	NA
Odds ratio (reference=Sweden)	0.208	NA	NA
Presence of a car			
X^2	0.126	1.419	NA
p-value	0.722°	0.234°	NA
Cramér's V	NA	NA	NA
Odds ratio	NA	NA	NA
Country if car present			
X^2	11.474	0.011	NA
p-value	0.001**	0.915°	NA
Cramér's V	0.262	NA	NA
Odds ratio (reference=Sweden)	0.256	NA	NA
Red light violation			
X^2	NA	27.519	1.313
p-value	NA	0.000***	0.188°
Cramér's V	NA	0.267	NA
Odds ratio (reference=violation of the traffic signal)	NA	0.099	NA

° Not statistically significant; * Significant on a 90% confidence level; ** Significant on a 95% confidence level; *** Significant on a 99% confidence level

Table 5: Statistical tests

In the following paragraphs, the results of the statistical tests listed in table 5 are described.

Red light violation

Red light violation is more common for male pedestrians than for female pedestrians. This value was statistical significant on a 95% confidence level. The finding is in accordance with former research stating that males are more inclined to violate the traffic signal than females (Rosenbloom et al., 2004). Young pedestrians are also more inclined to violate the traffic signal than older pedestrians. There is a statistical significant relationship between age and red light violation. Red light violation was significantly more prevalent at the Swedish intersection than at both Belgian intersections. When comparing the Cramér's V values, the association between country and red light violation and the association between age and red light violation are moderate. The association between gender and red light violation is weak.

As there was a relatively large number of pedestrians and a relatively low number of motorized road users at the Swedish intersection compared to the Belgian intersections, it is not sure whether there is a country effect or a traffic composition effect. However, in case only the traffic interactions were taking into consideration, the Swedish pedestrians still violated the pedestrian signal much more frequently than the Belgian pedestrians.

A multiple logistic regression model has been fitted to control the effects of 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 (with a 90 per cent confidence level). The effect of gender is not statistically significant so that variable has been removed. In table 6 and 7, the model estimates of the logistic regression model are presented.

Parameter	**B**	**SE**	**p-value**
(Intercept)	-2,643	0,3804	,000***
Child	0,407	0,6575	,535°
Young	1,077	0,4383	,014**
Middle	0,765	0,4514	,090*
Old (ref)	0	.	.
Sweden	1,270	0,2915	,000***
Belgium (ref)	0	.	.
(Scale)	1		

° Not statistically significant; * Significant on a 90% confidence level; ** Significant on a 95% confidence level; *** Significant on a 99% confidence level

Table 6: Logistic regression model pedestrian red light violation

	Wald Chi-Square	p-value
(Intercept)	61,576	0,000***
Age pedestrian	6,451	0,092*
Country	18,972	0,000***

° Not statistically significant; * Significant on a 90% confidence level; ** Significant on a 95% confidence level; *** Significant on a 99% confidence level

Table 7: Type 3 statistics logistic regression model pedestrian red light violation

At a 90 per cent confidence level, both "Age pedestrian" and "Country" are statistically significant. Young pedestrians are significantly more inclined to violate the traffic signal than old pedestrians. The pedestrians at the Swedish intersection are also significantly more inclined to violate the traffic signal than the pedestrians at the Belgian intersections.

The deviance and Pearson Chi-Square value do not indicate lack of fit or overdispersion. To conclude, this multiple logistic regression model indicates that both age and country have an effect. It is not only because there are relatively more young pedestrians at the intersection in Sweden that the red light violation rate is so much higher than at the intersections in Belgium.

Looking behaviour

Female pedestrians are turning their heads significantly more often than male pedestrians do. Fortunately, pedestrians violating the traffic signal at least appear to look sideways more often than pedestrians complying with the traffic signal. There is no significant association between looking behaviour and age, country and whether a car is approaching.

Yielding

The gender of car drivers is an influential factor for whether car drivers yield early or not. Male car drivers yield early less often than female car drivers. Older pedestrians get priority significantly more often than younger pedestrians. However, there is no evidence that car drivers yield early more often to pedestrians complying with the traffic signals than to pedestrians violating the traffic signal.

Discussion

Snyder and Knoblauch (1971) described in the so-called Behavioural Sequence Model interactions between pedestrians and motorized road users as a process consisting of six steps. Successful, safe interactions consist of both parties following these steps properly and in time. First, the road user must *search* for the other road user. Second, the road user must *detect* the other road user. After having detected, the situation must be *evaluated*. The road user has to evaluate whether it is necessary to take evasive action. After the evaluation phase, the road user has to choose between different ways of taking evasive action and take a *decision* about which type of evasive action is adequate in a certain type of traffic situation. The road user executes a certain kind of *action.* The last step in the Behavioural Sequence Model is the *vehicle response*.

If one fails in conducting one of these steps, or if one fails to do so in time, there can be a breakdown and the resulting situation could be a traffic accident. However, as there are two road users, the errors of one road user can be compensated by the other road user.

The traffic conflicts involving pedestrians can also be described in this way. Most of the observed traffic conflicts can be structured in subcategories according to specific characteristics.

1. The first group can be seen as conflicts where one of the persons involved is violating the traffic signal. Pedestrians violating the traffic signal deliberately 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 the presence of 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 right or 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, although this pedestrian has priority. Because

neither the car driver nor the pedestrian detected the other road user 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 the pedestrian enters the intersection from the opposite site as the turning vehicle. 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.

Traffic conflicts and traffic behaviour

Above, different behavioural aspects have been described. When comparing the behavioural patterns with the traffic conflict patterns, there are certain things that are noticeable. Firstly, most pedestrians (73%) turn their heads before crossing the intersection. However, when we look at the traffic conflicts, we see that the pedestrians do not turn their head in most occasions. In 6 out of 9 traffic conflicts (67%), the pedestrians do not turn their head.

Pedestrians at the intersections in Lund and Hasselt seem to be much more involved in traffic conflicts if they do not turn their heads prior to crossing. The pattern is still more clear when only focusing on interactions. There are 60 cases with individual pedestrians interacting with car drivers at the intersections in Lund and Hasselt. Out of these 60 pedestrians, 13 did not turn their heads (22%). 47 pedestrians did turn their heads (78%).

	# traffic conflicts (case)	**# interactions (control)**
not turning head	3	47
turning head	6	13

Table 8: Cross table looking behaviour and conflict prevalence

Odds ratio can be used in order to compute the strength and direction of the association between the behaviour and involvement in a traffic conflict. In former research, odds ratio has been used to describe the strength and direction of the association between infrastructural characteristics and involvement in traffic conflicts (Knipling, 2011).

The odds ratio for getting involved in a traffic conflict for pedestrians not turning their head is 7.233 (95% CI [1.588;32.924]).

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 and because of the very low number of observed traffic conflicts. 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. There is an indication that pedestrian looking behaviour might play an important role.

Definition of traffic conflicts

There are five traffic conflicts that can be considered as serious conflicts according to Shbeebs (2000) high definition of the relevant road user, while they are not considered as serious conflicts according to the conventional definition of the relevant road user in the Swedish Traffic Conflict Technique. The strength of the relationship between looking behaviour and being involved in a traffic accident differs but the direction of the relationship still holds.

The relationship between traffic conflict involvement and red light violation is not so clear. In two cases with pedestrians violating the traffic signal, there is a serious conflict according to Shbeebs interpretation but a slight conflict according to the "classical" Swedish Traffic Conflict Technique. This is due to the definition of the relevant road user. The pedestrian has more time to brake and in this way prevent an accident. According to the results from the Swedish Traffic Conflict Technique, crossing when the traffic light is green is more dangerous than crossing when the traffic light is red. As pedestrian looking behaviour is much better in case of red light violation, red light violation as such is not dangerous.

Traffic conflicts with pedestrians violating the traffic signal at two-phase intersections are traffic conflicts where the motorized road user is driving straight on. The result of that fact is that the speed of the car is relatively high. As the speed of the pedestrian is much lower, and as pedestrians violating the traffic signal expect oncoming cars while motorized road users usually do not expect pedestrians violating the traffic signal, it is often the pedestrian who takes evasive action in these situations. The consequence is that traffic conflicts are not considered as serious conflicts unless the conflict distance is around 0.5 meter, assuming that pedestrians walk with an average speed of 5 kilometer per hour. However, if a traffic accident would occur, the consequences are likely to be much more severe than for situations where the vehicle turns due to the higher impact speed.

Exposure

Another important issue is exposure. At the intersection in Lund, 5 serious conflicts involving pedestrians have been observed. At the intersection in Hasselt, there were 4 serious conflicts. However, the number of pedestrians at the intersection in Lund was much higher than the number of pedestrians at the intersection in Hasselt (404 pedestrians in Lund and 34 pedestrians in Hasselt during one hour). However, pedestrians not interacting with motorized road users can never be involved in a traffic conflict. It could be more appropriate to take the number of interactions into account instead of the number of pedestrians or the number of motorized road users. However, in this study not all traffic interactions in Lund could be observed due to the large number of pedestrians. There were 4 times more interactions in Lund than in Hasselt as we take into consideration that in Lund the observation took place at one intersection leg at the time. Consequently, the conflict rate per pedestrian and per interaction is much lower at the intersection in Lund than at the intersection in Hasselt. This result is in line with literature stating that the risk per pedestrian at signalized intersections decreases with an increasing number of pedestrians. This is sometimes called "safety in numbers" (Ekman, 1996 & Leden, 2002).

Differences in 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 red light so often compared to people at both Belgian intersections. There are different possible reasons for that:

- If the intersections in Lund and Hasselt would be representative for all urban intersections with a similar layout, then it could indicate a difference in traffic culture. As pedestrian safety in Sweden is generally higher than in Belgium (European Commission, 2012), subjective safety could also be higher. Pedestrians who feel safer could take more risks (Ibrahim et al., 2011). Another reason is the behaviour of the drivers at the Swedish intersection. The car drivers tend to yield for pedestrians even when they violate the traffic signal.

- Differences between red signal compliance could also 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 (Trafikverket, 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 there is no danger. However, the analysis above shows that the likeliness to violate the traffic signal does not depend on whether there is a vehicle approaching. This means that pedestrians do not tend to violate the traffic signal only if there is no vehicle approaching. When only taking into account those instances where there is a traffic interaction, red light violation is still much more prevalent at the Swedish intersection than at the Belgian intersections. 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. On the basis of this study, no further conclusions can be drawn.

- 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. It could be that low traffic volumes also stimulate red light violation.

Further research

This research is based on conflict observations and behavioural observations at three locations. This paper raises some interesting suggestions and findings that warrant further research.

The fact that the red light violation rate was much higher at the intersection in Sweden only gave an indication that red light violation might be more prevalent in Sweden, but at the same moment, vehicular flow was much lower at the intersection in Sweden than at the intersections in Belgium. Further research with a larger sample could elucidate the relationship between different countries and red light violation.

Video recording and analysis could enhance the timeframe for field observations. At the same time, it can make it possible to make field observations at different intersections simultaneously in order to enlarge the number of intersections being investigated and can guarantee a higher reliability of conflict measurements.

The relationship between pedestrian looking behaviour and involvement in traffic conflicts is a topic that could be studied more extensively. It was interesting that looking behaviour not seemed to depend on the location. Also the fact that pedestrian red light violation did not seem to depend on whether a vehicle is approaching warrants further research.

Conclusion

Red light violation is more prevalent among men and among young people. Red light violation is also much more prevalent at the Swedish intersection than at the Belgian intersections. There were no significant differences between pedestrians walking alone and pedestrians walking in a group. At all intersections combined, around 30 per cent of all pedestrians did not turn his head before crossing. Pedestrians violating the traffic signal look significantly better around before they cross than pedestrians complying with the traffic signal. For pedestrians violating the traffic signal, there is no indication that the risk of getting involved in a serious conflict is higher.

Another remarkable finding was the fact that red light violation did not seem to depend on whether a vehicle is approaching. If there is a traffic interaction in case of red light violation, pedestrians most often do not yield.

There is an indication that pedestrians who do not look over their shoulder before crossing signalized intersections are more involved in traffic conflicts. By a proper visual search, pedestrians can compensate for failures made by motorized road users.

The results of this explorative study raises some interesting questions for further research in which the discussed topics can be studied on a larger scale.

References

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

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.

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

Cools, M., Moons, E., Creemers, L., & Wets, G. (2010). Changes in Travel Behavior in Response to Weather Conditions. Transportation Research Record: Journal of the Transportation Research Board, 2157(-1)

Ekman, L. (1988). Fotgängares risker på markeret övergångsställe jämfört med andra korsningspunkter. Institutionen för trafikteknik, LTH.

Ekman, L. (1996). On the treatment of flow in traffic safety analysis: a non-parametric approach applied on vulnerable road users. Department of Traffic Planning and Engineering, Lund University. Bulletin 136.

El-Basyouny, K., & Sayed, T. (2013). Safety performance functions using traffic conflicts. Safety Science, 51(1), 160–164.

Elvik, R. (2008). *Handbook of Road Safety Measures*. (Elvik R., Ed.) (2nd Revised ed.). Emerald Group Publishing Limited.

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*. Bloomfield Hills (Michigan): Science Serving Society.

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

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

Hauer, E., & Garder, P. (1986). Research into the validity of the traffic conflicts technique. Accident Analysis & Prevention, 18(6), 471–481.

Hauer, E. (1997). *Observational Before-After Studies in Road Safety*. Bingley: Emerald Group Publishing Limited.

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.

Hydén, C. (1987). The development of a method for traffic safety evaluation: The Swedish Traffic Conflicts Technique. Lund: Lund University

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.

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

King, M. J., Soole, D., & Ghafourian, A. (2009). Illegal pedestrian crossing at signalised intersections: Incidence and relative risk. Accident Analysis & Prevention, 41(3), 485–490.

Knipling, R. R. (2011). Potential Safety Benefits of Motor Carrier Operational Efficiencies. Transportation Research Board.

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.

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.

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

Laureshyn, A., Svensson, Å., & Hydén, C. (2010). Evaluation of traffic safety, based on micro-level behavioural data: Theoretical framework and first implementation. Accident Analysis & Prevention, 42(6), 1637–1646.

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.

McClave, J. T., Benson, P. G., & Sincich, T. (2010). Statistics for Business and Economics, Books a la Carte Edition with MyStatLab (11e ed.). Pearson.

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

Rea, L. M., & Parker, R. A. (2012). Designing and Conducting Survey Research: A Comprehensive Guide. John Wiley & Sons.

Rosenbloom, T., Nemrodov, D., & Barkan, H. (2004). For heaven's sake follow the rules: pedestrians' behaviour in an ultra-orthodox and a non-orthodox city. Transportation Research Part F: Traffic Psychology and Behaviour, 7(6), 395–404.

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

Shinar, D. (1978). *Psychology of the Road: The Human Factor in Traffic Safety*. New York: John Wiley & Sons

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

STRADA – Swedish Traffic Accident Data Acquisition - Transportstyrelsen Retrieved December 12, 2012, from http://www.transportstyrelsen.se/en/road/STRADA/

Svensson, Å. (1992). *Vidareutveckling och validering av den svenska konflikttekniken (in Swedish) Further development and validation of the Swedish Traffic Conflicts Technique.* Lund: Department of Traffic Planning and Engineering, Lund University.

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.

Taubman - Ben-Ari, O., & Shay, E. (2012). The association between risky driver and pedestrian behaviors: The case of Ultra-Orthodox Jewish road users. Transportation Research Part F: Traffic Psychology and Behaviour, 15(2), 188–195.

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.

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

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.