Detailed Description of Bicycle and Passenger Car Collisions Based on Insurance Claims

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ABSTRACT

Today, cyclists constitute the highest percentage of severely injured road users in Sweden [1]. Collisions between bicycles and motor vehicles often have the most serious outcome. In order to mitigate the severity of the outcome or even to avoid these collisions, it is of great importance to investigate the circumstances and contributing factors why these collisions occur. As it is well known that bicycle accidents are underreported in official data bases [2] and information regarding accident details is very limited, the aim of the study presented here is to gain more detailed information about bicycle-passenger car collisions based on motor insurance claims collected from If P&C Insurance. Motor insurance claims which are based on the third party liability insurance include bicycle and passenger car collisions at all levels of crash severity and describe the situations in detail, often both from the driver's and cyclist's perspective [3]. For analysis, a data set of a total of 882 collisions between bicycles and passenger cars in Sweden (2005-2012) was used.

Results showed that over 78% of all bicycle- passenger car collisions were situations in which the bicycle and car crossed each other's paths. Collisions in which the bicycle and car went in the same or opposite direction were less frequent (11%) but here the injury severity was on average higher. With regard to the crossing situations, it was found that in over 53% of the collisions the cyclist crossed the roadway while coming out from a bicycle path. In about half of these collisions the driver reported that he/she did not see the cyclist before the collision. Analysis based on this novel data will contribute to a better understanding of bicycle-passenger car collisions in real road traffic situations which cannot be found in other data sources. It also facilitate the development of assistance systems and traffic planning to support bicycle safety for both car manufacturers and road planners.

Keywords: bicycle-car collision, accident scenarios, insurance claims, crossing situation, same/opposite direction situations.

1 INTRODCUTION

In Europe, the number of cyclists has increased significantly in the recent decades [4, 5]. Also in Sweden, cycling has become very popular [6]. However, road safety for cyclists is a challenge. Cyclists are vulnerable in road traffic and run relatively high risks of being involved in an accident [7-9]. Although fatal bicycle accidents have decreased substantially in Sweden during the last decades (Figure 1, left) [10], bicycle accidents often result in severe injuries for the cyclist [11].

One successful way for reducing fatal bicycle accidents resulted from infrastructure changes, such as bicycle paths which separate bicycles and motor vehicles [12]. However, there are still remaining traffic safety issues that need to be addressed. One of these issues is the fact that every year a large number of bicycle accidents with severe injuries for the cyclist are reported. For example, in Sweden, cyclists still constitute the highest percentage of severely injured road users (Figure 1, right) [11]. Especially, collisions between bicycles and motor vehicles/passenger cars are one of the most safety-critical situations with serious outcome [3, 13 - 15].

From accident data base analyses, it is well known that bicycle-passenger car collisions (from now on mentioned as "bicycle-car collisions") occur in different traffic context situations, but here detailed qualitative data about the collision situation is lacking. To understand why accidents happen it is of great interest, as to how the cyclist and driver interacted and moved towards each other before the collision occurred, for example, did the cyclist and driver cross each other's paths or did both move in the same direction. Furthermore, to understand injury mechanisms in the collisions, impact point, kinematics, and crash severity in the collisions are important factors to investigate.

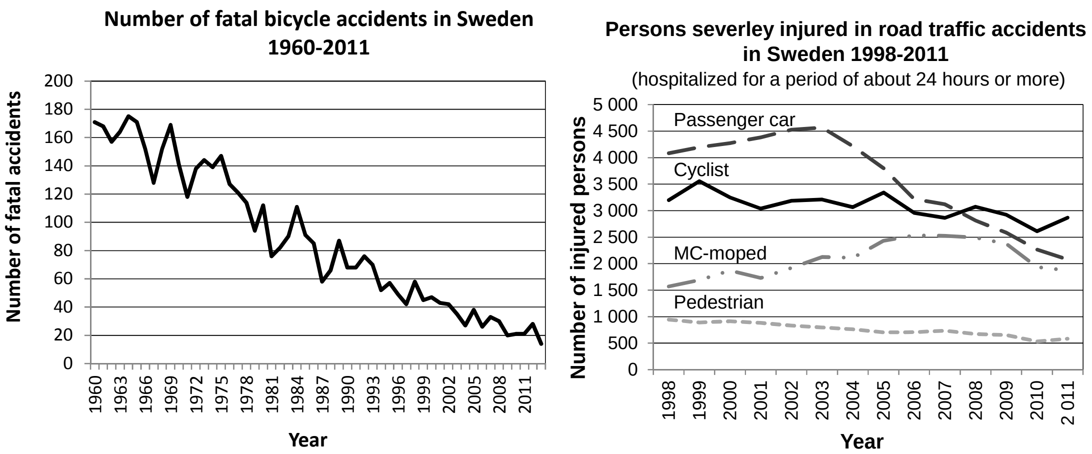

Figure 1. Number of fatal bicycle accidents (left) and persons severely injured in road traffic crashes (right) in Sweden (Source: Transport Analysis data) [11, 12].

To decrease the number of bicycle-car collisions and to mitigate the injury severity in these collisions, it is essential to better understand these safety-critical situations. Therefore, it is of great importance to analyse behaviors of both the cyclist and the driver in these situations as well as to investigate circumstances and contributing factors as to why these collisions occur. By structuring different traffic context situations using information from the pre-crash and crash events, such as did the cyclist and driver cross each other's paths or did both go in the opposite direction and factors as impact points and impact speed during the collision, accident and injury mechanisms can be identified. Unfortunately, regarding road traffic accidents with vulnerable road users, such as cyclists, lack of information and underreporting is a problem. In spite of official accident data bases using police and hospital reports (e.g., STRADA, [16]) it is well known that bicycle accidents are underreported and information regarding accident details is very limited. [2, 7, 17-20]. As a complement, accident data based on motor insurance claims are useful and promising data sets to gain more knowledge and a more comprehensive view about bicycle-car collisions in real road traffic conditions. According to the terms of insurance, drivers are obliged to report crashes with cyclists to the insurance company, thereby it is possible to get detailed information of all collisions across the spectrum of crash severity.

In the study presented here the aim was to use motor insurance claims based on the third party liability insurance [3] to analyse bicycle and passenger car collisions at all levels of crash severity. For investigating bicycle-car collisions, the goal was to describe and analyse the most common bicycle-car collision situations and to relate them to the consequences in terms of injuries and injury severity. Therefore, the following research questions were focused on: 1) what are the most common types of bicycle-car collisions related to the way bicycles and cars move towards each other (e.g., cyclist and driver crossed each other's paths or cyclist and driver moved parallel in the same or opposite direction) and 2) how these situations distinguish in the resulting injuries and injury severity. Furthermore, it was interesting 3) to find what kind of situational factors influence the injury severity (impact speed) or differ in the crash situations (e.g., light and weather conditions, urban areas, speed limits). Finally, factors such as impact direction and kinematics in the crash situations were analysed to enhance the understanding of the crash event which are useful information in finding efficient counter-measures in the development of cars and infrastructure planning.

2 METHOD

2.1 Data source

In the paper presented here, the analysis is based on data from bicycle and car collisions in Sweden, collected from If P&C Insurance (from now on *if*) the largest P&C insurance company in the Nordic region, which insures about 25% of all cars in Sweden including many different makes and models[3]. Cars selected are passenger cars class I, intended for passengers with no more than eight seats. In this data set, bicycle-car collisions were identified using motor insurance claims reported by the third party liability insurance which covers both damage to property and personal injuries.

The data includes detailed information about the accident scenario itself, both for the pre-crash and crash event. The pre-crash event is described by variables as 1) how the driver and the cyclist moved towards each other, 2) speed of the car before the accident, and 3) restricted view. In the same way the crash event is described by various variables such as 1) point of impact and 2) impact direction of bicycle and car during the collision. Furthermore, actions such as braking, steering, and movement pattern of the car are recorded. In addition, variables of more subjective character are recorded, e.g. estimated impact speed of the car or whether the cyclist/driver saw the other party before the collision occurred, this was recorded from the claims form and descriptions from the driver and the cyclist. For bicycle-car collisions in which the bicycle has hit the car (cycled into the car), obviously no impact speed for the car is calculated. To better describe the circumstances of the situation, environmental conditions (e.g., light conditions, road status), when and where the collision occurred (e.g., urban or rural area) as well as demographics about the driver and the cyclist is recorded. In total, in the data set 95 variables are available and can be coded per crash event. Further details about the data collection and its process using insurance claims are described in Isaksson-Hellman [3]. The data set used in the study presented here covered accidents all over Sweden including different car models, collected during the years 2005-2012. In total, 882 bicycle-car collisions were analysed. It should also be noted that only 50% of these accidents is covered in the official data, reported by the police (STRADA). Thus, using *if* insurance data [3] make it possible to study accidents of all type of crash severity and to give a good overview of the distribution of all kind of bicycle-car collisions. Furthermore, the *if* insurance data is more detailed compared to both hospital and police reported data and more detailed accident scenarios were defined with the aim of capturing accident characteristics and injury mechanism.

2.2 Personal injuries

In *if* insurance data, personal injuries are coded with respect to the Abbreviated Injury Scale (AIS) [21]. The AIS is an anatomical-based coding system created by the Association for the Advancement of Automotive Medicine (AAAM) that classifies each injury by body region according to its relative importance on a 6-point ordinal scale: One being a minor injury and six being a maximal injury (currently untreatable) (Table 1). An AIS-Code of 9 is also used to describe injuries for which not enough information is available for coding. An AIS-Code of 0 is used if there is no injury. MAIS, called Maximum AIS, is the highest AIS for a person, based on all injuries to different body regions. For example, if a person has an AIS2 injury to the upper extremity, and an AIS3 injury in the head, MAIS is equal to 3. All cases in the data were coded so that persons cannot be identified.

Table 1. Abbreviated Injury Scale (AIS).

AIS score	Injury
0	No injury
1	Minor
2	Moderate
3	Serious
4	Severe
5	Critical
6	Maximal
9	Not further specified

In the analysis presented here, the injury severity is grouped in MAIS2 and MAIS3+. MAIS2 injuries are moderate injuries, often fractures to the extremities or moderate concussion. MAIS3+ injuries are severe to fatal injuries most often to the head or thorax. Due to the frequences and character of the injuries it is appropriate to divide the injuries in these two groups.

2.3 Accident scenarios

In order to get an overview about the different types of the bicycle-car collisions, in the data set five main crash categories are defined (Table 2). The first three are chosen to distinguish between the movement patterns and direction of the bicycle and car: 1) bicycle and car cross each other's paths, ("*crossing situations*"), 2) bicycle and car move in the same/opposite direction ("*same/opposite direction situations*") and 3) bicycle cycles into an open car door, car standing still ("*door opening*").

Table 2. Main crash categories and group of scenarios.

Main crash categories	Group of scenarios	Number of scenarios
1. Bicycle and car cross each other's paths	Road crossing, cyclist comes from a bicycle path	8
	Road crossing , cyclist rides on the road	5
	Driveway crossing, cyclist comes from a bicycle path	6
	Driveway crossing, cyclist rides on the road	3
	Roundabout	1
2. Bicycle and car move in the same/opposite direction	Same/opposite direction, car and cyclist on same roadway	6
3. Bicycle cycles into an open car door, car standing still	Cyclist cycles into an open car door	1
4. Others	Parking lot	1
	Reversing	1
5. Unknown	Unknown	

As Table 2 shows, the *crossing situations* are defined as situations in which the bicycle and car cross each other's paths. They are subdivided into five scenario groups which define the type of roadway/driveway and the location the cyclist came from. Driveway includes entrance/exit to parking lot, petrol station, path to private garage, house etc. The purpose of this degree of details is the possibility to better understand injury and accident mechanisms as well as infrastructural weaknesses. As Table 2 shows, they include 1) roadway and 2) driveway crossing situations where the cyclist either comes from a bicycle path or rides on the road. Bicycle path is here in almost all cases, about 99%, a cycle facility separated from motor traffic by physical constraints. This distinction is made into the different scenarios due to existing differences in infrastructure, design, and operations (Figure 2). *Crossing situations* where the cyclist comes from a bicycle path are most frequent in the data set and mainly occur in/at intersections. The fifth scenario group of crossing situations includes roundabouts where the cyclist rides on the road in the roundabout. However, crossing the road before or after the roundabout coming from a bicycle path was coded as a “road crossing, cyclist comes from a bicycle path”.

The second main crash category *same/opposite direction situations* includes scenarios when the car and bicycle shared the same roadway (including marked bicycle lanes, 5%) either going in the same direction or in the opposite direction (on-coming situations). These situations can also occur in/nearby an intersection. For example, situations of this category includes situations 1) when the car overtook the bicycle too close, 2) moved in too tight in front of the bicycle, car overtook the bicycle, 3) run into the bicycle from behind, 4) during lane change or 5) in on-coming situations.

As a third category, a scenario describing the cyclist cycling into an open car door, car standing still is denoted as *door opening*. In most accident data sources (e.g. STRADA), this scenario is defined as a single bicycle accident but in *if* insurance data set it is considered as a collision between a bicycle and car, since this situation is covered by the third party liability insurance.

In total 32 detailed scenarios are defined for the main crash categories (Table 2). As an example, Figure 2 shows the different scenarios of the road *crossing situations* when the cyclist 1) came from a bicycle path and 2) rode on the road. (The most common crossing scenarios occur in connection to intersections, as in Figure 2, but can also be described at other road sections.

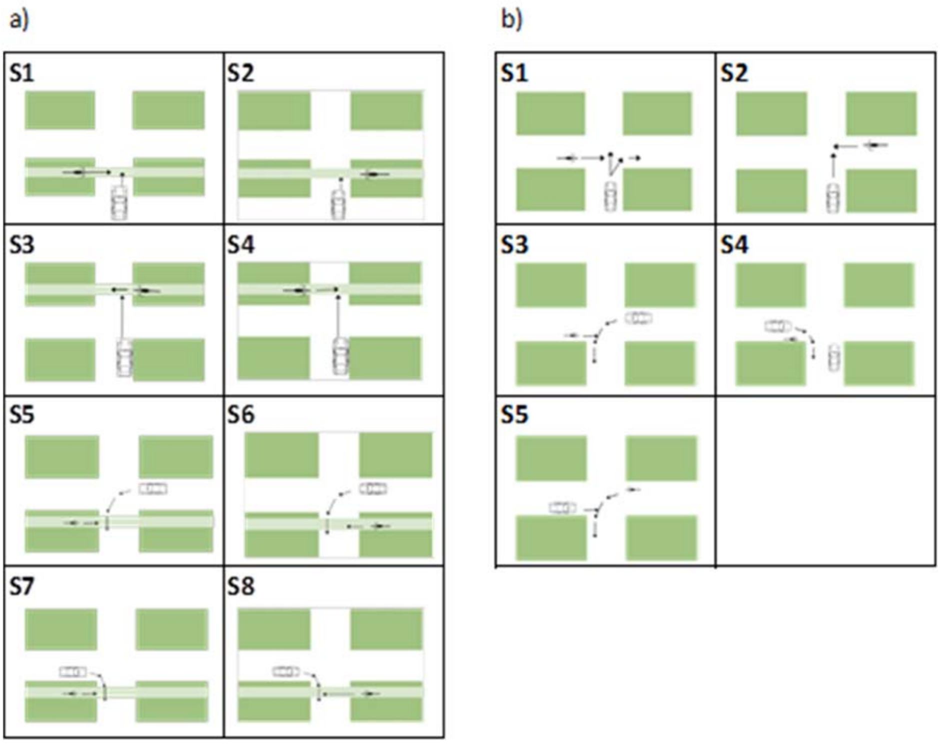

Figure 2. Road crossing scenarios with a) cyclist comes from bicycle path (n = 368) and b) cyclist rides on the road (n = 148).

2.4 Data analysis

In this study, results are presented in order to answer the three main research questions. First, the frequencies of the main crash categories (Table 2) are analysed to examine the most common types of bicycle-car collisions and safety-critical situations. Here, the first three main crash categories are related to the way the cyclist and the driver are travelling towards each other (e.g., cyclist and driver crossed each other paths or moved in the same direction etc.). Second, the injury risks within each of the three first main crash categories are calculated. This is done to investigate how these situations distinguish themselves in the resulting injuries and injury severity.

Finally, various distributions of influencing factors related to the different crash categories are analysed. This is also done to enhance the understanding of contributing factors that play an important role in finding countermeasures to reduce the number of bicycle-car collisions.

Analysis was carried out using SAS statistical software (SAS, Incorporated, Cary NC) and primarily involved descriptive statistics together with chi-square-test to perform the evaluation of significant differences.

3 RESULTS

In the analysis, the data set contains in total 882 bicycle-car collisions, collected in Sweden during the years 2005-2012. In the following study, the results are presented according to 1) the frequency of the five main crash categories 2) the injury severity risk within each main category, and finally 3) factors describing characteristics and circumstances of the different collision categories (e.g., environmental conditions, impact speed and kinematics).

3.1 Frequency of main crash categories describing accident scenarios for bicycle-car collisions

The overall distribution of the five main crash categories in the data set is shown in Figure 3. Here, it is important to mention that results represent the real outcome and give no information about the risk for a certain collision. As Figure 3 shows, the dominating accident scenarios with about 78% (n = 689) were situations in which the cyclist and driver crossed each other's paths. Table 3 gives an overview about the distribution concerning the different scenarios of the *crossing situations*. As Table 3 shows, the most frequent scenario was when the cyclist came from a bicycle path and crossed the path of the driver on the road (53.4%, n = 368). Less frequent but almost one fourth of all road *crossing situations* (21.5%, n = 148) was the scenario where the cyclist rode on the road and crossed the driver's path. Over 15% (n = 107) occurred on driveway, when the cyclist came from a bicycle path. Situations in which the cyclists rode on the road and crossed a driveway occurred in 4.8% (n = 33) of all the *crossing situations*. The same amount was found for situations inside a roundabout (4.8%, n = 33).

Collisions where the cyclist and driver shared the same roadway and moved in the same or opposite direction represented 10.7% (n = 94) of all collisions (Figure 3). Cyclists who cycled into an open car door were in total 4.4% (n = 39). The crash category *Others* included 3.4% (n = 30) of all the collisions, subdivided into situations which occurred on parking lots (1.4%, n = 12), and reversing (2.0%, n = 18). In 3.4% of the overall collisions, the information is insufficent and could not be defined into a certain category. Due to the small number of observations in these two last main crash categories, in the following analysis the category *Others* and *Unknown* are not described.

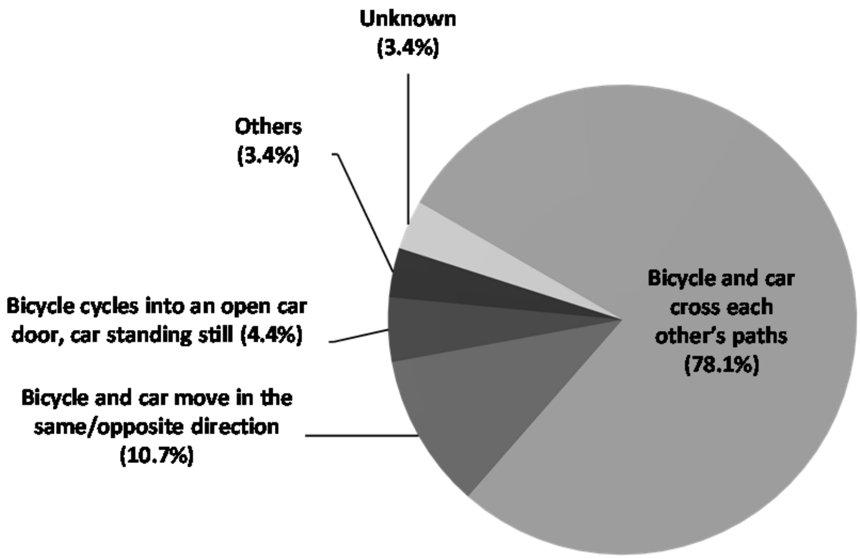

Figure 3. Distribution of main crash categories of bicycle-car collisions (N = 882).

Table 3. Distribution of the scenario groups of crossing situations (n = 689).

Crossing situations: Bicycle and car cross each other's paths	%
Road crossing, cyclist comes from a bicycle path	53.4
Road crossing , cyclist rides on the road	21.5
Driveway crossing, cyclist comes from a bicycle path	15.5
Driveway crossing, cyclist rides on the road	4.8
Roundabout	4.8

3.2 Injury severity

In this section the differences regarding injury severity for the *crossing situations* and *same/opposite direction situations* was analysed. In Figure 4, the injury risks for MAIS2 and MAIS3+ for the two crash categories are shown. The injury risk is the risk of an injury of a certain level within each category. According to this, in Table 4 the total number of injuries and accidents can be found.

As Figure 4 shows, the risk of a severe to fatal injury (MAIS3+) was significantly higher for collisions in the *same/opposite direction situations* compared to *crossing situations* ($\chi^2(1) = 23.1$, $p < .001$). Even if the total number of crashes in *crossing situations* was more than seven times as high, the number of fatal injuries was dominated by the *same/opposite direction situation* (Table 4). With regard to the moderate injuries (MAIS2), *crossing situations* dominated the total number of injuries (Table 4).

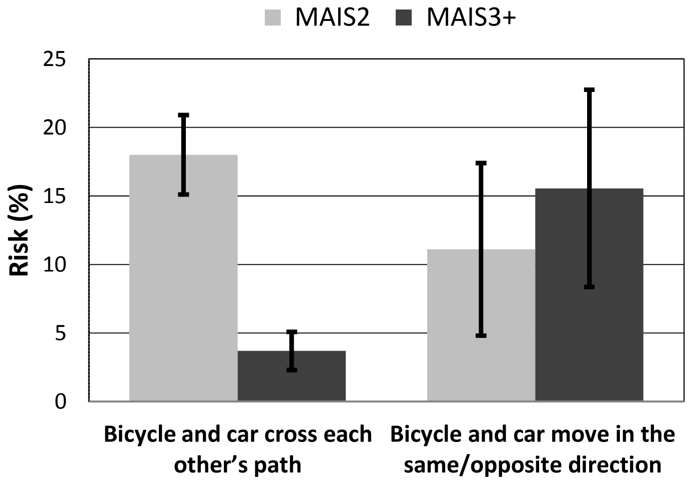

Figure 4. The MAIS2 and MAIS3+ injury severity risk for main crash categories: crossing situations (n = 689) and same/opposite direction situations (n = 94).

Table 4. Total number of injuries in the main categories: crossing situations and same/opposite direction situations.

Main crash categories	N	MAIS2	MAIS3+ (fatal)
Bicycle and car cross each other's paths	689	122	25 (4)
Bicycle and car move in the same/opposite direction	94	10	14 (7)

The scenarios of road *crossing situations* were analysed to understand the differences of injury severity in the presence of bicycle path or not. Comparing road *crossing situations* where cyclist came from a bicycle path with situations when the cyclist rode on the road showed a high MAIS3+ risk for the cyclist on the road, though not significant ($\chi^2(1) = 2.7$, $p = .100$).

In Figure 5a-b, the risk of AIS2 and AIS3-5 injuries per body region, subdivided into *crossing situations* (n = 689) and *same/opposite direction situations* (n = 94), are shown. With regard to AIS2 injuries, in both accident situations injuries to the extremities can be found. Here, the risk of upper extremity injuries was about 7-8%, the risk of leg injuries about 4%. In the *same/opposite direction situations*, injuries to the pelvis had as high risk as leg injuries. In both situations, moderate head injuries had a risk of 2-3%. With regard to AIS3-5 injuries head and thorax are body regions with high risks (Figure 5b). In the *same/opposite direction situations* the risk of head injuries is almost 5% and the risk of thorax injuries is between 2% and 3%.

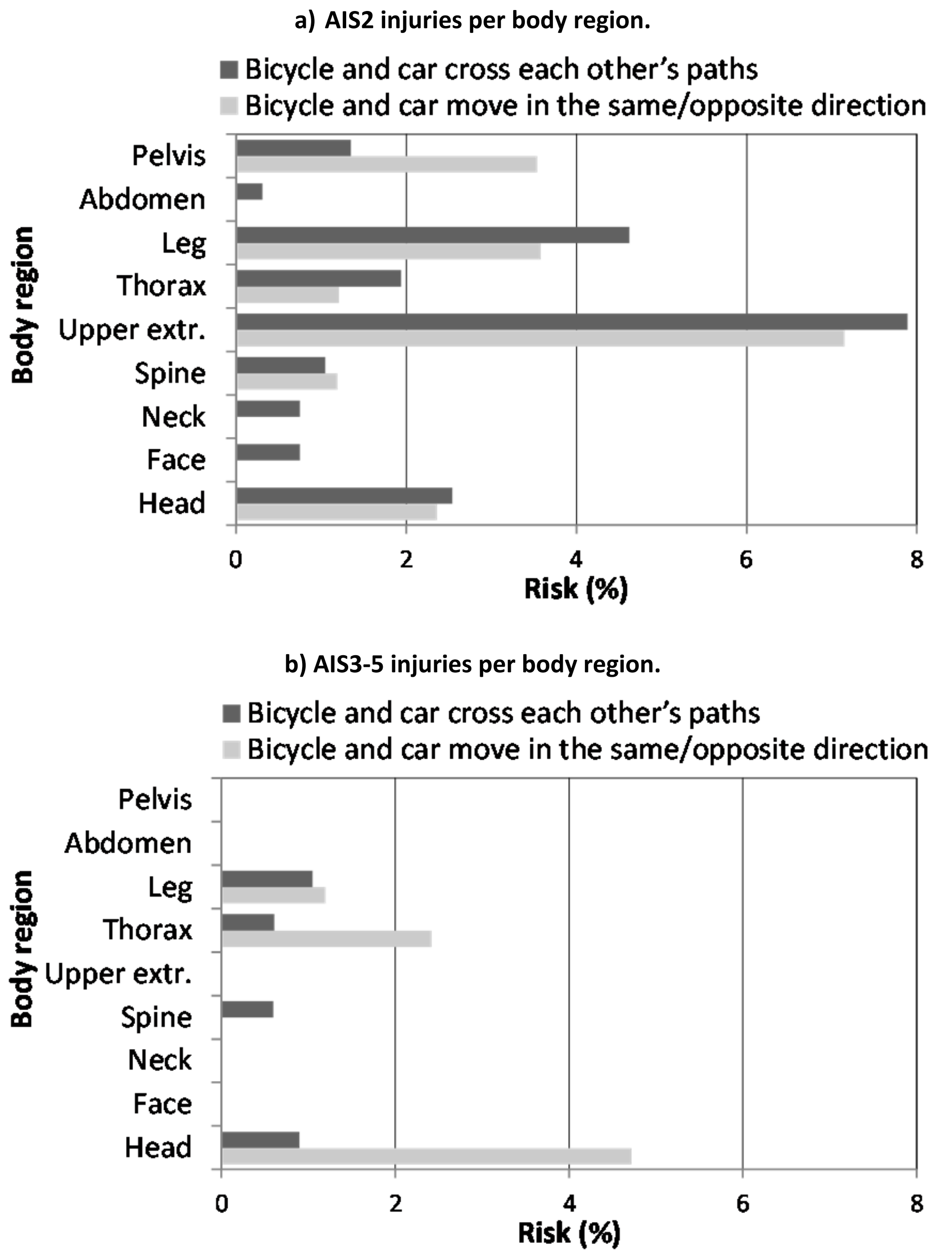

Figure 5. Risk of a) AIS2 and b) AIS3-5 injuries per body region, subdivided into crossing situations (n = 689) and same/opposite direction situations (n = 94).

Regarding the third main crash category *door opening* (n = 39), every fourth collision resulted in a MAIS2 injury, most often to the upper extremity.

3.3 Environmental characteristics and drivers' and cyclists' demographics in crossing and same/opposite direction situations.

In Table 5, distributions of different environmental characteristics, such as road status, light conditions, traffic environment and speed limit as well as demographics of both the driver and cyclist are presented. The outcome of the number of accidents under different conditions is depending on the exposure of when and where people are cycling. Due to the lack of exposure data in different conditions (e.g. rain, darkness) the risk of accidents in these situations can not be calculated.

As Table 5 shows, both *crossing situations* and *same/opposite direction situations* mainly occurred in good weather and good light conditions. With regard to the traffic environment, it was found that situations in which the cyclist rode in the *same/opposite direction* to a significantly higher degree occurred on roadways where the speed limits were higher than 50km/h compared to accidents in *crossing situations* ($\chi^2(1) = 28.6, p < .001$).

As Table 5 shows, both in *crossing situations* and *same/opposite direction situations* the driver was mainly male (67% vs. 70%). On average, the drivers were 51 years old (*crossing situations*: M = 51.1 years; SD = 17.4 years; *same/opposite direction situations*: M = 51.1 years; SD = 17.3 years).The cyclists were a little bit younger; in the *crossing situations* on average 38.4 years old (SD = 18.1 years) and in the *same/opposite direction situations* 41.5 years (SD = 20.7 years). Here, in both situations the gender of the cyclists was almost balanced.

Table 5. Distribution of a) environmental charateristics with regard to road staus, light, traffic environment and speed limit and b) demographicsregarding cyclist's and driver's gender and age, subdivided into the crossing situations (n = 689) and same/opposite direction situations (n = 94).

a) Environmental characteristics:

	Bicycle and car cross each other's paths (%)	Bicycle and car move in the same/opposite direction (%)
Road status		
Dry	67.1	67.7
Wet	13.6	6.4
Icy	1.3	6.5
Snow	0.6	0.0
Unknown	17.4	19.4
Light		
Daylight	81.4	86.0
Dark	9.0	7.5
Dusk/dawn	6.2	1.1
Unknown	3.3	5.4
Traffic environment		
Urban areas	91.1	76.3
Non urban areas	3.5	16.1
Unknown	5.4	7.5
Speed limit		
<=50 km/h	75.6	57.0
51-100 km/h	3.1	20.4
Unknowm	21.4	22.6

b) Demographics:

	Bicycle and car cross each other's paths (n = 689)	Bicycle and car move in the same/opposite direction (n = 94)
Gender of the cyclist		
Male (%)	54.1	54.3
Female (%)	45.7	45.7
Unknown (%)	0.0	0.0
Gender of the driver		
Male (%)	66.8	70.2
Female (%)	31.8	24.5
Unknown (%)	1.4	5.3
Age of the cyclist		
Mean (years)	38.4	41.5
Std dev (years)	18.1	20.7
Age of the driver		
Mean (years)	51.1	51.1
Std dev (years)	17.4	17.3

3.4 Characteristics of the accidents in crossing and same/opposite direction situations.

To understand the differences in frequency and injury severity between the *crossing* and *same/opposite direction situations*, characteristics such as impact speed, impact direction, and kinematics as well as if the driver saw the cyclist before the accident were investigated.

In Figure 6, the cumulative distributions of impact speed in both the *crossing* and *same/opposite direction situations*, when the car hit the bicycle, are shown. As information on bicycle speed is very limited, impact speed in situations when the bicycle hit the car is not analysed. As Figure 6 shows, accidents where the cyclist and driver drove in the *same/opposite direction*, the impact speed was on average higher compared to the situations when they crossed each other's paths. According to Table 5, over 16% of these accidents took place in non-urban areas and with higher speed limits.

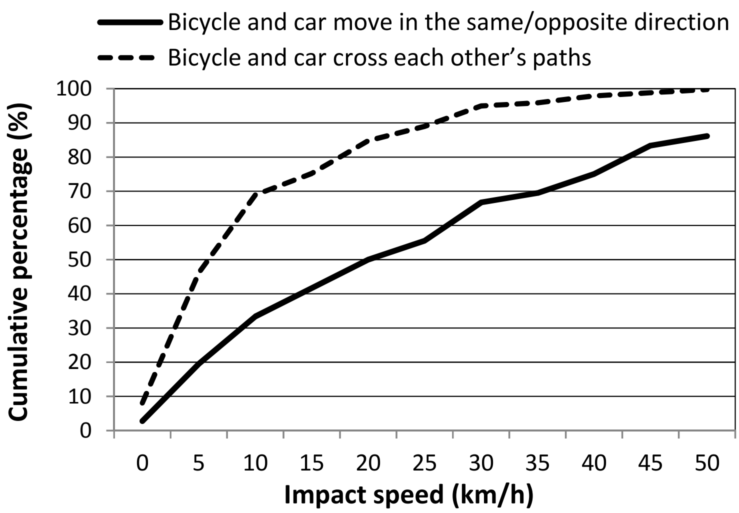

Figure 6. Cumulative distribution of impact speed when the car hit the bicycle, subdivided into the *crossing situations* (n = 334) and *same/opposite direction situations* (n = 36).

Figure 7 shows the distribution of impact direction of the cyclist in the a) *crossing situations* (n = 689) and b) *same/opposite direction situations* (n = 94). As Figure 7 shows, the impact direction differs due to the characteristics of the situation. In the *crossing situations*, impact from left and right were more common (in total 43.6%) in comparison to the *same/opposite direction situations* (in total 22.2%). In contrast, impact from the rear was more frequent with 25% of the *same/opposite direction situations* than in *crossing situations* where it was 5%. Situations where the cyclist was hit from the rear in crossing situations can be exemplified by looking at Figure 2b S1, when the car is turning right.

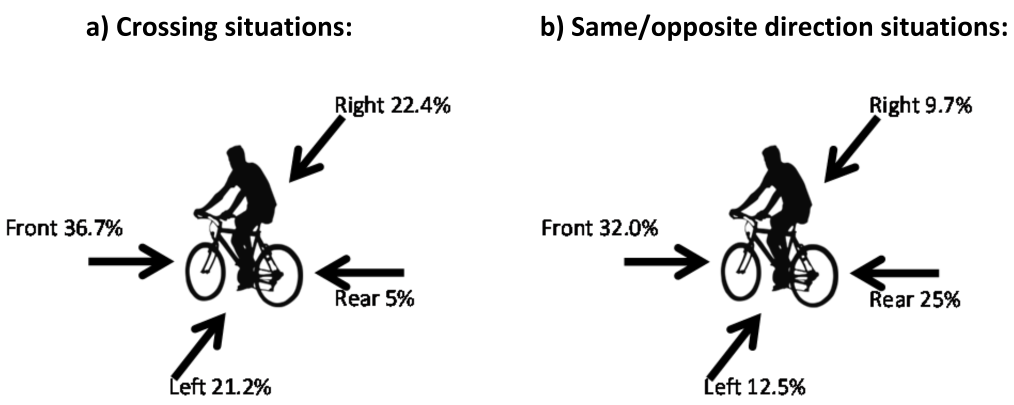

Figure 7. Distribution of impact direction of the cyclist in a) crossing situations (n = 689) and b*)* same/opposite direction situations (n = 94).

The kinematic was analysed to understand how the cyclist moved during the crash event. Figure 8 shows the distribution of the kinematics, subdivided into the *crossing situations* and *same/opposite direction situations*.

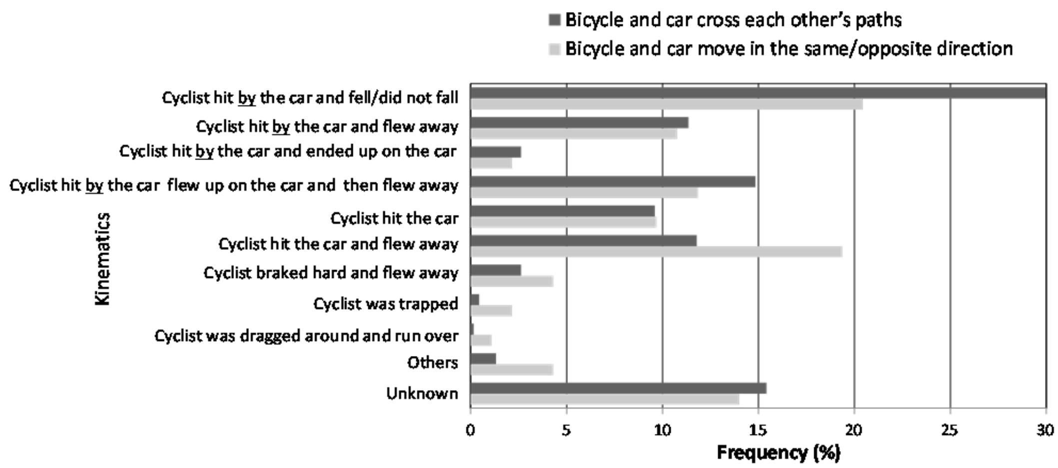

Figure 8. Distribution of the kinematics, subdivided into the crossing situations (n = 698) and same/opposite direction situations (n = 94).

As Figure 8 shows, in *crossing situations* the most common situation was found when the cyclist was hit by the car (car ran into the bicycle), just stopped and either could keep the balance or, in some cases, fall to the ground (30%). This mainly occurred in *crossing situations*. In contrast, in the *same/opposite direction situations* it was more common that the cyclist hit (cycled into) the car and flew away (20%). and landed some distance from the spot where the car and the bicycle crashed.

One important factor both for the occurrence of the accident and in the outcome of injury severity is if the driver saw the cyclist before the accident occurred. This information was recorded from the claims submitted by the driver, in a subjective manner. As Figure 9 shows, in the *crossing situations* the driver stated that he/she did not see the cyclist in about 50% of all the *crossing situations.* This was significantly higher compared to the *same/opposite direction situations* where the driver did not see the cyclist before the crash in about 30% of the collisions ($\chi^2(1) = 14.3$, $p < .001$). Looking at the group of *crossing situations* where the cyclist comes from a bicycle path shows almost the same result, about 45% of the drivers did not see the cyclist before the collision.

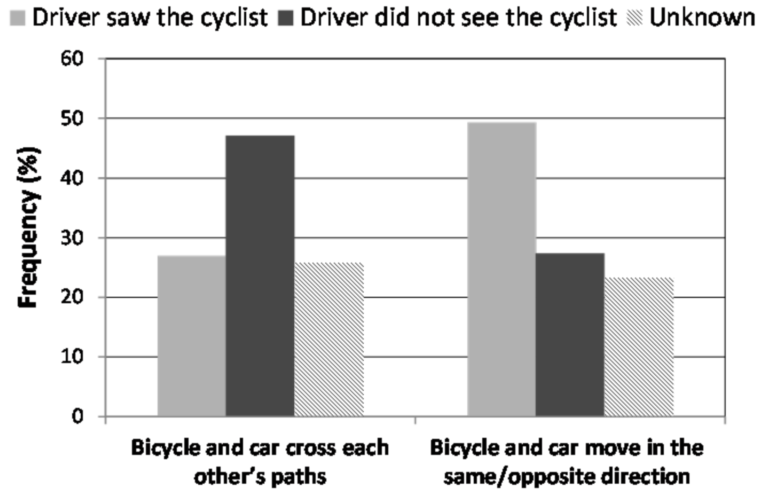

Figure 9. Distribution of situations when the driver reported that he/she saw/did not see the cyclist before the accident, subdivided into crossing situations (n = 689) and same/opposite direction situations (n = 94).

4 DISCUSSION

The aim of the study presented here was to analyse bicycle-car collisions in Sweden (2005-2012) based on *if* motor insurance claims. This useful and promising data enables more detailed information and thus a comprehensive view about real bicycle-car collisions in traffic supplementary to official accident data sets. In the study, a total of 882 bicycle-car collisions were analysed. With regard to the results found here, six key facts should be highlighted:

First, the results showed that *crossing situations* - when the cyclist and driver had to cross each other's paths are the most frequent collision situations found in the data set (78%). This result is consistent compared to other research studies which can be found in literature [22-24]. This reflects of course the Swedish situations since this is Swedish data, the numerous collisions in crossing situations is thus found in other countries even if the percentage can vary due to infrastructural differences [25,26]. Moreover, the results here also showed that in almost 70% of these crossing situations the cyclist came from a bicycle path before the collision occurred. Collisions in which the cyclist and driver moved in the *same or opposite direction* are clearly less frequent (11%). However, those situations seem to be the most dangerous as they showed a significantly higher risk for severe to fatal injuries (MAIS3+). This is in line with the decreasing trend of fatal accidents in connection with the expansion of the number of bicycle paths in the last decades. A comparison of these two main crash categories is of great interest for further research. For example, it would be interesting to investigate why people decide to cycle on the road or on the bicycle path when both exist. Is this related to limitations in the infrastructure (e.g., the bicycle path is missing, bad maintenance, quality or accessibility [27]) or related to personal preferences (e.g., to get a quicker ride by going on the road with fewer stops).

Second, one explanation for the higher risk for severe injuries in the *same/opposite direction situations* is the impact speed of the car. Results showed that on average in the *same/opposite direction situations* the speed was higher compared to the *crossing situations*. Almost one fourth of these collisions occurred with a speed limit above 50km/h. This seems to be related to the fact that in crossing situations which are mainly at or in intersections drivers have to slow down to be able to turn and/or interact with other road users [3, 28-30]. Overall, it indicates that speed is an important factor to take into account in planning road environments, in particular at intersections. For example, road sites where cyclists and drivers share the space speed limits lower than 50km/h are needed. Furthermore, traffic calming measures both at intersections and other road sections where one can expect that cyclists and motorists might meet on the same road seems to be appropriate so that drivers reduce their speed.

The third key fact is related to the high number of moderate injuries (MAIS2) to the cyclist in the *crossing situations*, especially fractures on the extremities and concussion, relatively often resulting in some degree of impairment [1]. Human suffering caused by being involved in an accident, especially suffering permanent injuries should not be underestimated. From society's point of view this can constitute significant costs. Traditionally, monitoring and reporting of road safety has focused on fatal accidents. However, this is changing as in Sweden one aim of the work with road safety at the national level is to consider serious injuries, especially injuries with higher risk of long term consequences [1]. From this point of view, moderate injuries (MAIS2) become very important and should be taken into account for increasing bicycle safety in road traffic, especially in *crossing situations*. Further research is needed, to how the moderate injuries (AIS2) distribute to the different scenarios of *crossing situations* presented here.

Fourth, in connection to the finding mentioned above it was found that in *crossing situations* 50% of the drivers reported that he/she did not see the cyclist before the collision occurred. Compared to *same/ opposite direction situations* in only 30% this was reported by the drivers. This indicates that especially in *crossing situations* which mainly occur in intersections, visibility is an important factor contributing to the collision. This is consistent with other research studies which can be found in literature. Here, especially impairment of driver's attention, expectation or attention allocation are emphasized [29-31]. In these collisions also darkness and bad weather affected the visibility and are more pronounced than in the *same/opposite direction situations* [3]. This is an interesting result and will be further investigated in a direction of understanding behavioral factors in this type of crashes and how this can be adapted to the design of collision warning systems, e.g. see study by Werneke et al. [32].

Fifth, depending on impact direction, impact point, and crash severity, the injuries in body parts of the cyclist varied. In crossing situations the cyclist was mainly hit by the car from the side and front, which is natural due to the way they move toward each other. In collisions when the cyclist and driver went in the same or opposite direction, the cyclists were more often hit from behind or in front when the car overtook the cyclist and did not leave enough space. This is an interesting point to look at in further research if the driver misinterprets the speed of the cyclist.

Sixth, with regard to the third main category *door opening*, more than every fourth accident results in a moderate injury (MAIS2). There are also fatal accidents where the cyclist has cycled into the car in very high speed and has been thrown off the bike sustaining fatal head injuries. These accidents can be a problem for cyclists going downhill or passing outside parked cars on narrow city roads. As a result, planning of paths for cyclists in relation to parked cars must be considered to avoid this type of collisions.

Overall, separating bicycle and motor vehicles has been successful in reducing fatal bicycle accidents. However, there are still a lot of safety issues to consider. In the study presented here we focused on the current status and remaining problems due to bicycle and car collisions.

One limitation in this analysis is that collisions between bicycles and heavy vehicles, such as trucks and buses, are not included. As these collisions are known to be very fatal and a problem in specific situations as truck turning right in an intersection, further research is needed here as well.

Findings of bicycle-car collisions based on detailed motor insurance claims leads to deeper knowledge and input on how these safety-critical situations occur. This is very useful and promising data and enables to improve road safety for cyclists by identifying various types of countermeasures, e.g.,

- Improvement in road infrastructure: 1) to build coherent cycle paths without too many stops covering the whole city to be able to avoid sharing the roadway with motorists, 2) to build one-way cycle paths to get less problems on the path in meeting situations this also has a potential to create fewer conflict situations at intersections.
- Improvement in infrastructure planning and maintenance: to use these statistics to have preparedness for keeping the bicycle paths in good conditions all year around, continuous inspections of the surfaces where cyclists are passing.

- Development of active safety systems in vehicles to warn the driver before the safety-critical situation occurred, and thus to mitigate or even avoid the collision. By the knowledge of movement patterns of the cyclist and driver sensors and technical solutions can be optimized to avoid the most common and greatest hazards or developing 'forgiving' surface on the car where impacts are frequent etc.
- Intelligent Transport Systems, like communication between vehicles, warning systems in the cellphone for both the drivers and cyclists (apps).
- Adaptation of training concepts for both drivers and cyclists, include information about the most common and dangerous bicycle-car conflict situations.

CONCLUSIONS

In conclusion, in this study motor insurance claims were used to analyse bicycle and passenger car collisions at all levels of crash severity. The aim was to describe and analyse the most common collision situations and to relate them to the consequences in terms of injuries and injury severity. The results showed that *crossing situations* - when the cyclist and driver had to cross each other's paths are the most frequent collision situations. In contrast, collisions in which the cyclist and driver moved in the *same or opposite direction* are clearly less frequent but interestingly here the most severe injuries can be found. It was clear that high speed plays an important role in the occurrence of severe injuries but also that the frequent but less serious accidents cause many moderate injuries for the unprotected cyclist. In crossing situations the driver frequently stated that he/she did not see the cyclist indicating that visibility as well as impairment of driver's attention are important factors contributing to the collision. At last, the different scenarios describing how the driver and the cyclist moved towards each other as well as impact direction, impact points etc. gives insight in what happens during the collision. In total, six key factors were highlighted and suggestions of different countermeasures were discussed. This comprises many areas such as infrastructure, vehicle development, road user behavioural patterns to mention some examples and lays the basis for many interesting areas that hopefully leads to a successful process towards a safe traffic environment for cyclists.

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