

CAR-TO-CYCLIST CRASHES IN EUROPE AND DERIVATION OF USE CASES AS BASIS FOR TEST SCENARIOS OF NEXT GENERATION ADVANCED DRIVER ASSISTANCE SYSTEMS – RESULTS FROM PROSPECT

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ABSTRACT

The presence and performance of Advanced Driver Assistance Systems (ADAS) has increased over last years. Systems available on the market address also conflicts with vulnerable road users (VRUs) such as pedestrians and cyclists. Within the European project PROSPECT (Horizon2020, funded by the EC) improved VRU ADAS systems are developed and tested. However, before determining systems' properties and starting testing, an up-to-date analysis of VRU crashes was needed in order to derive the most important Use Cases (detailed crash descriptions) the systems should address. Besides the identified Accident Scenarios (basic crash descriptions), this paper describes in short the method of deriving the Use Cases for car-to-cyclist crashes.

Method

Crashes involving one passenger car and one cyclist were investigated in several European crash databases looking for all injury severity levels (slight, severe and fatal). These data sources included European statistics from CARE, data on national level from Germany, Sweden and Hungary as well as detailed accident information from these three countries using GIDAS, the Volvo Cars Cyclist Accident database and Hungarian in-depth accident data, respectively. The most frequent accident scenarios were studied and Use Cases were derived considering the key aspects of these crash situations (e.g., view orientation of the cyclist and the car driver's manoeuvre intention) and thus, form an appropriate basis for the development of Test Scenarios.

Results

Latest information on car-to-cyclist crashes in Europe was compiled including details on the related crash configurations, driving directions, outcome in terms of injury severity, accident location, other environmental aspects and driver responsibilities. The majority of car-to-cyclist crashes occurred during daylight and in clear

weather conditions. Car-to-cyclist crashes in which the vehicle was traveling straight and the cyclist is moving in line with the traffic were found to result in the greatest number of fatalities. Considering also slightly and seriously injured cyclists led to a different order of crash patterns according to the three considered European countries. Finally the paper introduced the Use Cases derived from the crash data analysis. A total of 29 Use Cases were derived considering the group of seriously or fatally injured cyclists and 35 Use Cases were derived considering the group of slightly, seriously or fatally injured cyclists. The highest ranked Use Case describes the collision between a car turning to the nearside and a cyclist riding on a bicycle lane against the usual driving direction.

Discussion

A unified European dataset on car-to-cyclist crash scenarios is not available as the data available in CARE is limited, hence national datasets had to be used for the study and further work will be required to extrapolate the results to a European level. Due to the large number of Use Cases, the paper shows only highest ranked ones.

INTRODUCTION

In 2015 in the European Union 2,065¹ cyclists were killed in road crashes which accounts for a decrease by 42% since 2000, see **Figure 1**. Since 2010 the number of cyclist fatalities in the EU is stagnating. Nearly half of these cyclists died in crashes involving one passenger car.

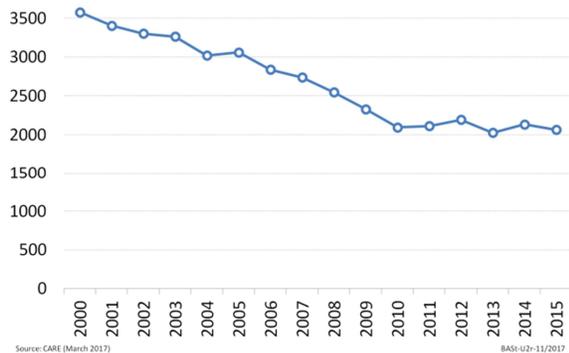


Figure 1: Fatally injured cyclists in EU28 (years 2000-2015; Source: CARE)

AsPeCSS [1] showed that among car-to-cyclist crashes, crossing accidents with both opponents travelling straight were very common. Situations where the car hits the cyclist while turning either to the right or to the left were considered also to be of high importance. Longitudinal accidents with both, car and cyclist travelling in the same direction are quite common in the UK (and other EU countries), however less prominent in the Netherlands. AsPeCSS has also pointed out the following differences between cyclists and pedestrians crashes. First, pedestrians move

relatively slow with velocities between roughly 3 km/h and 8 km/h, whereas bicyclists are much faster and often reach speeds around 25 km/h. Second, while in most crashes pedestrians contacted with their heads on the car’s bonnet or the lower part of the windscreen, cyclists tend to hit higher.

Further, it has to be noted that a significant number of cyclists got injured in crashes involving no other crash partner or involving a crash partner other than a passenger car.

The past decade has seen significant progress on active pedestrian safety, as a result of advances in video and radar technology. In the intelligent vehicle domain, this has recently culminated in the market introduction of first-generation active pedestrian safety systems, which can perform autonomous emergency braking (AEB-PED) in case of critical traffic situations. The European Horizon2020 project PROSPECT aims to improve significantly the effectiveness of active Vulnerable Road User (VRU) safety systems compared to those currently on the market. This will be facilitated by a better understanding of the crash circumstances in crashes between passenger cars and pedal cyclists for which adequate technologies will be developed. This includes the identification of the most relevant road traffic ‘accident scenarios’. As an example, the accident scenarios from CATS [2] were defined by combining the orientation of the bicycle with respect to the car and the driving manoeuvre of the car and the bicycle. However, no detailed information about the collision situation, e.g. road layout or traffic regulation, was included in the scenario definitions.

¹ 2,065 killed cyclists including latest available data from Bulgaria (2009), Slovakia (2010), Lithuania (2012), Ireland (2013), Sweden (2014)

In PROSPECT, the identified ‘accident scenarios’ were abstracted into relevant ‘target scenarios’ or ‘use cases’, which are essential for the development of systems as well as for the evaluation of the system performance later in the project.

METHOD

Accident Data Sample

Several crash databases including international, national and in-depth crash information have been analysed. The analysed databases were the CARE² database (Europe), the German, Swedish and Hungarian national road traffic statistics, as well as the German In-Depth Accident Study (GIDAS), in-depth data from Pest county (Hungary) and the Volvo Cars Cyclist Accident Database (V_CAD) (Sweden).

To achieve the greatest potential for comparison, the same key crash characteristics were used in the analysis of all databases, such as the limitation to two crash participants, the cyclist’s injury severity, accidents of latest years and basic descriptions of the participants’ trajectories. As far as possible the cyclists’ impact locations on all sides of a vehicle were considered, except the rear.

Definitions

Within PROSPECT, an ‘Accident Scenario’ is described by the type of road users involved in the accident, their movements (e.g., the moving direction of the cyclist relative to the vehicle) described by ‘accident types’ and further relevant contextual factors like the course of the road, light conditions, weather conditions and view obstruction. As an example, “vehicle goes straight, cyclist crosses from the nearside behind an obstruction” represents an accident scenario.

The wording ‘Target Scenario’ or ‘Use Case’ is often used to describe scenarios that safety systems are intended to address. Within PROSPECT, ‘Target Scenarios’ are equal to ‘Use Cases’. They are derived from accident scenarios by adding more detailed information about the road layout, right of way, as well as manoeuvre

intention of the driver. Crashes assigned to one specific ‘accident type’ can be split into several Use Cases.

For example, the accident scenario “cyclist crossing from the right” (here further detailed by the accident type “342” as used in GIDAS) can be split into several Use Cases, see **Figure 2**. These include the situations “Car driver approaches an intersection with the intention to go straight *with right of way*, while cyclist is crossing from the right on the sidewalk *in travel direction*”, “Car driver approaches an intersection with the intention to go straight with *the duty to “stop”*, while cyclist is crossing (*illegally*) from the right on the sidewalk against travel direction” or “Car driver approaches an intersection with the *intention to turn right*, while cyclist is crossing (*illegally*) from the right on the sidewalk against travel direction”.

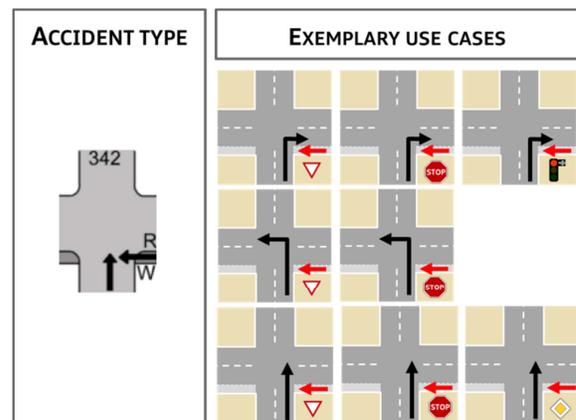


Figure 2: Example for the derivation of Use Cases from Accident Types / Scenarios

The identified Use Cases form the basis for the derivation of Test Scenarios and thus, will be used to establish requirements for improved active vehicle safety systems.

Accident Scenarios

Five Accident Scenarios were analysed for Germany, Sweden and Hungary using their national road traffic statistics. Due to substantial differences in the definitions of accident types in the analysed databases, accident scenarios needed to be defined in a rather general way to allow aggregation and comparison of data from different sources.

In-depth crash datasets from the above-mentioned countries have also been analysed

² European centralised database on road accidents which result in death or injury across the EU

regarding these Accident Scenarios but, due to their lower representativeness, were primarily used for subsequent detailed crash investigations.

Regarding car-to-cyclist crashes five Accident Scenarios were considered: (I) “Car straight on, Cyclist from nearside”, (II) “Car straight on, Cyclist from farside”, (III) “Car turns”, (IV) “Car and cyclist in longitudinal traffic” and (V) “Others”, see **Table 1**. Note: the exemplary pictograms show straight roads except for accident scenario (III), but crashes could also occur at an intersection.

Table 1: PROSPECT Cyclist Accident Scenarios

	Exemplary pictograms
(I) Car straight on, Cyclist from near-side	
(II) Car straight on, Cyclist from far-side	
(III) Car turns	
(IV) Car and cyclist in longitudinal traffic	
(V) Others	

Derivation of Use Cases

Use Cases for car-to-cyclist crashes have been identified for Germany and Hungary. However, in PROSPECT, the priority was set on German in-depth crash data (GIDAS) as several variable definitions varied too much between the countries considered and the Hungarian in-depth crash data sample was too small (N=100) and could not provide a comparable information level. Further, the focus of the Use Case analysis was set on urban crashes to meet project requirements.

Finally, to identify the most relevant car-to-cyclist crash situations, a detailed analysis was performed in five steps based on 4,272 car-to-cyclist accidents in urban areas using GIDAS data from 2000-2013. **Figure 3** illustrates steps 1-3 whereas **Figure 4** shows steps 4 and 5. In GIDAS, the coding of accident types allowed for the distinction of various crash situations such as “a cyclist crossing the road in front of a car on a straight road” or “a cyclist used the bicycle path to cross the road in front of a car at a junction”. In the first analysis step only those accidents were considered that were coded with an accident type

with a relative frequency of at least 1% resulting in 3,497 accidents.



Figure 3: Derivation of Use Cases, steps 1-3

In a second step, all of these accidents were analysed case-by-case, adding supplementary information about drivers’ tasks, infrastructure and priority regulation (n=3,171 accidents) that were not distinct hard-coded in GIDAS. In the next step of the analysis, Use Cases were identified that describe the crash situation based on:

- Priority regulation;
- Cyclist’s riding direction;
- Driver’s manoeuvre intention; and
- Road geometry.

Then, the dataset was split in two parts. Part I considered car-to-cyclists crashes with “killed or seriously injured” (KSI) cyclists (N=515). Part II complemented part I by taking also slightly injured cyclists into account (N=2,669), i.e. 62% of all car-to-cyclist crashes. Both sub-datasets were then analysed separately for the identification of Use Cases.

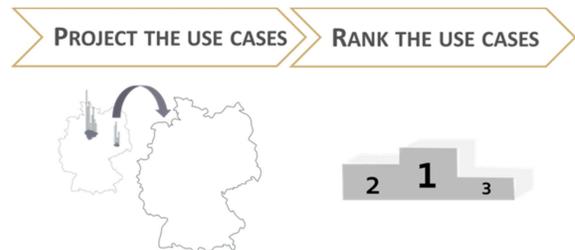


Figure 4: Derivation of Use Cases, steps 4-5

In order to control for biases within the dataset, the identified Use Cases were projected (weighted) towards the German national statistics based on the distribution of accident types and injury severities. In a final step, the Use Cases were ranked based on their projected frequency (weighting for Germany) as well as the cyclist’s injury severity and associated socio-economic injury costs based on a method developed in ASSESS [3].

SELECTED RESULTS FROM CRASH DATA ANALYSIS

Germany

In 2014 there were 3,377 fatalities in crashes on German roads including 396 cyclists. While 25% of the fatally injured cyclists were involved in single cyclist crashes with no other accident participants, the most relevant crash opponent for cyclists was the passenger car (34%). Focusing on crashes with two participants over a four year period, the most relevant crash opponent for killed cyclists was the passenger car (42%), as can be seen in **Figure 5**.

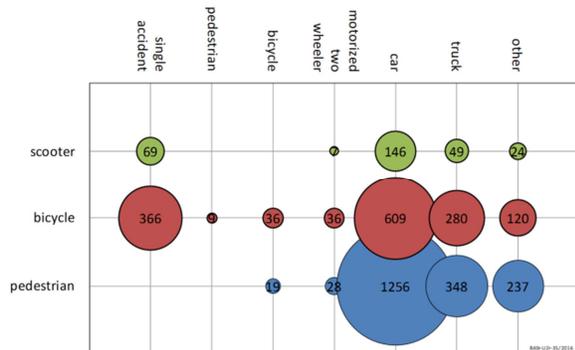


Figure 5: Fatalities by crash opponent, Germany, 2011-2014, crashes with two participants

Figure 10 provides an overview on the sum of the number of killed and seriously injured (KSI) cyclists by crash opponent and age group. It can be seen that cyclists aged 15 years and younger as well as cyclists aged 45 years and older were often injured.

Figure 11 shows the numbers of fatally injured persons in 2014 by traffic participation and age group. It can be seen that in particular older cyclists suffered more often from fatally injuries compared to younger ones.

Focusing on cyclist fatalities in crashes with a car per 1 million inhabitants emphasizes the importance of older cyclists, see **Figure 6**. For example, the fatality rate for cyclists aged 75 years and older is 4-5 times higher than for mid-aged cyclists around 40 years.

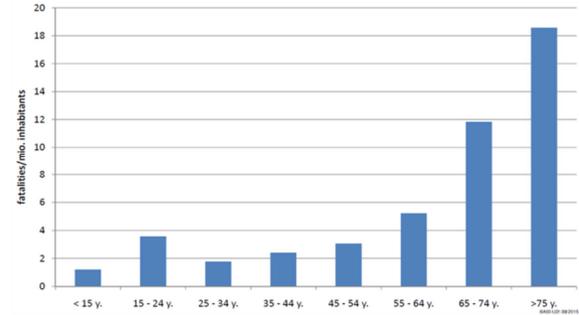


Figure 6: Fatally injured cyclists per 1 million inhabitants of age group in car-to-cyclist crashes in Germany (2012-2014)

The German accident statistics does not offer the same detail of accident type information for all federal states. An analysis of the integrity of the data from the years 2009-2014 showed that the desired information level (namely, the 3-digit coding of accident types also used in GIDAS) is provided to nearly 100% by 5 (out of 16) federal states (Lower Saxony, North Rhine-Westphalia, Rhineland Palatinate, Saxony-Anhalt and Saarland). According to internal studies at BAST, these five states represent the German accident occurrence quite well. Therefore, only this data was used for the following analysis.

The analysis included crashes between two participants only (here: exactly one passenger car and one cyclist) and was conducted for urban and rural areas for the accident years 2011-2014, see **Table 2**. Consequently, the dataset included 118 cyclist fatalities, 9,275 seriously and 60,592 slightly injured cyclists. For KSI, Accident Scenarios (I) and (III) showed highest shares in urban areas, compared to the Accident Scenarios (I) – (IV) in rural areas. Regarding killed cyclists, in urban areas the Accident Scenario (I) was most frequent compared with Accident Scenario (IV) in rural areas.

Table 2: Cyclist casualties in crashes with cars by Accident Scenarios, Germany, 2011-2014. Highest numbers for KSI and fatalities were highlighted.

Group	Urban areas					Rural areas				
	KSI	Killed	Serious	Slight	Total	KSI	Killed	Serious	Slight	Total
V	20%	23%	20%	21%	21%	12%	7%	12%	11%	11%
I	26%	27%	26%	27%	27%	28%	24%	28%	34%	33%
II	16%	17%	16%	14%	14%	22%	27%	21%	16%	17%
III	28%	14%	28%	28%	28%	19%	10%	19%	24%	23%
IV	8%	18%	8%	8%	8%	20%	32%	19%	15%	16%
Parking	1%	1%	1%	2%	2%	0%	0%	0%	1%	0%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Hungary

For Hungary, data from the Hungarian Central Statistical Office (KSH) has been analysed. The number of car-to-cyclist crashes has increased by 8% in Hungary between 2011 and 2014. The amount of crashes with serious injuries to the cyclists increased in the same time by 17%, see **Figure 7**.

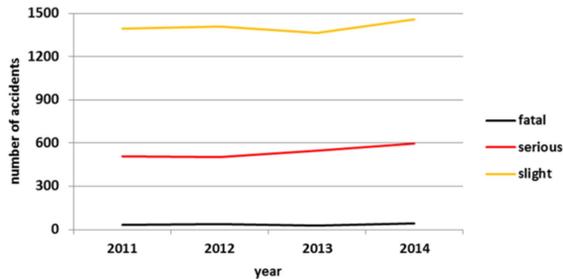


Figure 7: Number of car-to-cyclist crashes (Hungary, 2011-2014)

Figure 12 shows absolute numbers of road fatalities by age group and traffic participation in Hungary in years 2011-2014. It can be seen that unlike other traffic participants, cyclist and pedestrian fatalities occurred predominantly in the older age groups. The most endangered cyclist and pedestrian age group is between 55 and 64 years.

Rural areas have been identified as being linked to higher cyclists' injury severities as the impact speeds of the vehicles were on average highest on these roads.

Regarding the car driver's main fault, "priority rule violation" (48%, 3,777 crashes) and "inappropriate changing of lanes" (26%, 2,086 crashes) in car-to-cyclist crashes were seen most often in Hungary, see **Figure 8**.

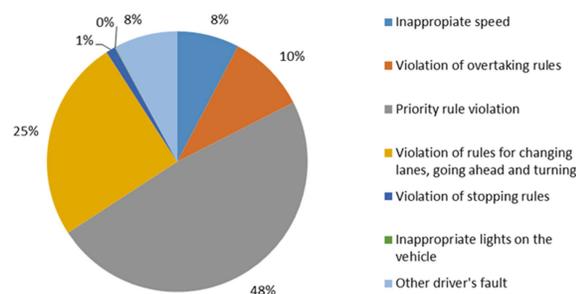


Figure 8: Driver's fault in car-to-cyclist crashes (Hungary, 2011-2014)

In Hungary there are 10 main categories describing accident types, all together 87 types on two levels. The most frequent types of crashes between passenger cars and cyclists (N = 7,794) who got injured or killed were "collisions of crossing (but not turning) vehicles at intersections" (29%, 2,264 crashes), followed by "collisions of crossing and turning vehicles at intersections" (27%, 2,078 crashes), see **Figure 9**.

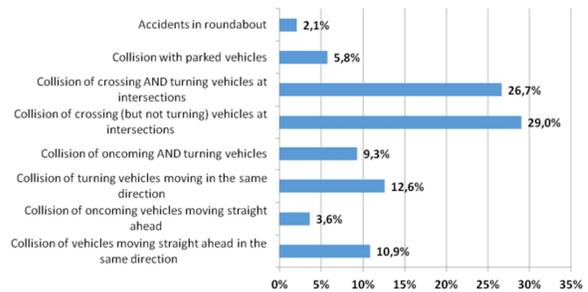


Figure 9: Share of accident types of car-to-cyclist crashes (Hungary, 2011-2014)

Sweden

From 2009-2013, there were 1,489 fatalities recorded in the Swedish national road crash database STRADA. Over this five year period, 7% of the fatally injured were cyclists, more than double pedestrians (15%), and 55% car occupants. The majority of the car occupant fatalities (20%) were in the age of 18-24, see **Figure 13**. More than two-thirds (67%) of the cyclist and pedestrian fatalities were above 55 years. Eight percent for both cyclist and pedestrian fatalities were younger than 18 years.

When crashes with fatalities and seriously injured traffic participants (according to the injury classification by the police) were considered together, then of the total number of casualties (N=16,830), 57% were car occupants, 10% were cyclists and 11% were pedestrians. The majority of KSI car occupants (25%) were in the age group 18-24 years. Most of the KSI pedestrians were older than 75 (18%), while most KSI cyclists were in the age group 45-54 (18%), see **Figure 14**.

The analysis of the Volvo Cars Cyclist Accident Database (V_CAD) comprised 311 car-to-cyclist crashes between years 2005-2013. Detailed injury information was available for 308 cyclists with a total of 786 injuries. Out of that, 72 cyclists

suffered from an injury severity of MAIS 2+. V_CAD's conflict situations classification scheme allows for the analysis of the basic trajectories of cyclists and cars. A detailed description of these conflict situations can be found in [4] or [5].

The majority of the crashes in V_CAD were assigned to "crashes in which the car went straight and the cyclist crossed from either left or right" (situation "SCP") with 34% of all MAIS 2+ injured cyclists. "Car turned and cyclist approached from opposite direction" situations accounted for 17% of MAIS 2+ crashes. In 10% of the crashes with injured cyclists, the cyclist hit the car door that was being opened by the car driver or a passenger. Two out of the 72 reported MAIS 2+ injured cyclists were fatalities. They were both involved in 'front to front' crashes in Oncoming situations.

A mapping of the V_CAD data to the PROSPECT Accident Scenarios was performed. Details on this mapping can be found in [4]. Car turns (III) is the most common type of crash (37%) followed by (II) Car straight on, Cyclist from farside (20%) and (V) Others (20%) where the latter one includes situations with cars standing still, dooring, and car reversing crashes. Scenario (I) Car straight on, Cyclist from nearside and (IV) Car and cyclist in longitudinal traffic accounted for 14% and 9%, respectively.

Overall

The highest numbers of fatalities per inhabitants can be observed in countries where cycling is very common and the bicycle is used as a daily transportation means such as in The Netherlands and in Denmark. Similar to the observation for pedestrians made in previous projects, see e.g. [6] or [7], older cyclists have the highest risk to get fatally injured in most countries due to their high vulnerability. This raised injury risk is further supported by knowledge about mobility habits of elderly. For instance, in [8] the national travel survey in Sweden was analysed (years 2005-2006) regarding exposure data by age groups. It was found that the number of journeys in the highest age groups (65 years and older) is less than 50% compared to any other age group. However, combining the last two age groups in **Figure 6** shows that people aged 65 or older suffer the greatest number of KSI cyclist injuries of all age

groups, hence the rate of KSI injuries per journey is the highest in this age group by far.

PROSPECT confirmed that older cyclists suffered higher injury severities more often than younger ones, male cyclists were injured more often than females, higher injury severities (in particular fatal crashes) happened more often on rural roads and that crashes occurred most often in fine weather and daylight conditions (see e.g., [4], [8] or [10]).

Crash databases from Germany, Hungary and Sweden have been analysed regarding car-to-cyclist crashes of recent years. The five considered Accident Scenarios are: (I) "Car straight on, Cyclist from nearside", (II) "Car straight on, Cyclist from farside", (III) "Car turns", (IV) "Car and cyclist in longitudinal traffic" and (V) "Others". The results are provided in **Table 3**.

Focusing on killed and seriously injured (KSI) cyclists, results for Germany, Hungary and Sweden were similar regarding scenarios (I) and (II); around 42%-52% of all casualties were assigned to these scenarios. However, the results varied a lot between the considered countries for Accident Scenarios (III) and (IV). In particular, Hungarian data showed substantially more crashes of cyclists in longitudinal traffic compared to Germany and Sweden. Focusing on killed cyclists in car-to-cyclist crashes, it can be seen that in all countries the accident scenario (IV) (longitudinal traffic) had the greatest relative frequency of all accident scenarios ranging from 25-64%.

Table 3: Comparison of the relative frequencies of the PROSPECT Accident Scenarios in Germany, Hungary and Sweden, built-up and non-built-up areas, (major deviations are highlighted in red)

		I	II	III	IV	V	Parking	Total
Germany	KSI	27%	17%	27%	10%	19%	1%	100%
	Killed	25%	23%	12%	25%	14%	0%	100%
	Serious	27%	16%	27%	10%	19%	1%	100%
	Slight	27%	14%	28%	9%	20%	2%	100%
Hungary	KSI	42%		6%	29%	23%	0%	100%
	Killed	33%		1%	64%	2%	0%	100%
	Serious	42%		7%	26%	24%	0%	100%
	Slight	42%		8%	24%	26%	0%	100%
Sweden	KSI	28%	33%	13%	17%	10%		101%
	Killed	23%	27%	3%	40%	8%		101%
	Serious	29%	34%	15%	11%	11%		100%
	Slight	34%	33%	12%	7%	13%		99%

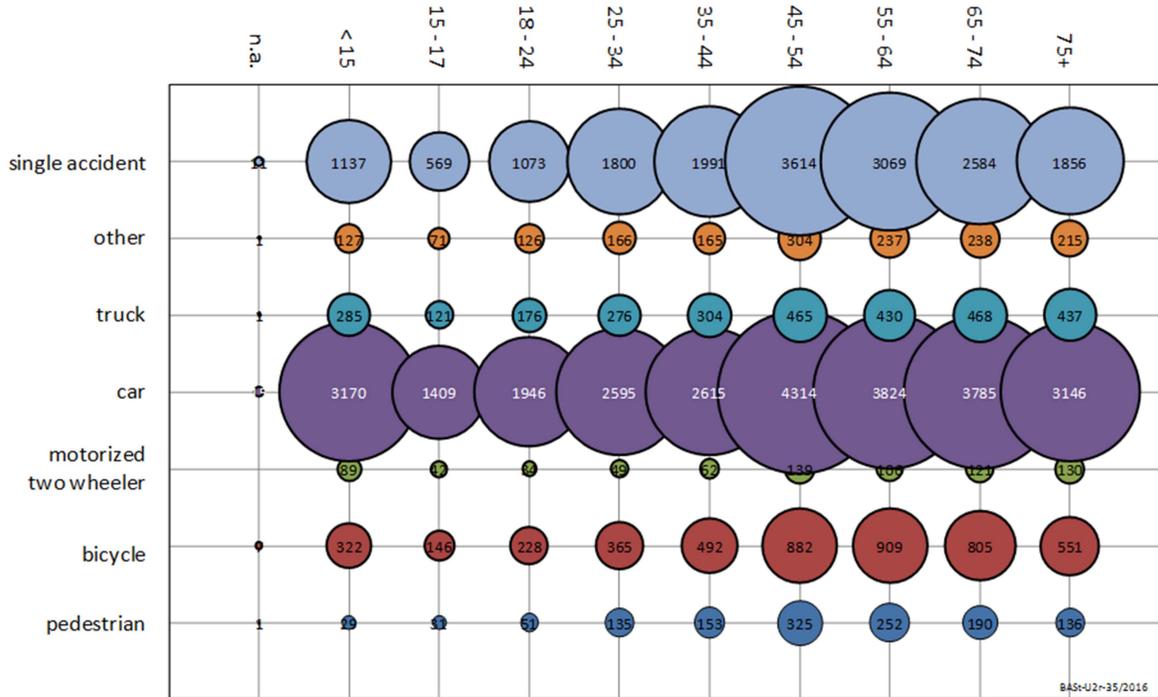


Figure 10: Killed and seriously injured cyclists by crash opponent and age group in Germany, 2011-2014 (single crashes or crashes with two participants involved).

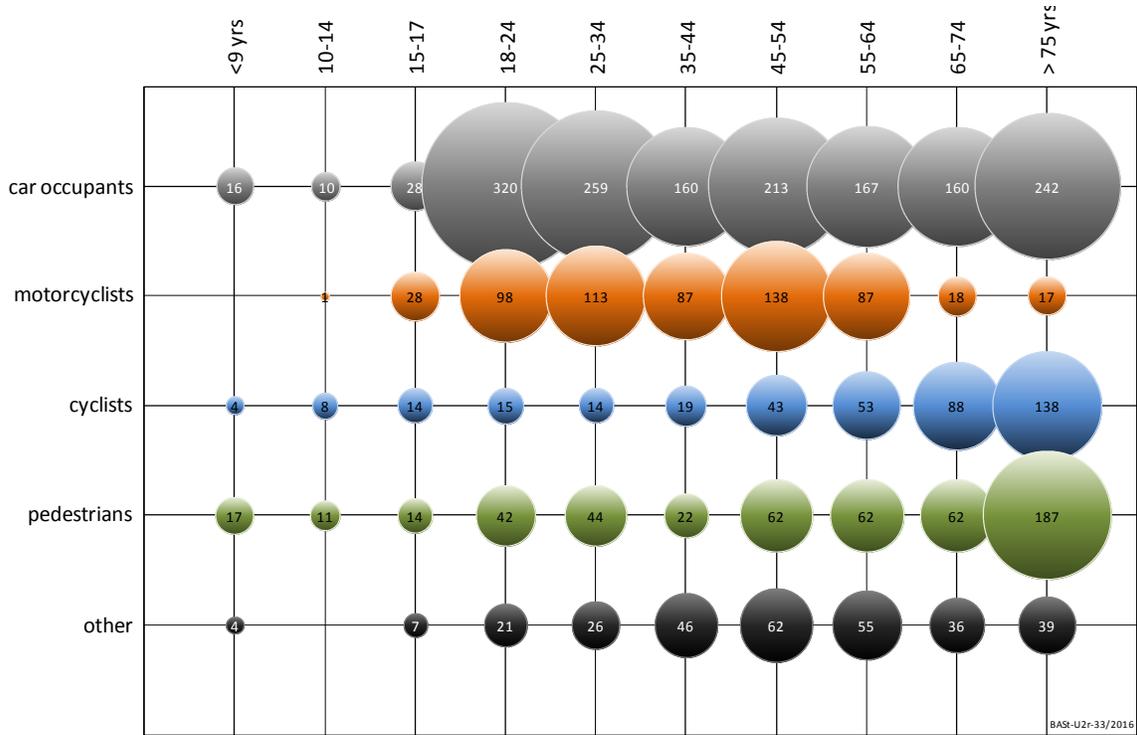


Figure 11: Fatalities in Germany 2014 by age group and traffic participation

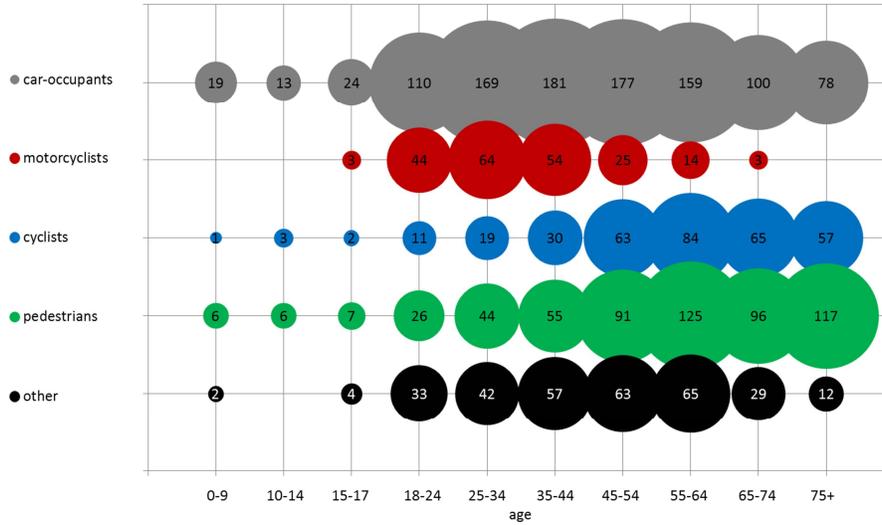


Figure 12: Killed traffic participants by age and traffic participation in Hungary, 2011–2014.

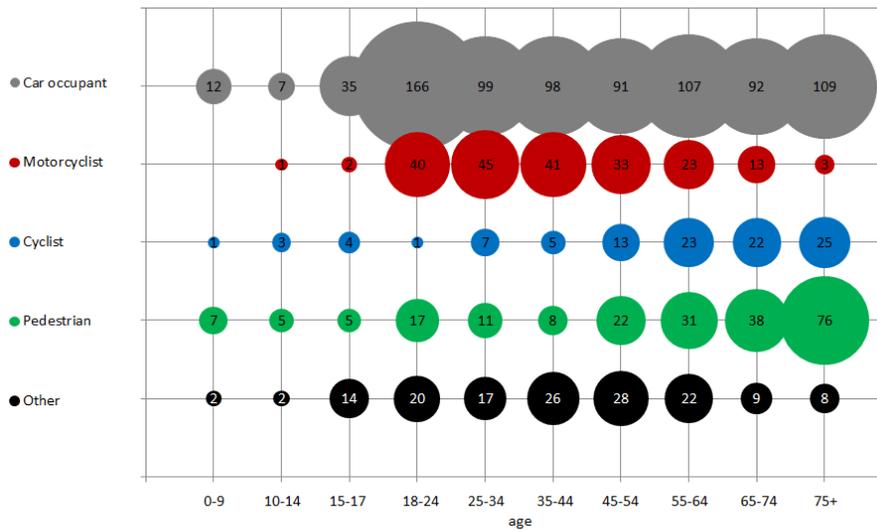


Figure 13: Killed traffic participants by age group in Sweden, 2009-2013.

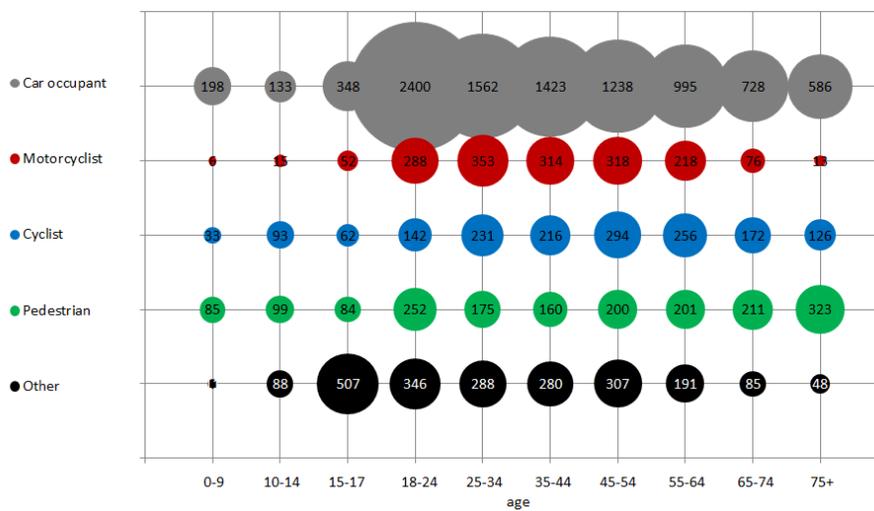


Figure 14: Killed and seriously injured traffic participants by age group in Sweden, 2009-2013.

RESULTS FROM USE CASES ANALYSIS

GIDAS data from years 2000-2013 was used to derive a set of Use Cases for car-to-cyclist crashes, see also Section Method. This paper concentrates on a selection of these. A complete list of the Use Cases derived can be found in [11].

The GIDAS dataset was split in two parts. Part I considered crashes with “killed or seriously injured” (KSI) cyclists (N=515), resulting in 29 Use Cases. In Part II, crashes with slightly and seriously injured cyclists as well as killed cyclists (N=2,669) were taken into account resulting in 35 Use Cases covering 62% of all car-to-cyclist accidents.

Figure 15 shows the ten highest ranked Use Cases for Part I and Part II. Use Cases ranked 1-5 are identical and Use Cases 6 and 7 changed their order. Starting with rank 8, Use Cases differed for both groups of the cyclists’ injury severity.

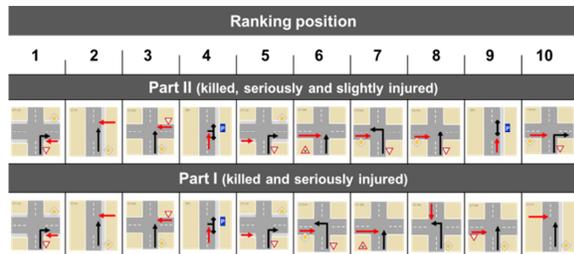
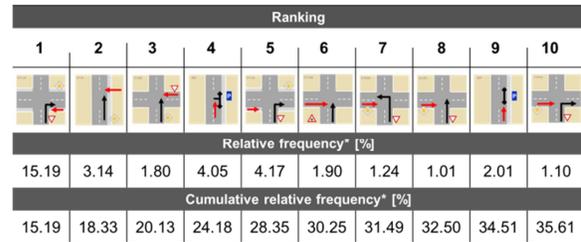


Figure 15: Ten highest ranked Use Cases of car-to-cyclist crashes (based on GIDAS, 2000-2013)

From this point on, this paper focuses on results of Part II.

Figure 16 shows the ten most relevant Use Cases of Part II covering about 36% of all car-to-cyclist crashes (based on N=4,272 crashes). It can be seen that some Use Cases are higher ranked than others although their frequency is lower. This is because of the method applied multiplying weighting factors (considering socio-economic costs) to the number of casualties of all injury severity groups (slightly, seriously and fatally injured).



*with regard to all car-to-cyclist accidents (n=4,272)

Figure 16: Car-to-cyclist Use Cases for urban areas based on German crash data (GIDAS) including slightly, seriously injured and killed cyclists (cyclist riding direction marked with red arrows, car’s direction with black)

Table 4 specifies the top 5 ranked Use Cases by a textual description. Corresponding driving and collision speeds of the passenger car for each of these Use Cases as well as for all others were summarized in [11].

Table 4: Description of top 5 ranked Use Cases for car-to-cyclist crashes (slightly or seriously injured or killed cyclists) in urban areas

Use Case Ranking	Description of crash situation
1	A passenger car travels on a minor road approaching a 3-arm (50%) or 4-arm junction (14%) intending to turn right. The driver does not give priority (as indicated by a stop or yield sign) to the cyclist crossing from the right, riding on the sidewalk/cycle lane.
2	A passenger car is going straight. A cyclist crossed the road from the sidewalk/cycle on the right directly in front of the car.
3	A passenger car travels on the main road approaching a 3- (31%) or 4-arm junction (31%) intending to go straight. A cyclist approached from the right side intending to cross the junction, not giving priority (as indicated by a yield sign) to the car.
4	Cyclist overtook a vehicle, while door opening on driver’s side.
5	A passenger car travels on a minor road approaching a 3- (49%) or 4-arm junction (7%) intending to turn right. The driver does not give priority (as indicated by a stop or yield sign) to the cyclist crossing from the left, riding on the sidewalk/cycle lane.

Crossing scenarios play a predominant role (compared to longitudinal traffic scenarios). Focusing on the crossing scenarios from Figure 16, the first three Use Cases describe crossing situations, in which the cyclist violated the road traffic regulation and was coming from the nearside, while Use Cases with drivers violating road traffic regulations rank between 5 and 10 and involve cyclists crossing from the farside (see Figure 17).

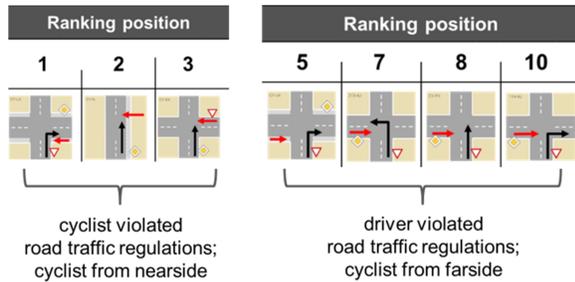


Figure 17: Drivers collided more often with cyclists from the nearside when the cyclist violated road traffic regulations or behaved unexpectedly

To evaluate the interaction between the cyclist's riding direction and right of way violations, those accidents in which the cyclists crossed from the farside were compared with the same situations, but changed priority regulations, see Figure 18. It was found that Use Cases had a higher relevance when the car driver had no right-of-way compared to Use Cases, in which the car driver had right-of-way (ranked as not from high importance "NA").

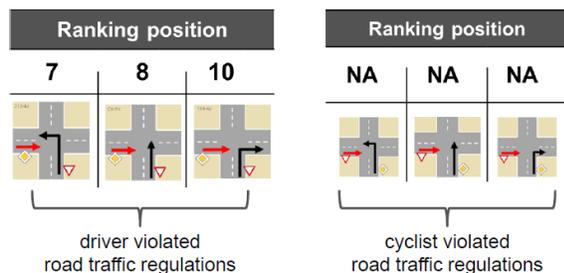


Figure 18: Comparison of similar situations (in terms of cyclist's riding direction and driver's manoeuvre intention) with different right of way regulations

Comparing these crashes (cyclist approached from farside) with those in which the cyclist approached from nearside, showed the opposite results regarding the frequency of violations

against traffic rules and their consequences in terms of number of crashes. Thus, the cyclist neglected more often the right of way than the car driver.

In a next step of the analysis, combinations of different parameters were analysed, e.g. the cyclist's riding direction and manoeuvre intention. Figure 19 shows two situations, in which the driver intended to turn right at a junction without priority and a crossing cyclist on the sidewalk.

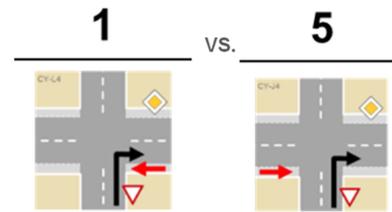


Figure 19: Cyclists on the bicycle lane

Based on the direction of the cyclist, the relevance for the cyclist crossing from the nearside (Rank 1) is higher than for the cyclist crossing from the farside (Rank 5). As previous studies have shown, see e.g. [12], drivers tend to focus even more on the left side when turning to the right. So the chances are higher to see the cyclist on the farside while looking for a gap. In addition, the authors of the present paper believe that drivers tend to not expect cyclists from the nearside who ride against the traffic direction. Further, the rate of obstructions for nearside cases is about double as high (26%) as in farside cases (12%).

Comparing different cyclist riding directions at non-junction situations, similar results were derived, with nearside situations higher ranked than farside ones, see Figure 20.

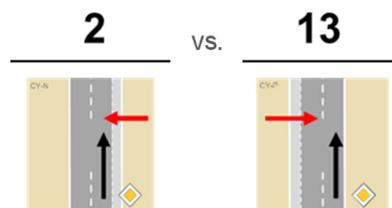


Figure 20: Cyclist appears suddenly

Both situations were assumed to be unexpected for the driver, but as the driver has more time to react when the cyclist crosses from the farside,

the observed (and also weighted) frequency in the database was lower. In addition, the collision speeds are lower in the farside scenario due to additional time for the driver to brake. Both situations have a very high proportion of view obstructions at about 50%.

The following part of the analysis focuses on the influence of the car driver's manoeuvre intention. **Figure 21** shows two situations with cyclists crossing from the nearside on the sidewalk with different manoeuvre intentions of the car drivers, i.e. turning right or left.

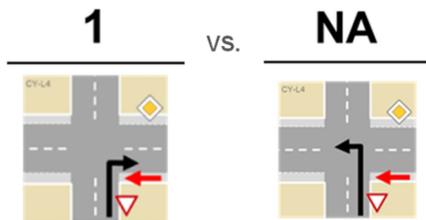


Figure 21: Cyclist from nearside

Though the Use Case with the driver turning right had the highest relevance in the database, the frequency of the identical situation with different manoeuvre intention was very low. It was believed that this is because of an improper allocation of the driver's attention due to the driver's expectation. Drivers failed to look for the cyclist crossing from the nearside when turning to the nearside. Furthermore, 26% of both situations included view obstructions.

Figure 22 shows equivalent situations, but with the cyclist crossing from the left. In these situations, cases with drivers intending to turn right also had a higher relevance. It was believed that in right-hand traffic, car drivers turning to the right pay less often attention to cyclists approaching from the farside compared to car drivers turning to the left. In addition, about 25% of these accidents happened during dark lighting conditions.

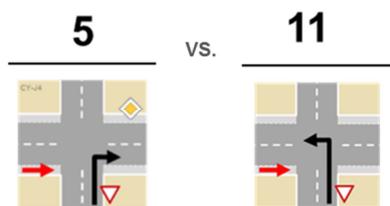


Figure 22: Cyclist from farside

DISCUSSION

A unified European dataset on car-to-cyclist crashes is not available as the data available in CARE is limited, hence national datasets had to be used for the study and further work will be required to extrapolate the results to a European level.

As the structure of the databases was quite different, not all results for different countries could be compared directly (e.g., due to their case inclusion criteria, number of relevant cases, the level of detail and different definitions for parameters). Nonetheless, trends could be identified from the analysis.

To achieve the greatest potential for comparison, the same key crash characteristics were used in the analysis of all databases, such as the limitation to two crash participants, the cyclist's injury severity, accidents of latest years and basic descriptions of the participants' trajectories. Limiting the analysis of crashes to two participants was deemed reasonable because the share of crashes involving VRUs with three or more participants is comparatively low, see e.g. [4].

Focusing on killed and seriously injured (KSI) cyclists, results for Germany, Hungary and Sweden were similar regarding scenarios (I) and (II); around 42%-52% of all casualties were assigned to these scenarios. However, the results varied a lot between the considered countries for Accident Scenarios (III) and (IV). In particular, Hungary seemed to have major issues with cyclists in longitudinal traffic compared to Germany and Sweden, which could also be caused by infrastructural differences. Focusing on killed cyclists in car-to-cyclist crashes, it can be seen that in all countries the accident scenario (IV) (longitudinal traffic) had the greatest relative frequency of all accident scenarios ranging from 25-64%. This may be linked to the higher car impact speeds observed on rural roads.

The results gained from the V_CAD database differ from those seen in the Swedish national data (STRADA) where (I) and (II) were most frequent, see **Table 3**. Apart from the slightly different injury severity threshold (MAIS 2+ in V_CAD and KSI in STRADA), one reason for this

could be the issue of underreporting certain types of accidents in the police data; see e.g., [4]. Another reason could be the data available to derive accident scenarios is rather limited in STRADA (seven accident types for which manual coding was required to transform them to accident scenarios [4] compared to the detailed conflict situation classification scheme in V_CAD) and different injury severity distributions. Also, V_CAD is focused on crashes involving Volvo cars while STRADA includes cars of all makes.

The Accident Scenarios described in the previous sections could only provide a limited amount of information on the causation of the crashes and their features and this was not sufficient for further system development steps in PROSPECT. Therefore, Use Cases have been derived from these Accident Scenarios for car-to-cyclist crashes.

In a first step, German traffic crash data (GIDAS) has solely been used for the development of PROSPECT's Use Cases. This work has separately been published in Deliverable 3.1 [11] and the paper "Car-to-cyclist accidents from the car driver's point of view" [13]. Use Cases of car-to-cyclist crashes were also derived for Hungary. However, the Hungarian KSH database did not specify in greater detail the crash participants' moving directions in all cases. Therefore, it was decided to use a detailed investigation of a sample of 100 crashes from Budapest and Pest county for the analysis of the Use Cases. But, as this sample was small it was not possible to apply the same method from [13] to the Hungarian dataset. Due to the different data inclusion criteria, it was not possible to harmonize these Use Cases. Nevertheless, the major conclusions were the same.

GIDAS data was used to derive a set of Use Cases for car-to-cyclist crashes describing their causations more in detail. The most common contributing factor to the crashes was "disregarding traffic regulations", seen for both cyclists and car drivers.

Further results showed that the drivers' task and the orientation of cyclist have an influence on the frequency of collisions. For example, the cyclist violated traffic regulations as the wrong driving direction on a bicycle lane was chosen to cross a

road. Potentially, the car driver failed to watch out for this unexpected traffic situation, as the cyclist would have to approach from the other side, and thus, drove into the intersection area colliding with the cyclist. The analysis of Hungarian crash data confirmed that the primary reasons of car-to-cyclist crashes were the violation of traffic rules and the delay of action.

The analysis of Use Cases has shown the importance of driving context in affecting road crashes. This aspect is not addressed by current state-of-the-art AEB systems which typically take solely technical parameters like velocities and distances into account. The results presented in this paper support the development of future advanced driver assistance systems by providing a detailed description of the underlying driving situation.

Usually, crash databases are analysed in a descriptive way. However, to calculate the risks of getting injured or killed requires also information on uninjured casualties (but involved in a crash), information on underreporting and exposure data (e.g. mileage) which is rarely available. For instance, the large majority of single cyclist crashes (which also constitute the largest proportion of cyclist crashes in Sweden) are unreported by the police [4]. These are general issues, presumably valid for all European countries.

CONCLUSIONS

Several European crash databases have been analysed towards crashes between passenger cars and cyclists. Among others, it could be shown that:

- Older cyclists suffered more often from higher injury severities compared to younger ones;
- Male cyclists were injured more often than females;
- Higher injury severities (in particular fatal crashes) happened more often on rural roads; and
- Crashes occurred most often in fine weather and daylight conditions.

Five general Accident Scenarios were defined for car-to-cyclist crashes and it was found that in all three countries considered, the accident scenario (IV) (longitudinal traffic) had the greatest relative frequency of cyclist fatalities. However, substantial differences were found in the distribution of Accident Scenarios between the countries when killed and seriously injured (KSI) cyclists were considered together.

For the intended improvement of active vehicle safety systems additional details were required (e.g. right of way or the layout of an intersection), hence further analysis was conducted to derive Use Cases from the Accident Scenarios. While the identified Use Cases (N=29) describing crashes with “seriously or fatally injured cyclists” differed from the Use Cases (N=35) describing crashes with “slightly, seriously or fatally injured cyclists”, the seven highest ranked Use Cases of both groups were the same.

In conclusion, the task of the car driver as well as the cyclist’s riding direction have a huge influence on the relevance of car-to-cyclist collisions. The detailed case-by-case crash analysis provided the basis for manifold parameter variations in specific situations. This method allows the derivation of specific hypotheses for crash causing factors which, for example, could also be proven in driving studies.

Detailed crash causation analyses for different countries showed that the most common contributing factor to the crashes was “disregarding

traffic regulations” seen for both cyclists and car drivers.

Differences in the data sources have posed serious limitations to the analysis in terms of available details. The harmonization of road accident data collection and coding (e.g. comparable sampling criteria and classification of accidents by different aspects, including accident types) for all EU countries is required and would be effective in the EU to determine road traffic safety priorities.

RECOMMENDATION

Historically, the first and still the most reliable variable for the comparison on accident situation between countries is the number of fatalities in road crashes. Comparing the number of slightly or seriously injured people among European countries yields less reliable results as such comparisons are affected by a large number of factors, including different definitions, different health care systems, different organizational issues of rescue services and alert chains, different organizations of police, different insurance-practice and -culture, different traffic laws and also the different definitions of injury severity. Therefore, it would be important to have a common definition for “road traffic crashes” and for injury severities in order to remove part of the uncertainty.

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