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Pre-crash motion and conditions of bicyclist-to-car crashes in Sweden

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ABSTRACT

Cars have recently been equipped with pedestrian detection sensors and autonomous emergency braking (AEB) systems to protect pedestrians in car crashes. The natural next step is to develop these systems to also detect and brake for bicyclists. To develop these systems for optimized protection also for bicyclists it is necessary to understand the pre-crash kinematics and other important parameters in car-to-bicyclist crashes.

The aim of this study was to study the pre-crash conditions of car-to-bicyclist crashes. Two datasets were used. The Swedish Transport Administration fatal database was queried 2005-2014 for fatal car-to-bicyclist crashes. The STRADA database was queried 2010-2014 for AIS2+ car-to-bicyclist crashes. The focus of the study was on the bicyclist and car motion preceding the accident, but parameters included were also traffic environment, light and weather conditions, victim age etc. To understand the pre-crash kinematics, each crash was studied in detail.

The query resulted in 104 fatal and 435 AIS2+ car-to-bicyclist crashes.

It was found that the two most common injurious car-to-bicyclist accident scenarios in Sweden was the bicyclist crossing a road (from left or right) where the car was driving straight. This was most common in urban areas. For fatal accidents it was followed by a scenario where the car was passing a bicyclist on a straight rural road and the bicyclist turned in front of the car. For injured bicyclists it was followed by a scenario where the car was turning left and the bicyclist was crossing the road that the car was turning into from right side, a typical urban junction scenario. In all four scenarios daylight and dry conditions were dominating. These four scenarios represented around 70% of all accident scenarios for both AIS2+ and fatally injured bicyclists in Sweden.

When developing active safety systems for passenger cars, it is important that they are based on the most common accident types in real traffic regarding car and bike motion, lighting and weather conditions and size of the bicyclist. The information in this study, in conjunction with studies from other databases, could be used to develop test scenarios to evaluate and develop these systems.

Keywords: bicyclist, car crash, pre-crash motion.

1 INTRODUCTION

World-wide it is estimated that over 500 000 pedestrians and bicyclists are killed annually in road traffic [1]. In the European Union more than 7 000 pedestrians and 2000 bicyclists are killed annually, which is approximately 27% of all fatalities [2]. In Sweden, approximately 45 pedestrians and 20 bicyclists are killed annually [3] which account for 15% and 9% of all road fatalities respectively. Virtually all road pedestrian fatalities and a majority of the cyclist road fatalities are caused by crashes with vehicles [4]. In larger European cities, bicycle transportation is increasing [5], likely due to congestion, fuel prices and an increasing awareness of its health benefits. Pedestrians and bicyclists already make up roughly half the traffic fatalities in urban areas in the EU [6], risking fatalities to increase with increased bicycle use.

Steps have been taken in Europe and Asia to legislate minimum pedestrian protection performance for passenger cars. Consumer organizations rate pedestrian protection performance of cars since 1999 in Europe for passive (in-crash) safety and cars are now equipped with energy absorbing bumpers and hoods, as well as deployable hoods. These measures have proven effective in reducing pedestrian injury. Strandroth et al. [7]showed a significant correlation between car Euro NCAP pedestrian score and injury outcome in real-life car to pedestrian crashes. Beginning 2016 active safety systems, such as autonomous braking or warning for pedestrians will be assessed and included in the rating. These tests consist of three scenarios which are intended to represent the most common accident scenarios for pedestrians, regarding pedestrian motion before crash. It is planned by EuroNCAP to start active safety system testing for bicyclists in 2018 [8]. Van Schijndel et al showed in data from four countries that most common car-to-bicyclist crashes were a car driving straight impacting a crossing bicyclist. Most accidents occurred in an urban setting, in junctions, and with impact to the car front.

It is important to understand more details on bicyclist–to-car crashes to be able to develop test scenarios that most effectively can assess real-life protection performance. The aim of this paper was to investigate Swedish accident data to conclude the pre-crash motion and other relevant accident parameters of bicyclists and cars involved in crashes with each other.

2 METHOD

Swedish real-life crash data was obtained from two different national databases, the STRADA database for non-fatal AIS2+ cyclist accidents, and the Swedish Transport Administration (Trafikverket) in-depth database for fatal cyclist accidents. The dominating injury in the STRADA database are minor injuries (AIS1) but to prevent them from dominating the results, these were excluded to focus on the moderate and more severe injured bicyclists.

The data acquisition system STRADA contains police records and hospital admission data. Police data includes all reported road crashes with personal injuries and is the basis for the national statistics. The hospital records in STRADA are collected from emergency hospitals and consist of ICD diagnoses and AIS coded injuries. As of 2014 all Swedish emergency hospitals but one are linked to STRADA and the database can thereby be considered representative for Swedish conditions even with respect to injury data. All crashes between cars and bicyclists resulting in an AIS2+ injury, included in police records and hospital admission data in STRADA, during the period Jan 1st 2010 to Jan 31st 2014 were selected. If the bicyclist was fatally injured the case was not included.

Since STRADA only contains information on cases where the victim is taken to hospital, victims which die on the accident site are not included in STRADA. The fatal accidents were therefore studied in a different database, the Trafikverket in-depth database, which investigates every fatal road accident in Sweden. Investigators from the seven STA regions analyze all fatal traffic crashes in Sweden since 1997, assembling on-site comprehensive information of road and surrounding conditions, detailed vehicle data including photo documentation and all available medical and forensic records from the casualty. (Such details include vehicle type and model year, pictures of the crashed vehicle and the crash scene, road surface, lighting, bicyclist height, gender and age, bicyclist direction, visibility, injury details, etc.) Fatal injury is defined as mortality within 30 days due to crash-related injuries. Cases from 2005-2014 were included in the analysis. The longer time period for fatal cases was necessary to get a sufficient number of cases.

For both datasets, accidents with bicyclists of all ages impacted by passenger cars, including side-swipes and reversing cars were included. Parameters studied were bicyclist and car motion, road layout, light conditions, precipitation, car impact point, season, speed limit, age, gender and helmet use. A pre-defined table of definitions of crash scenarios was developed as part of the international research project CATS (see Figure 1). Each case was studied in detail to conclude the crash scenario including directions before impact of the car and the bicyclist. The results on accident scenarios and relevant parameters will be presented as distributions.

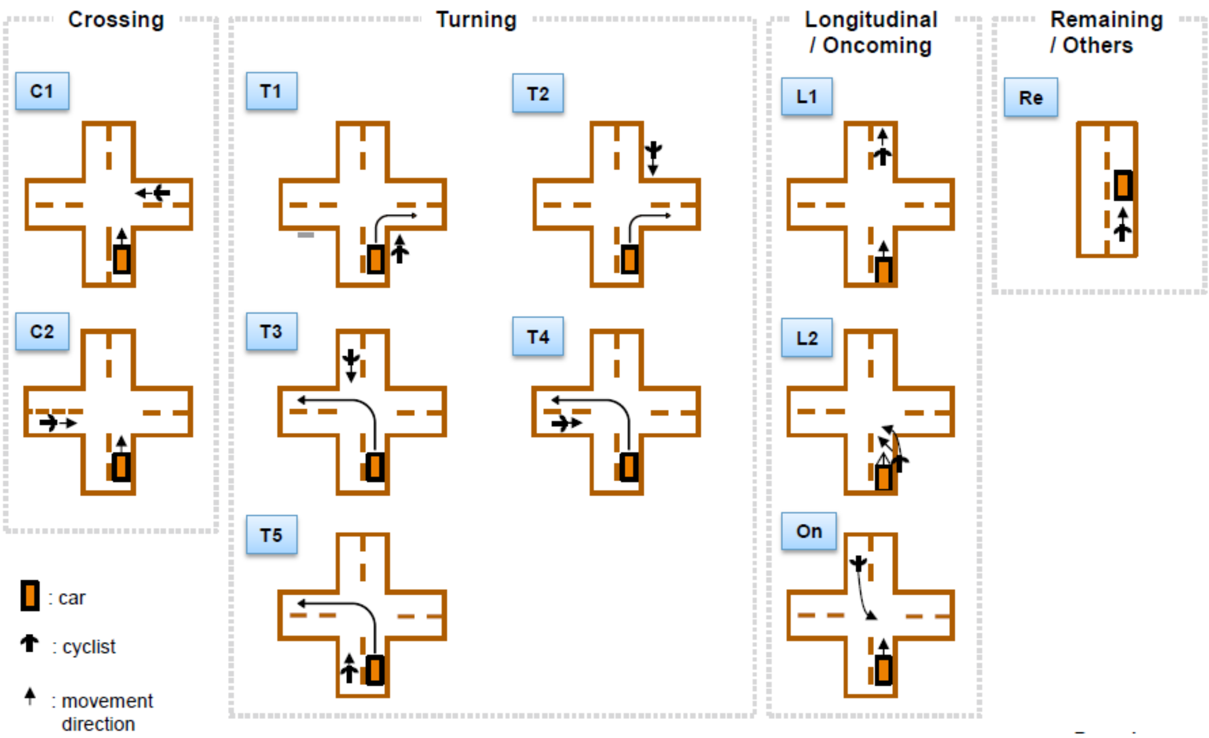


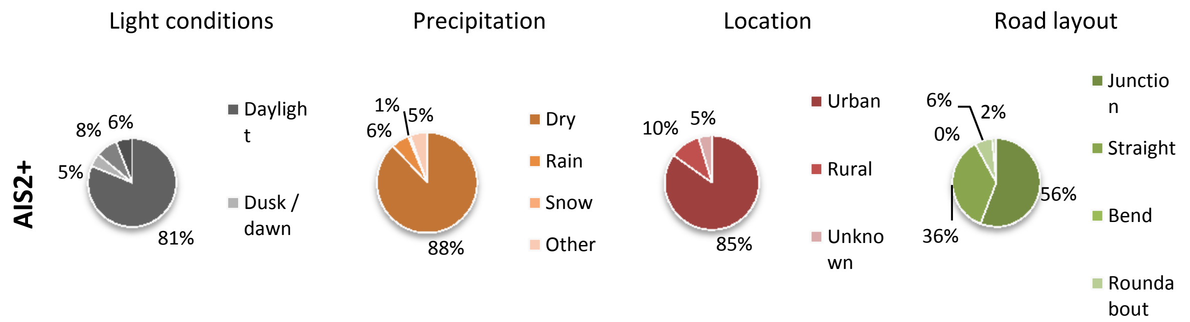
Figure 1. Accident scenario definition (from the CATS project)

3 RESULTS

For the AIS2+ (non-fatal) cases, data from 2010 to 2014 was included to limit the amount of data for analysis. For this time period of approximately four years, 1569 accidents occurred where a bicyclist was impacted by a passenger car and sustained an AIS1+ (non-fatal) injury. Of these, 552 bicyclists sustained AIS2+ injuries, of which 435 cases could provide enough information to conclude the relevant parameters included in this study. For the fatal cases, 104 cases met the inclusion criteria for the selected time period 2005-2014.

A. General accident parameters

For both groups the accidents occurred most frequently in daylight and dry conditions (see Figure 2). For the injured group the accidents occurred predominantly in urban areas and in junctions, while the fatal accidents occurred more often in rural areas and straight roads.



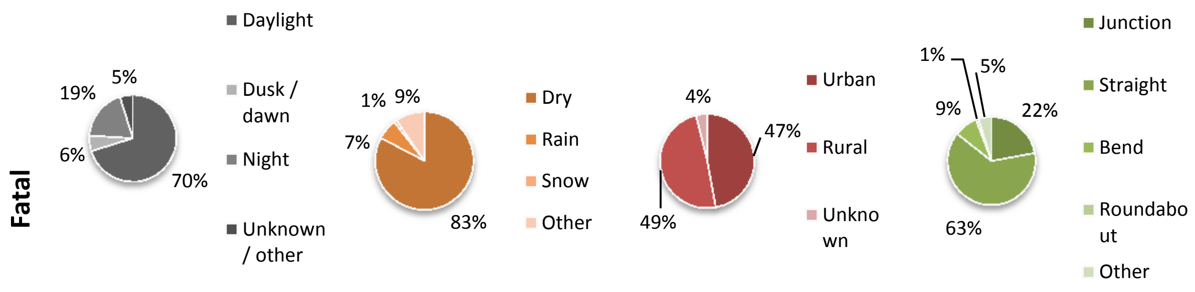


Figure 2. Accident parameters for all accidents regarding light conditions and road layout, for AIS2+ injured (top) and fatally injured (below)

A large majority of the accidents occurred when the car was driving forward for both groups (see Figure 11 in Appendix). Logically in most cases the bicyclist impacted the front or side of the car. Most accidents happened during summer season (see Figure 12 in Appendix) for both groups, while posted speed limit differed between the groups. The accidents for the injured group occurred most frequently in 50 km/h areas, while the fatal group was split more evenly between areas from 50 up to 90 km/h. A majority of victims in both groups were males, while age differed between the groups (Figure 3). The largest injured age groups were 20-60 years old, while the largest fatally injured age groups were 60-90 years old.

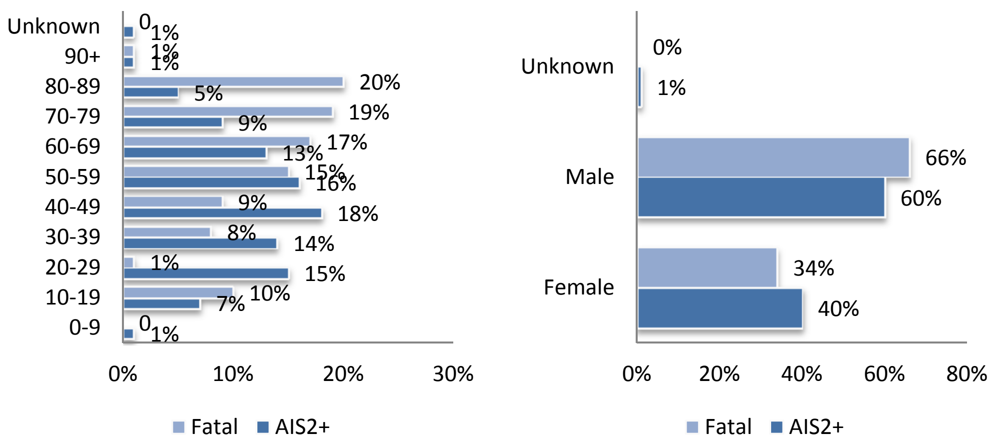


Figure 3. Accident distribution for all accidents regarding age (left) and gender (right)

The bicyclist was wearing a bicycle helmet in 33%/14% of the AIS2+/fatal cases, and the mean car model year was 2003 and 1997 respectively.

The most common accident scenarios were, for both the non-fatally injured and the fatally injured group, the bicyclist impacted when crossing the road (from left or right) where the car is driving straight (C1 and C2). See Figure 4. For the fatal group the scenario with the bicyclist riding straight in the same lane and turning in front of the on-coming car (L2) was the third most common, while the third most common for the injured group was the scenario where the car was turning left and the bicyclist was crossing the road that the car turned into from the right side (T3).

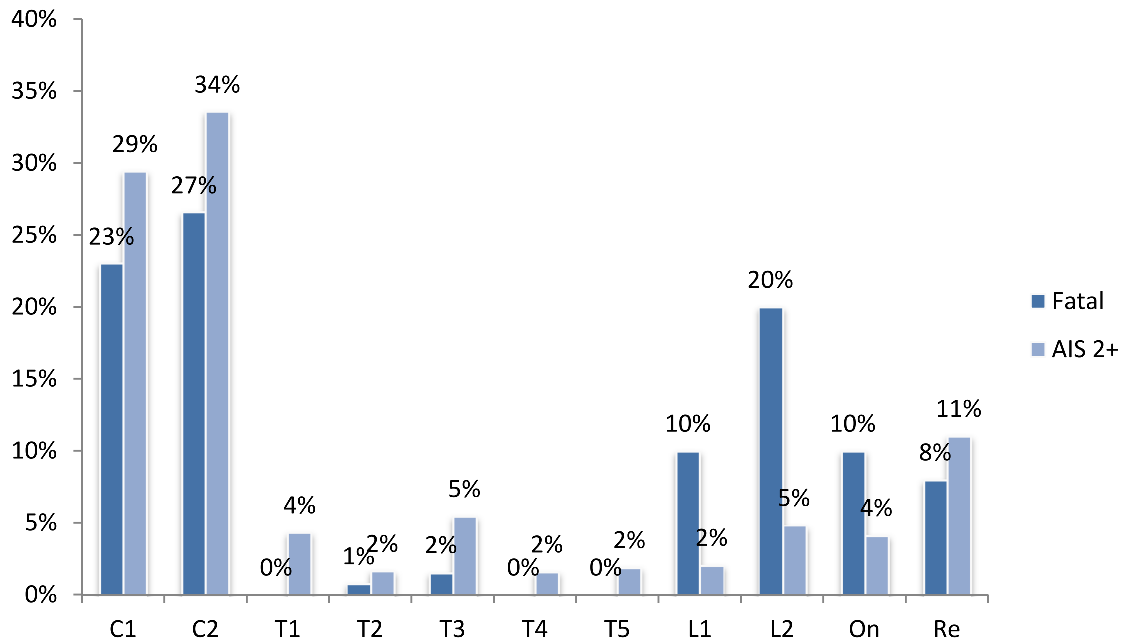


Figure 4. Accident scenario distribution

B. Most frequent scenarios in detail

The five most common scenarios for each group were selected for detailed study regarding the most important parameters. These scenarios made up 78% of the crashes of the AIS2+ injured and 89% of the fatal crashes. See Table 1.

Table 1. Ranking and accumulated frequency of most common scenarios for the two bicyclist groups

	AIS2+	Accum. freq.	**Fatal**	Accum. freq.
1	C2 (car straight, bike from left)	34%	C2 (car straight, bike from left)	27%
2	C1 (car straight, bike from right)	63%	C1 (car straight, bike from right)	50%
3	T3 (car left, bike from right)	68%	L2 (car/bike in same lane, bike turns)	70%
4	L2 (car/bike in same lane, bike turns)	73%	L1 (car into bike from rear)	80%
4	T1 (car left, bike from left)	78%	On (car/bike straight, opposite directions)	89%

Scenarios C2 and C1, the cyclist crossing from left/right when car is driving straight, had similar patterns in general (Figure 5 and Figure 6). Most accidents occurred in daylight and dry conditions for both these scenarios. Urban areas dominated the accidents for the injured while rural areas also were common for the fatally injured. Regarding road layout it differed also between the scenarios. While junction and straight road dominated to a similar extent for both groups in scenario C1 (cyclist coming from right), fatally injured for scenario C2 (cyclist from left) were dominated by cases on a straight road.

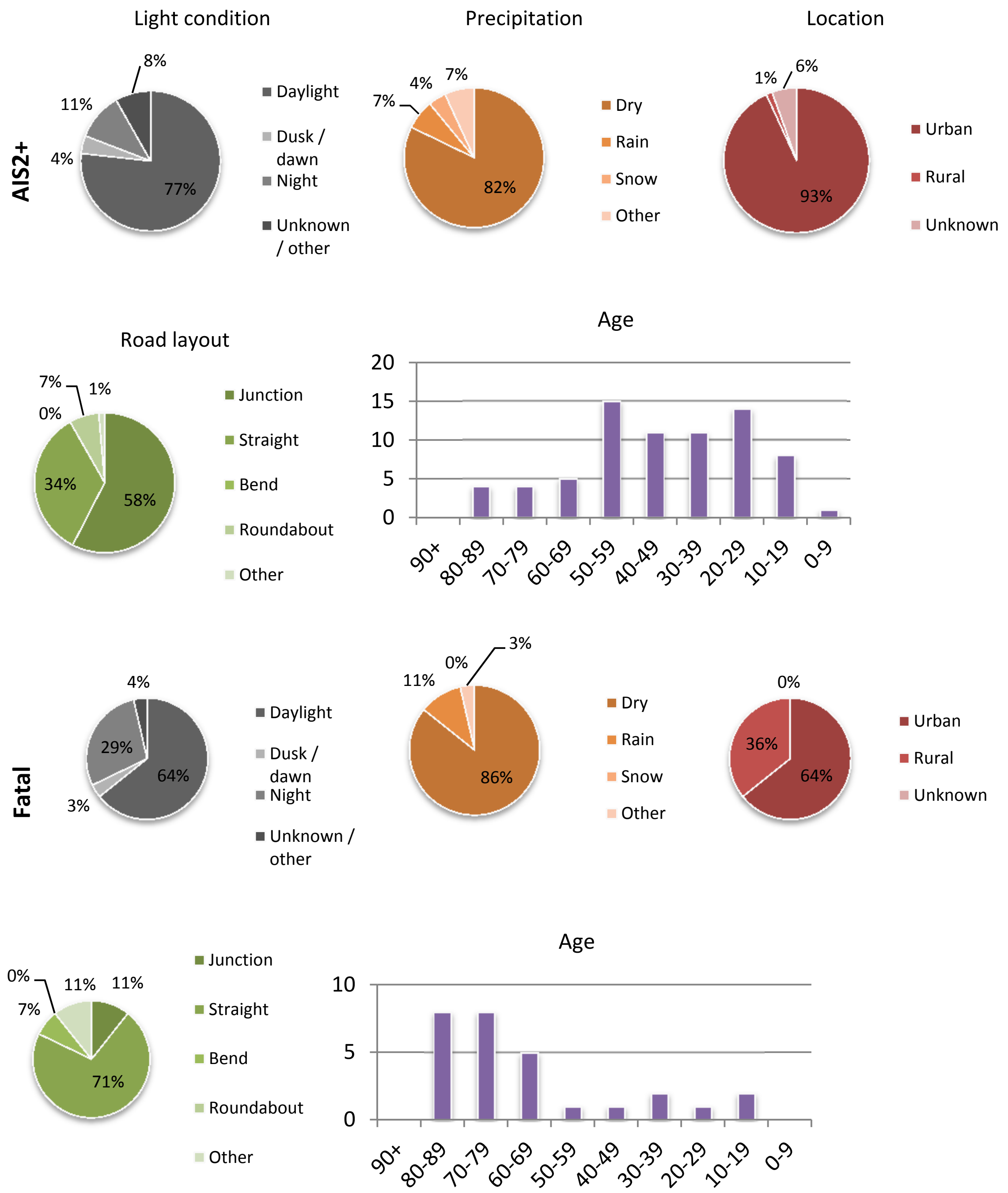


Figure 5. Accident parameters for scenario C2 (cyclist coming from left, car driving straight); AIS2+ injured (top) and fatally injured (below)

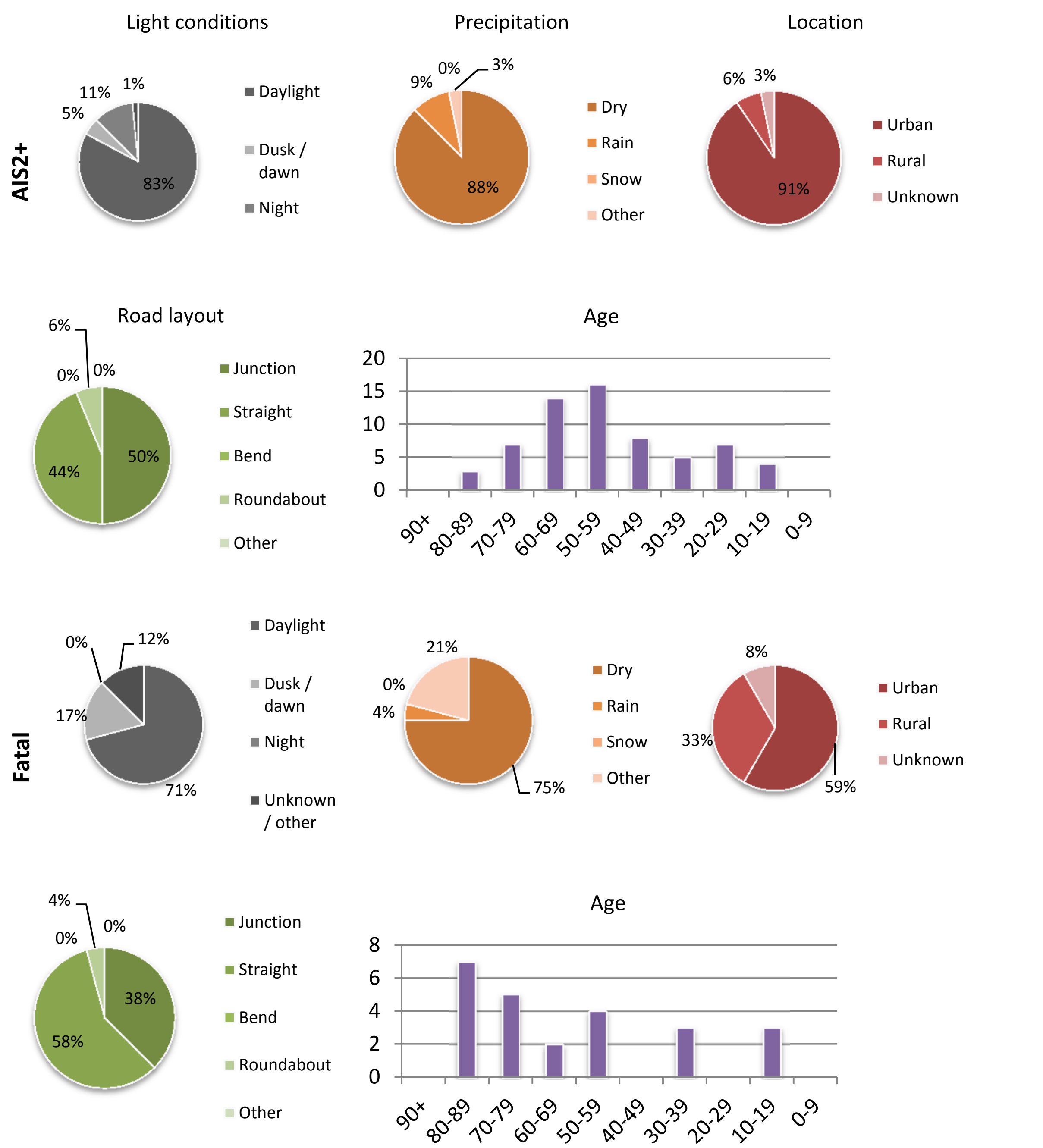


Figure 6. Accident parameters for scenario C1 (cyclist coming from right, car driving straight); AIS2+ injured (top) and fatally injured (below)

The T3 scenario was the third most common for AIS2+ injured bicyclists. In this scenario the car turned left and impacted a bicyclist crossing the road that car turned into from the right. It occurred most frequently in daylight in urban junctions. See Figure 7.

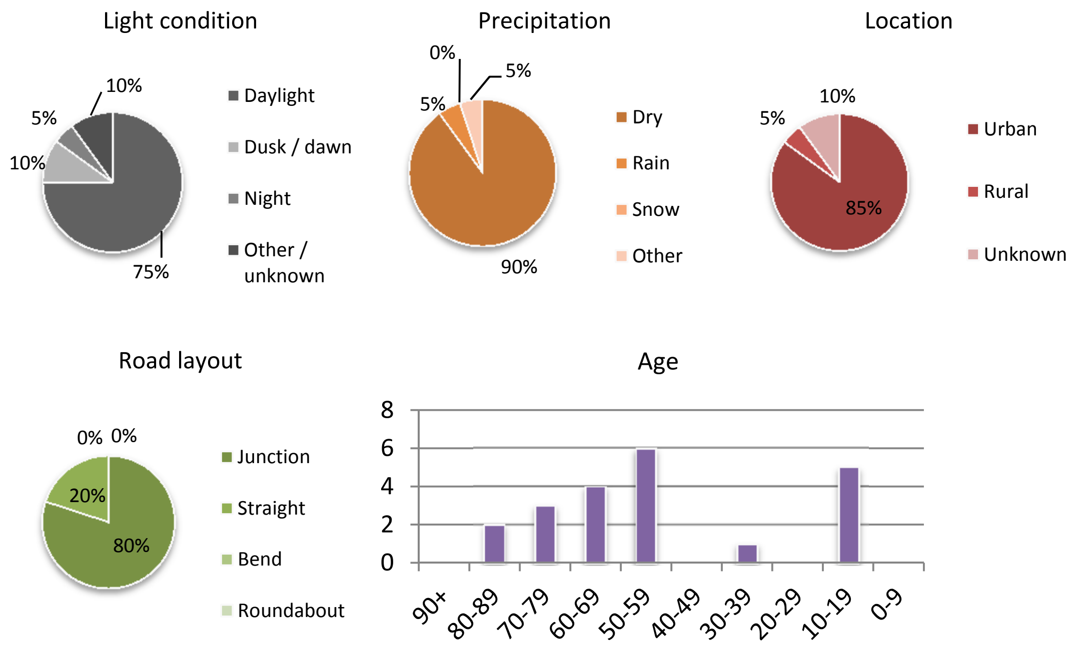


Figure 7. Accident parameters for <u>AIS2+ injured in scenario T3</u> (car turning left, bicyclist crossing the street the car is turning into from right)

The third and fourth most frequent scenarios, for fatally injured and AIS 2+ injured respectively, was the L2 scenario, the bicyclist riding straight in the same lane and turning in front of the on-coming car. Like C1 and C2 (bicyclist crossing from left/right) it is most common with daylight and dry conditions. While this scenario is still most frequent in urban settings for injured, it occurs predominantly in rural areas for fatal accidents. For both groups it is most common on a straight road. See Figure 8 and Figure 9.

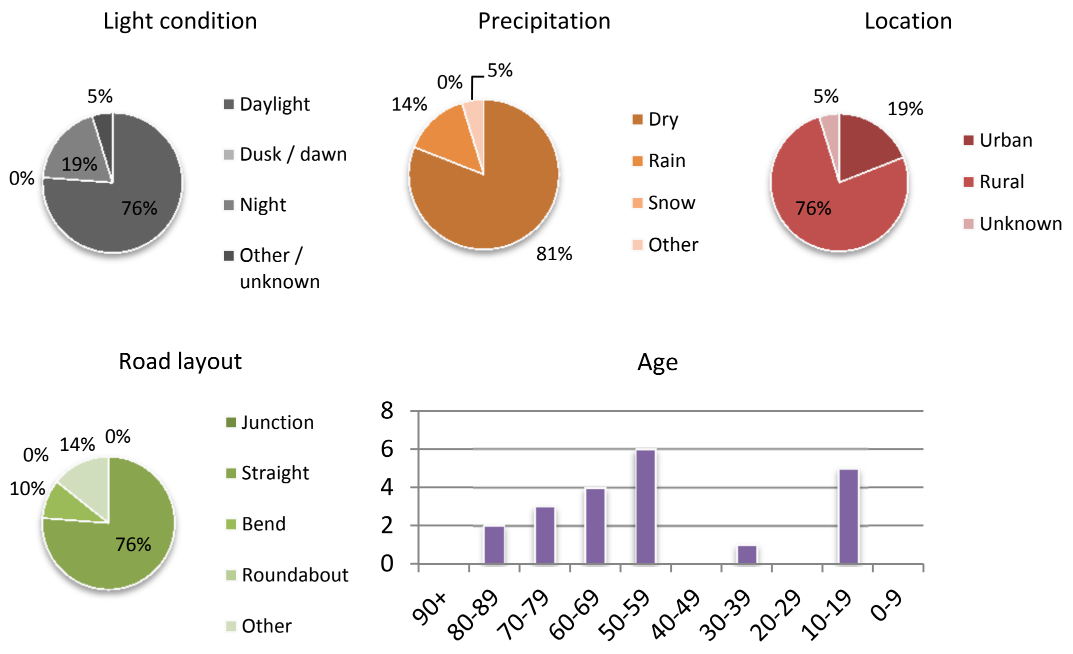


Figure 8. Accident parameters for <u>fatally injured in scenario L2</u> (bicyclist riding straight in the same lane and turning in front of the on-coming car)

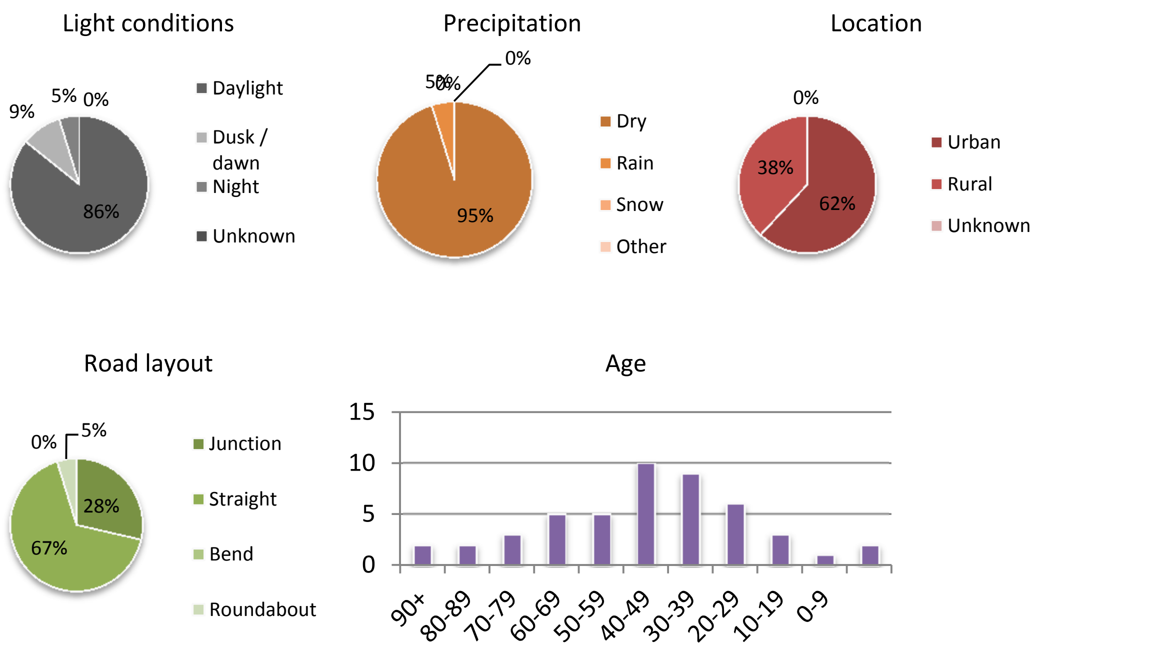


Figure 9. Accident parameters for <u>AIS2+ injured in scenario L2</u> (bicyclist riding straight in the same lane and turning in front of the on-coming car)

L1 type collisions, where a car catches up to a bicyclist in front of it and crashes into it from behind, make up 10% of fatal collisions. A clear majority of these cases took place during daytime and in dry conditions. This scenario occurs mostly in rural areas, and on straight roads. See Figure 10.

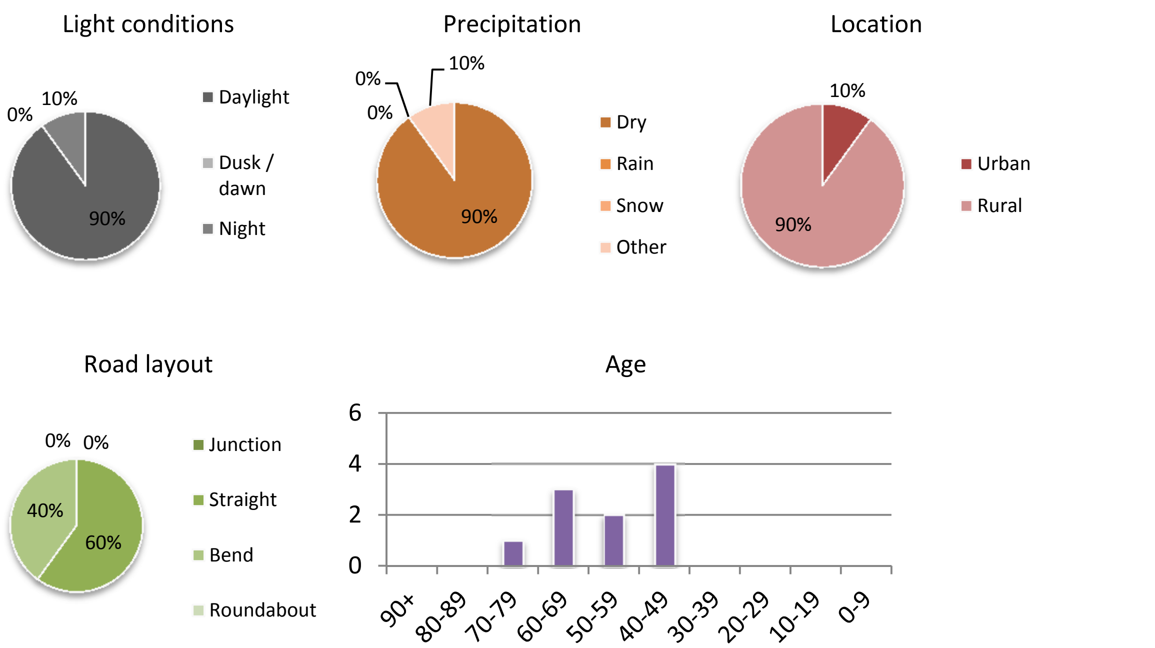


Figure 10. Accident parameters for <u>fatally injured in scenario L1</u> (car catching up to and crashing into bicycle travelling in the same direction)

In the T1 scenario, a car turning right collides with a bicyclist riding in a direction parallel to the car's original driving direction. This type of collision makes up 4% of the AIS2+ injured. In line with the majority of scenarios, daylight and dry conditions are most common. Urban areas and junctions dominate in this scenario. See Figure 13 in Appendix.

In 10% of fatal injured, the accident is an Oncoming collision, where the car and bicyclist are travelling in opposite directions and collide frontally. In this scenario, a majority of the accidents occurred at nighttime, but dry conditions are still most common. A majority of these collisions occurred in rural areas. The oncoming type collisions were more evenly divided when it came to road layout, with similar occurrence of junction and straight roads. See Figure 14 in Appendix.

The "Re" category – the Remaining/Others group – also made up a considerable share of the accidents for the AIS2+ and fatally injured. Since this category contained those scenarios that could not be fitted into other categories, this group was divided into subtypes (see left Figure 15 in Appendix). The most common subtypes were bicyclist biking into an opened car door, car reversing or standing still. The accidents in the Remaining/Others group occurred mainly in urban areas and on straight roads. See Figure 15 in Appendix.

4 DISCUSSION

This study concluded the most common scenarios when a bicyclist was impacted by a passenger car in Sweden. The most common scenarios were the bicyclist crossing the road from left or right in front of a car driving straight for both AIS2+ injured and fatally injured bicyclists (scenarios C2 and C1). These accidents occurred predominantly in urban areas, in daylight and in dry conditions. The age was generally higher among the fatal victims, who were most frequently elderly (70+), while the injured were most frequently 50-70 years old.

The third most common scenario for fatal accidents (and fourth for injured) was the bicyclist riding in the right part of the lane when a car was passing and the bicyclist suddenly turned in front of the oncoming car (scenario L2). These accidents occurred predominantly on straight roads in rural areas, in daylight and dry conditions.

The third most common scenario for injured bicyclists was a scenario when the car was turning left and the bicyclist was crossing the street, which the car was turning into, from the right side (T3). The dominating share of car-to-bicyclist crashes occurred in daylight and dry conditions. This is different to car-to-pedestrian crashes which occur more frequently in dark and rainy conditions [9, 10]. The dark condition is therefore planned to be included in Euro NCAP AEB tests in 2018 [8], a condition which not seems important to incorporate in bicyclist AEB tests, according to this data. Also car-to-bicyclist accidents seem to occur at a higher rate in junctions compared to car-to-pedestrian crashes.

To conclude, the most common accident scenarios for AIS2+ injured and fatally injured bicyclists, were bicyclists crossing from left/right when car was driving straight, car turning left and bike crossing from right and finally bicyclist turning in front of an approaching car in the same lane. For both groups these scenarios covered around 70% of all accident scenarios. If a test method could cover these scenarios it would therefore represent a majority of car-to-bicyclist crashes in Sweden.

The results in this study are in line with a parallel study in the CATS project on data from six countries in Europe [11]. Also in the other countries the crossing and longitudinal scenarios were common in fatal accidents as well as oncoming, and for severely injured bicyclists turning scenarios were increasingly common.

Safety systems that could address these most common accidents include the safety systems already developed to detect and mitigate in pedestrian accidents, such as pedestrian warning or autonomous emergency braking (AEB) systems. They typically use radar and cameras to detect the pedestrian. To detect also bicyclists they may need a larger field of view, due to a possible higher travelling speed of the bicyclist and that the turning scenario is fairly frequent. Another solution could be portable bike-to-car communication devices or smart-phone solutions, which could be automatically detected by the car and thereby predict a potential crash. The travelling and impact speeds of the bicyclist and the car were not available in these databases and need to be studied in other databases. In the "Remaining" category (Re) it was found that bicyclists were fairly frequently injured when riding into an opening car door (4-5% of all cases), or that the car was reversing (1-5%). It is suggested to study whether a blind spot system or a rear-ward facing ultra-sound, radar or camera would be effective to mitigate or prevent these accidents.

When developing active safety systems for passenger cars, such as warning systems or autonomous emergency braking systems, it is important that they are based on the most common accident types in real traffic regarding car and bike motion, light and weather conditions and road architecture. The information in this study, in conjunction with studies from other databases, can be used to develop test scenarios to evaluate and develop these systems.

5 CONCLUSIONS

It was found that the most common accident scenarios in Sweden when a bicyclist was injured when impacted by a passenger car was:

- car driving straight, bicyclist crossing from left, daylight and dry conditions, urban areas (*AIS2+ and fatal*)
- car driving straight, bicyclist crossing from right, daylight and dry conditions, urban areas (*AIS2+ and fatal*)
- bicyclist turning in front of passing car in same lane, daylight and dry conditions, rural areas (*fatal*)
- car turning left and bicyclist crossing the road that the car was turning into from right, daylight and dry conditions, urban junctions (*AIS2+*)

These four scenarios represented around 70% of all accident scenarios for both AIS2+ and fatally injured bicyclists in Sweden.

When developing active safety systems for passenger cars, it is important that they are based on the most common accident types in real traffic regarding car and bike motion, lighting and weather conditions and size of the bicyclist. The information in this study, in conjunction with studies from other databases, can be used to develop test scenarios to evaluate and develop these systems.

REFERENCES

1. Naci, H., D. Chisholm, and T.D. Baker, *Distribution of road traffic deaths by road user group: a global comparison.* Inj Prev, 2009. **15**(1): p. 55-9.
2. DaCoTA EU project. *Road Safety Knowledge System*. 2014 [cited 2014 05-21]; Available from: http://safetyknowsys.swov.nl/Statistics/Basic-fact-sheets.html
3. Swedish Transport Agency. *Annually killed in road traffic crashes by age and gender*. 2014 [cited 2014 05-21]; Available from: http://www.transportstyrelsen.se/sv/Press/Statistik/Vag/Olycksstatistik/Polisrapporterad-statistik/Nationell-statistik/Arsstatistik/
4. SIKA, *Road traffic injuries 2008*, 2009, Statens Institut för Kommunikationsanalys.
5. Thiemann-Linden, J., *Bicycle Use Trends in Germany*, 2010, German Institute of Urban Affairs (Deutsches Institut für Urbanistik): Berlin.
6. ERSO. *CARE database -Traffic safety basic facts 2012*. 2012 2014-03-16]; Available from: http://ec.europa.eu/transport/road_safety/specialist/statistics/care_reports_graphics/index_en.htm.

7. Strandroth, J., et al., *The Correlation Between Euro NCAP Pedestrian Test Results and Injury Severity in Real-Life Crashes with Pedestrians and Bicyclists.* STAPP Car Crash Journal, 2014. **58**.
8. EuroNCAP. *2020 ROADMAP*. 2014; Available from: http://www.euroncap.com/technical/technicalpapers.aspx.
9. Fredriksson, R., P.-O. Bylund, and M. Öman, *Fatal vehicle-to-bicyclist crashes in Sweden – an in-depth study of injuries and vehicle sources.* Ann Adv Automot Med, 2012. **56**: p. 25-30.
10. Fredriksson, R. and E. Rosén, *Priorities for Bicyclist Protection in Car Impacts – a Real life Study of Severe Injuries and Car Sources*, in *IRCOBI (International Research Council On the Biomechanics of Impact) Conference*2012: Dublin, Ireland.
11. Op den Camp, O.M.G.C., J. Uittenbogaard, and S.H.H.M. Buijssen, *Overview of main accident types in car to cyclist accidents for use in AEB-system test protocol*, in *International Cyclist Safety Conference*2014: Göteborg, Sweden.

APPENDIX

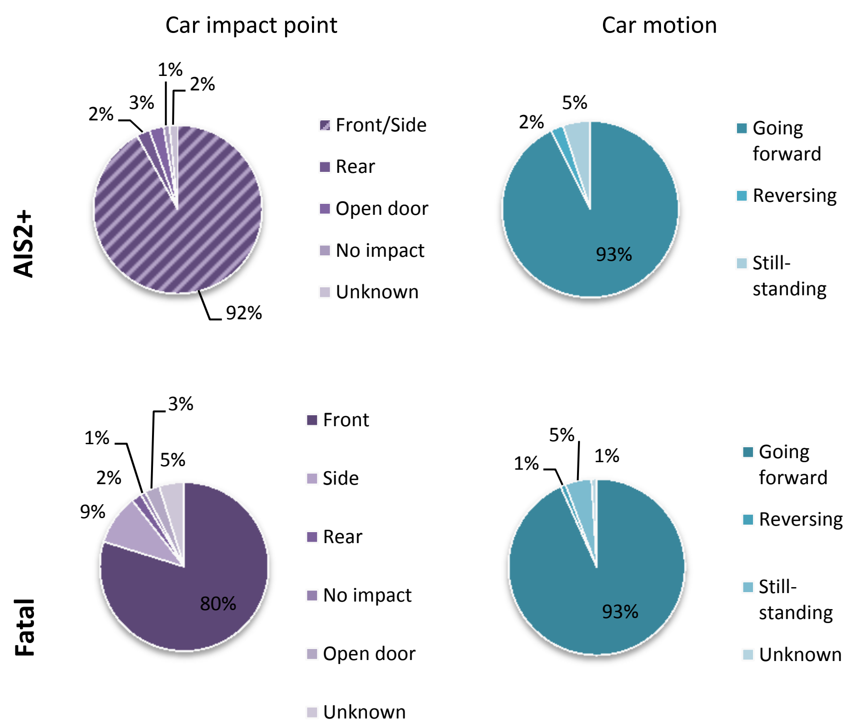


Figure 11. Accident parameters for all accidents regarding car impact point and car motion, for AIS2+ injured (top) and fatally injured (below)

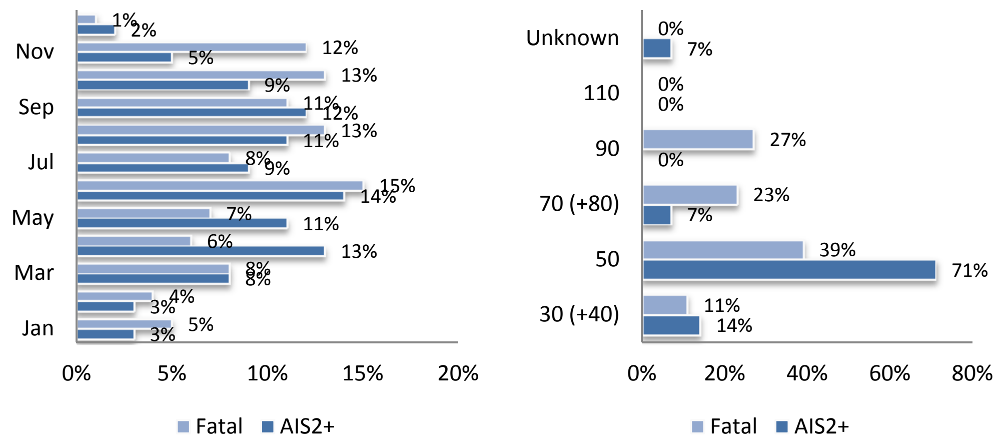


Figure 12. Accident distribution for all accidents regarding season (left) and posted speed limit (right)

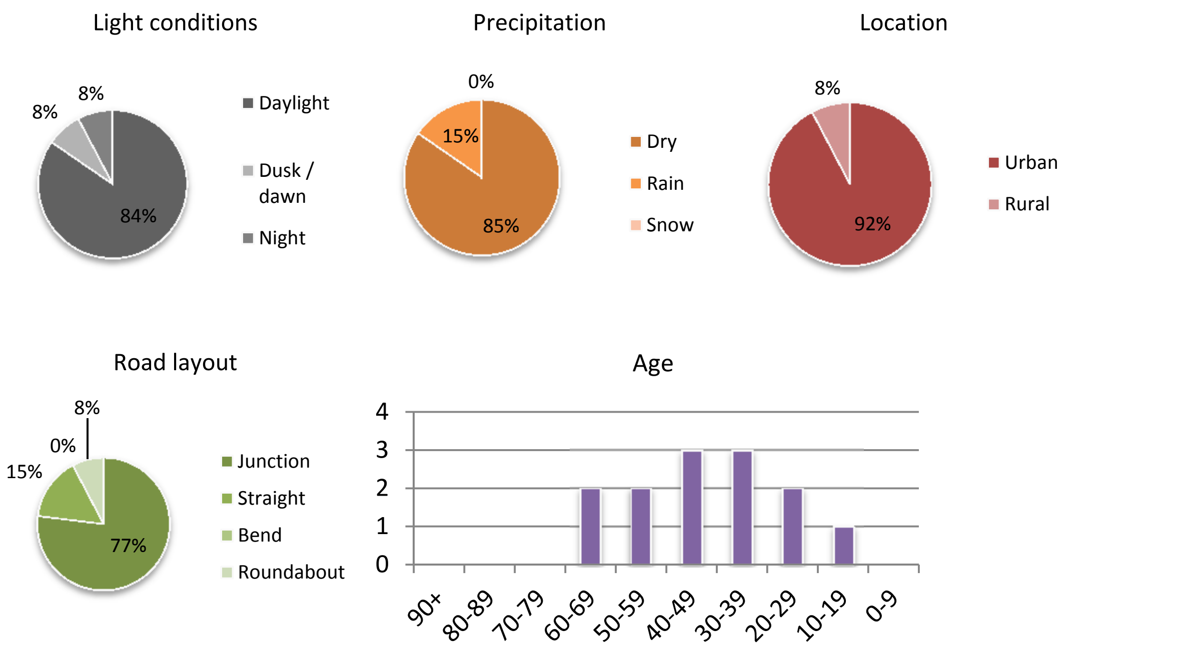


Figure 13 . Accident parameters for AIS2+ injured in scenario T1 (car turning right and colliding with bicyclist travelling parallel to car´s original direction)

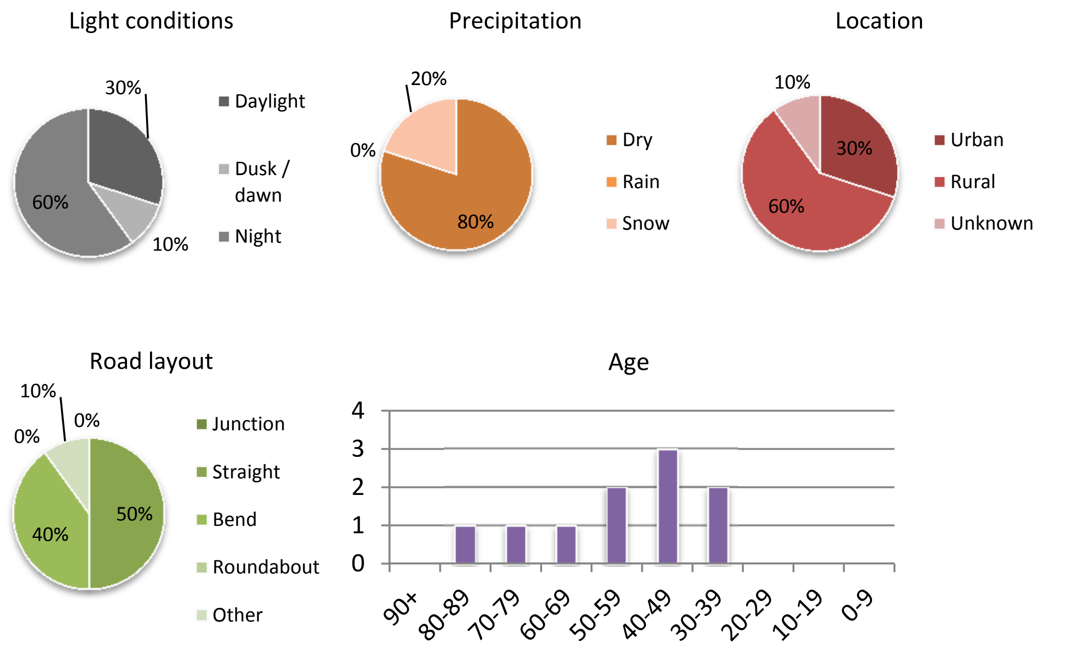


Figure 14. Accident parameters for <u>fatally injured in scenario On</u> (oncoming type collisions)

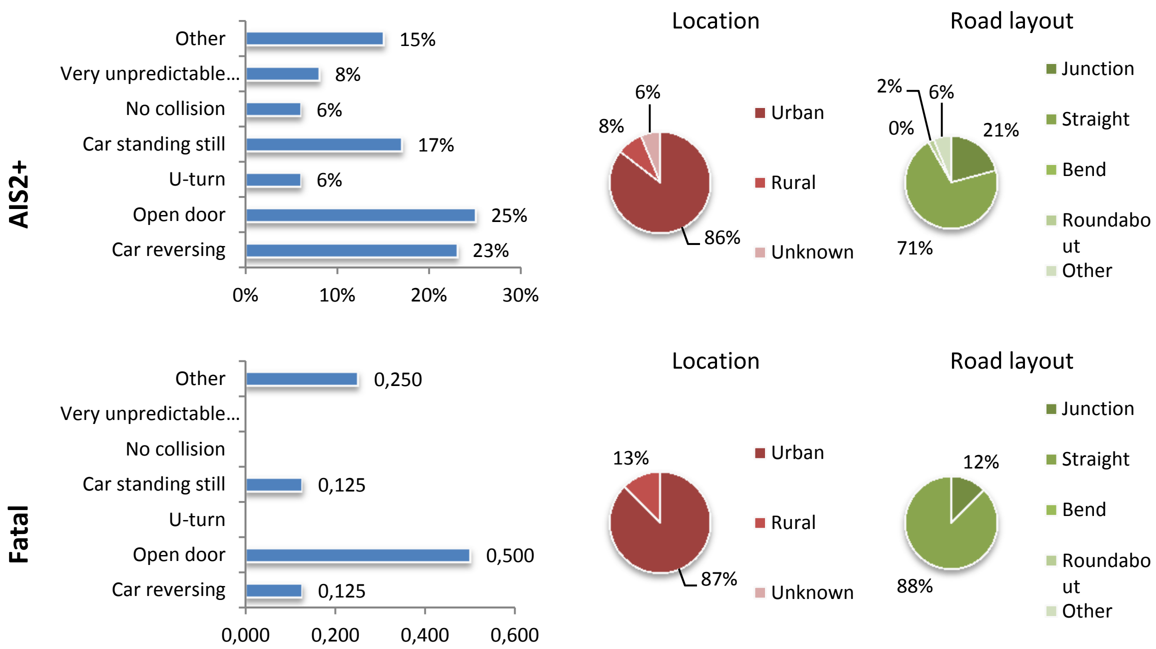


Figure 15. Subtypes and accident parameters for <u>scenario Re</u> (Remaining / Others), AIS2+ injured (top) and fatally injured (below)