Car-to-cyclist accidents from the car driver's point of view

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ABSTRACT

A promising approach to prevent road traffic accidents between passenger cars and cyclists is the development of driver assistance systems. To develop such systems with maximum effectiveness in road traffic, car-to-cyclist accidents have to be analysed from the car driver's point of view to gain insight into the situations with which the drivers were faced and especially why they failed to manage these crash situations. The EU funded project PROSPECT (Proactive Safety for Pedestrians and Cyclists) considered this approach and made the presented research possible. This paper reports findings from a case-by-case analysis of 3,550 car-to-cyclist accidents in Germany. The results of the accident analysis confirm findings of previous studies showing that crossing scenarios play a predominant role in car-to-cyclist accidents. Moreover, the results show that both the orientation of the cyclist and the driver's task (in terms of the driver's maneuver intention, road layout, traffic regulations) have an influence on the distribution of those scenarios in so far as certain combinations lead to a higher or lower distribution. The results contribute towards a better understanding of possible reasons why the driver failed to manage certain situations. Regarding PROSPECT, the most relevant use cases will be used to specify and develop advanced measures that will be implemented in the next generation of active safety systems.

Keywords: car-to-cyclist accidents, crossing accidents, perceptual error, expectation

1 INTRODUCTION AND MOTIVATION

According to the World Health Organization, every year 1.25 million people are dying from road traffic accidents. Among them 49% of these road traffic deaths are pedestrians (22%), cyclists (4%) and motorcycles (23%).[1]

In Europe, the number of bicycle fatalities decreased by about 32% between 2004 and 2013. While the absolute numbers are going down, the relative proportion of bicyclist fatalities amongst other road user fatalities is increasing, thus indicating their high level of vulnerability (see Figure 1).

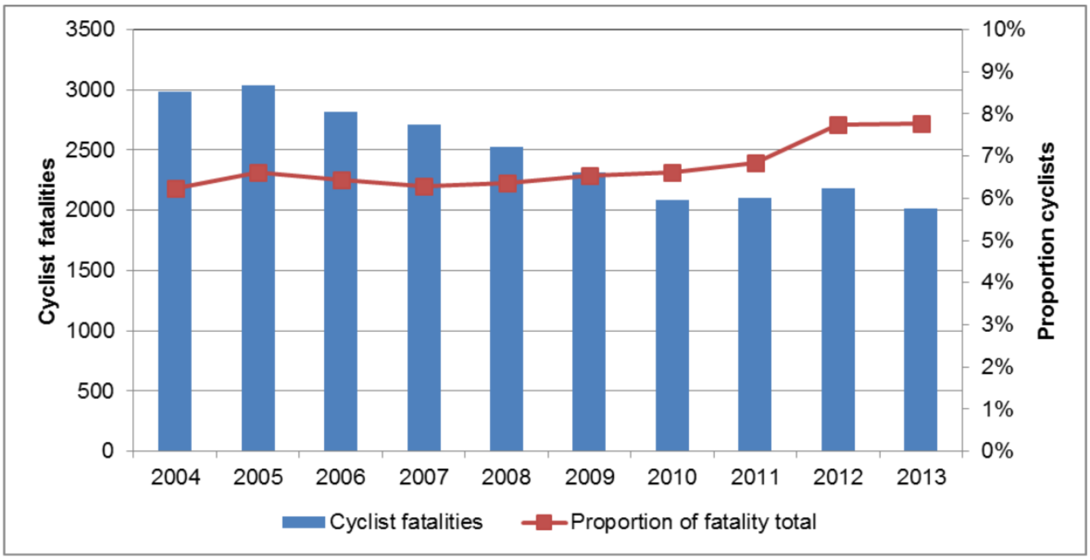


Figure 1. Road traffic deaths by type of road user in Europe (Source: WHO's Global Status Report on Road Safety, 2015)

In Germany, 354 cyclists died in road traffic accidents in 2013. While 25% of the fatally injured cyclists were involved in single vehicle crashes with no other accident participants, the most relevant accident opponent for cyclists remains to be the passenger car (39%). This emphasizes the importance for a better understanding of car-to-cyclist accidents.

In order to address this and other issues, the EU funded project PROSPECT (Horizon 2020, May 2015 – October 2018) started in 2015 with the aim to lay the foundation for next generation active safety systems for protecting Vulnerable Road Users (VRU). The emphasis is on two groups with large shares of fatalities: cyclists and pedestrians. The project will focus particularly on urban environments, where the large majority of VRU accidents occur [2].

Compared to first generation Autonomous Emergency Braking (AEB) Pedestrian Systems currently on the market, PROSPECT aims to improve the effectiveness and the overall system performance by expanding the scope of scenarios for a better understanding of vehicle-VRU accidents. For the timeframe 2020–2025, the introduction of the new generation of safety systems in the broad market will enhance VRU road safety, contributing to the 'Vision Zero' objective set out in the Transport White Paper of no fatalities or serious injuries in road traffic [3]. Furthermore, test methodologies and tools developed within PROSPECT shall be considered for 2018 and 2020 Euro NCAP tests, supporting the European Commission goal of halving the total number of road deaths for the 2011–2020 time frame [4].

This paper reports about an in-depth accident analysis based on German data in order to determine accident scenarios with the highest relevance for car-to-cyclist collisions.

Although there is no sensible lack of statistics regarding car-to-cyclist accidents, most of the analyses are based on aggregated accident scenarios resulting in a loss of information. As an example, the accident scenarios from CATS [5] are defined by combining the orientation of the bicycle with respect to the car and the driving maneuver 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. As previous studies have shown that "in a given environment-infrastructure-drivers' visual scanning differentiates according to their specific task" [6, p. 153], such additional information is important to understand why a particular accident might have happened. Based on the results of this unobtrusive field study it was found that drivers turning right at a T-junction focus their visual attention on the left side. Thus, they may "actively but unintentionally" [6, p. 153] miss imminent dangers from the right such as a cyclist coming from the right. This contrasted with the visual attention of drivers turning left, who divided their attention between both sides. This behavioral pattern of drivers was also supported by accident data, showing large differences between drivers turning right colliding with a cyclist coming from the right (n=27) and those turning left colliding with a cyclist coming from the right (n=3). Based on literature, two kinds of perceptual errors are known: either the responsible party looked but failed to see (e.g. [7]) or the responsible party failed to look (e.g. [8]). Based on the results mentioned above, it seems that the first kind of perceptual error plays a larger role in those situations in which the driver's task and the cyclist's direction match each other (e.g. left turning vehicle and cyclist coming from the right) and the latter kind plays a larger role in those situations in which the driver's task and the cyclist's direction do not match each other (e.g. right turning vehicle and cyclist coming from the right). However, analyses which consider such aspects are still rare, especially in connection with other accident situations (e.g. cyclist crossing the street outside of junction areas).

So far only a few researchers (e.g. [9]) take the drivers' task in a given infrastructure into account by determining typical car-to-cyclist accident scenarios, but conclusions regarding the causes of these scenarios are rarely made. As a result, there is a perceived need to examine car-to-cyclist accidents from the driver's point of view in terms of driver task (road layout, traffic regulation and the driver's manoeuver intention). It is of particular importance to deduce hypotheses for possible reasons for why the drivers may have failed to manage the situations with which they were faced.

Current state-of-the-art Automatic Emergency Braking (AEB) systems for VRUs mostly take solely technical parameters like velocities and distances into account. The systems react identically no matter why the driver failed to handle the situation himself. Increasing system performance requirements driven by legislation and consumer organizations will lead to earlier brake initiation times, which simultaneously increase the risk of false activations and therefore, might cause annoyed drivers to turn off these systems. Hence, systems need to understand in which situations driver's failed to avoid the collision and for what reason. Based on this knowledge, advanced driver assistance systems can be developed, that support the driver by adapting warning times and modes, as well as brake initiation times based on the situation, with which the driver's faced.

2 METHODOLOGY

The methodology described in the following has been applied to identify the most relevant use cases and involves five stages, as shown in Figure 2.

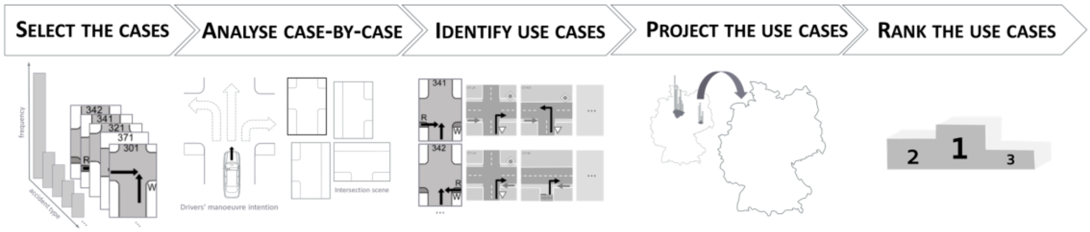


Figure 2. Methodology to identify the most relevant use cases

Stage 1: Select the cases

National statistics like the Federal Statistical Office of Germany (DESTATIS) provide information about all police-reported traffic accidents in Germany. However, the information about the accident scenario itself is limited to variables such as the "kind of accident", "type of accident" and the "opponent". The coding "type of accident" (or accident type) can offer a meaningful insight to the situation before the collision occurred. As example, in the German statistics there are seven main types of accidents (coded as type 1 to type 7). Each of these main types can be further detailed into sub-types that range up to three levels (e.g., accident type "372"). However, in the German accident statistics this 3-digit accident type information is not available for all federate states of Germany. Therefore, data from the German In-depth Accident Study (GIDAS) has been used that can be regarded as representative for Germany [10] and offers the possibility of deriving e.g., detailed crash configurations and speeds of the crash participants. The extrapolation from this GIDAS analysis to Germany is described in Stage 4 of this paper. Finally, the present GIDAS analysis focussed on crashes with two participants, thus between one cyclist and one passenger car occurred during the years 2000 and 2013 (N=4,272). The "type of accident" (UTYP) describes the situation or the conflict that resulted in the accident, indicating how the conflict was touched off before the collision. Accident types are clustered in seven categories: driving accident, accident caused by turning off the road, by turning into a road or crossing it, accident caused by crossing the road, accident involving stationary vehicles, accident between vehicles moving along in carriageway and other accidents. Within these seven general accident types, further specification is available coded in the 3-digit accident type. As an example, UTYP 342 belongs to the category of accidents caused by turning into a road or crossing it (see Figure 3). The second digit refines the situation definition towards a cyclist with priority crossing on the bikeway. With the third digit, information is given about the directions of both participants towards each other, i.e. cyclist crossing from the right side in UTYP 342.

For the presented analysis, accident types (UTYP) with a frequency of less than 1% were excluded except the accident types with the 3-digit code UTYP 501 (vehicle or cyclist stationary, other participant approaching from behind in the same direction) and UTYP 582 (cyclist colliding with door opened at the driver side). Furthermore, the longitudinal accident types with the 3-digit code UTYP 601 (car and cyclist moving in the same direction) and UTYP 681 (car and cyclist moving towards each other, i.e. oncoming traffic) are included as well. Although they have a frequency below 1%, a previous study has shown that "longitudinal scenarios in which car and cyclist are driving in the same direction and the cyclist is hit at the rear end by the car also cover a significant portion of serious accidents" [5]. Accounting for these limitations the number of examined car-to-cyclist accidents added up to 3,497 cases (82% of all cases) composed by 18 different accident types (see Table 1).

Table 1. Accident types which lie within the limitations of this study

Accident types (3-digit code)	Relevance [%] n=4,272
All accident types	**100**
Considered accident types	**81.9**
Crossing scenarios	*57.6*
301, 302, 303, 321, 341, 342, 371, 372	
Turning scenarios	*17.9*
211, 224, 223, 243, 244	
Longitudinal scenarios	*1.7*
601, 681	
Other scenarios	*4.7*
581, 582, 501	
Excluded accident types	**18.1**

Stage 2: Analyse case-by-case

The aim of the second stage was to add supplementary information about the drivers' tasks. As pointed out in the introduction, there is a perceived need to examine car-to-cyclist accidents from the car driver's point of view in terms of driver's task (road layout, traffic regulation and driver's manoeuver intention). However, the driver's manoeuver intention was not available for every accident type based on the information from the UTYP as illustrated in Figure 3. GIDAS implemented this information in 2005, coding the intention of the driver, prior to the collision based on an interview with the driver. Therefore, the remaining cases (n=3,550) were analyzed case-by-case. In addition, the categorization of the variable "accident scene" (hereinafter "road layout") was refined and the variables "traffic regulation" and "cyclist's orientation" are coded with respect to the driver's perspective.

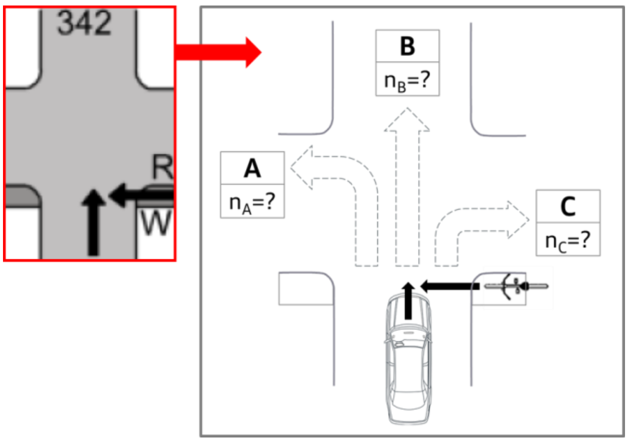


Figure 3. Unclear driver's manoeuver intention within UTYP 342; Legend: **'W'**= user close-by has to wait, **'R'**= indicates bikeway, **'A','B' & 'C'**= represents driver's maneuver intention (turning left, going straight, turning right)

During the case-by-case analysis further filter criteria were used considering different reasons (see Table 2), resulting in n=3,171 cases. For instance, crashes in rural areas and/or accidents with uninjured cyclists were excluded due to the focus of PROSPECT. Furthermore, crashes were excluded from the sample in which the priority regulation was unknown as this influences essentially the accident type. Finally, different error types (slips, lapses, mistakes or violations) have different implications for their prevention. In accordance with Reason [11] 'violations' represent a deliberate disregard of rules and regulations. However, this could not be proven for the selected crashes and thus, it was not possible to investigate the 'Red light violation' as major fault causing the crash.

Table 2. Exclusion criteria for case-by-case analysis

Exclusion criteria	Rationale
Uninjured cyclists	Focus of PROSPECT is on injured cyclists
Rural accidents	Focus of PROSPECT is predominantly on crashes in urban environments
Unknown accident types	Crashes which could not be assigned clearly to a specific situation.
Special cases (parking, U-turn, traffic light failure)	Special cases would require a separate analysis as the method used was not considered to be appropriate for these cases.
Unclear priority regulation	The way of right was defined as key parameter of the method used to categorize the crash situations.
Red light violation	In most cases with red light violation it was not identifiable whether this offence principally caused the crash.

Stage 3: Identify use cases

For each accident type so called use cases were derived by analyzing the accidents regarding the driver's maneuver intention, the cyclist's orientation with respect to the vehicle, the road layout, traffic regulation from the driver's perspective and the cyclist's road usage. Accidents with similar parameters were assigned to the same use case. The frequency of different use cases within one UTYP can be very different. However, since the purpose of the analysis was to provide a condensed set of the most relevant scenarios, only scenarios with an occurrence frequency of 10% or more are considered for the analysis. This procedure is conducted twice taking into account different injury severities. In part I only accidents with severely or fatally injured cyclists were considered and part II included also slightly injured cyclists. Since it is known that car-to-cyclist accidents (especially the outcome of these) are influenced by various parameters (see e.g. [12]), for every use case distributions of relevant parameters are extracted from GIDAS. Environmental conditions such as view obstructions (yes/no) and the daytime (day/night/dawn) as indicator for the light conditions were taken into account, as well as the accident participants' initial and collision velocities (0-80 km/h) and the age of the cyclist (0-90 years).

Stage 4: Project the use cases

As the identified use cases based on GIDAS represent only a subsample of all police-reported accidents, a projection to the German accident statistics DESTATIS was considered useful using primarily the shares of crash assigned accident types and the injury severity for the matching. However, in the German accident statistics the 3-digit accident type information is not available for all federal states of Germany. An analysis of the integrity of the data from the years 2009-2014 showed that this information level is only provided to nearly 100% by 5 (out of 16) federal states (Lower Saxony, North Rhine-Westphalia, Rhineland Palatinate, Saxony-Anhalt and Saarland) which by random, represent the German accident occurrence quite well. It was concluded to use only data from these 5 federal states for the following analysis [13].

The German national accident data analysis involved crashes between 2 participants only (here: exactly one passenger car and one cyclist) in urban areas ("innerorts") of the accident years 2011-2014. Consequently, the dataset included 118 cyclist fatalities, 9,275 seriously and 60,592 slightly injured cyclists.

In this context, it is assumed that the distribution of use cases derived from a period of 13 years can be directly transferred to an average of accident years 2011-2014. Due to low case numbers in GIDAS for the multitude of use cases, this assumption could not be validated.

Stage 5: Rank the use cases

In order to obtain a ranking for the use cases that includes frequency as well as injury outcome, the method developed within the project ASSESS [14] was applied using weighting factors derived from injury costs on each injury severity. The formula is described below for the use cases in part I and part II.

$$\boldsymbol{Rankvalue\ (use\ case\ x)_{PARTI}} =$$

$$(\#severly\ injured)\ \times 0.11 +\ (\#fatalities)\ \times 1$$

$$\boldsymbol{Rankvalue\ (use\ case\ x)_{PARTII}} =$$

$$(\#slightly\ injured)\ \times 0.011 + (\#severly\ injured)\ \times 0.11 +\ (\#fatalities)\ \times 1$$

3 IDENTIFIED USE CASES

For part I of the analysis, a total of 29 different use cases out of 18 accident types were identified. Part II of the analysis resulted in 35 different use cases. Due to the large number of use cases in both parts, only findings for the most frequent class of scenarios will be presented in this paper. A detailed report on all use cases can be found in Deliverable 3.1 of PROSPECT [4].

As described in Table 1 (see section 2), the most frequent class of scenarios consists of crossing scenarios accounting for 58 % of all accidents. This is in line with previous findings (see e.g. [5],[12],[15]). The class of crossing scenarios can be subdivided into crossing scenarios at intersections (see section 3.1) and crossing scenarios outside of intersections (see section 3.2). For both types of crossing scenarios, findings regarding identified use cases as well as their comparison with each other within and between accident types will be presented below.

3.1 Use cases for crossing scenarios at intersections

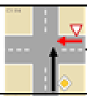
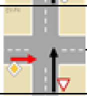
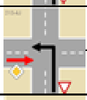
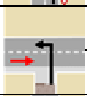
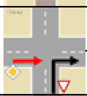
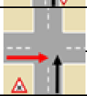
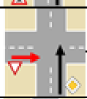
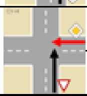
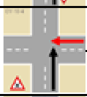
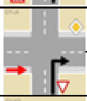
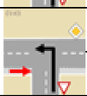
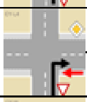
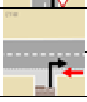
Table 3 shows the identified use cases for crossing scenarios at intersections. The use cases are presented in pictograms, showing the junction layout, the intention of the road user and applied right-of-way laws. Regarding the intention, red arrows describe the cyclist's intention (going straight, turning left or right), while black arrows show the driver's intention. The applied right-of-way laws are depicted as traffic signs/traffic lights. The layout itself shows the type of junction (e.g. 4-arm junction, exit/entrance) as well as the cyclist's used traffic way, i.e. whether the cyclist was driving on the street or beside the street on a separate bike lane. In addition, Table 3 contains information about the relative frequency of a use case within one accident type (hereinafter distribution), as well as the distributions of relevant parameters (driver's initial velocity, view obstructions and the daytime). All distributions are listed for part I and II of the analysis, i.e. for the different categories of injury severity. For the comparison of use cases with each other between accident types, Appendix A displays the relative frequency of a use case regarding all bicycle-to-car accidents (hereinafter relevance). As described in section 2, only use cases with a distribution greater or equal 10% are depicted. With this definition, some use cases were only considered relevant for part I or II of the analysis and marked as not considered for the other part of the analysis.

Comparisons within accident types

1) UTYP 301: Accident type 301 is represented by two different use cases. In the first use case, a cyclist is crossing from the right violating the right-of-way of the car, whereas in the second use case, the cyclist is crossing from the left and the car violated the right-of-way of the cyclist. For both analyses (part I and part II), the use case, in which the cyclist was violating the car's right-of-way (301_1), had a higher distribution. Only 12% (part I) of these accidents happened during nighttime or dawn, but in 41% (part I) of these accidents an obstruction was present. In contrast, only 10% (part I) of the accidents with the car violating the cyclist's right-of-way (301_2) included a view obstruction, whereas 40% of these accidents happened during nighttime or dawn. An indicator of the higher distribution of the second use case within UTYP 301 regarding all injury severities (part II) compared to severely and fatally injured cyclists only (part I) is the lower initial velocity for the yield scenario, resulting in lower injury severities [4].

2) UTYP 321: For part I of the analysis, use cases, in which the cyclist violated the right-of-way of the passenger car (321_1 & 321_2; 48%), have a higher distribution compared to those scenarios, in which the car violated the right-of-way of the cyclist (321_3; 19%). Regarding part II of the analysis, the distribution between the different traffic violation situations is about equal (38% (321_1&321_2) vs. 35% (321_3 &321_4). For both parts of the analysis one use case each is not considered as it occurred with a frequency of below 10% (exclusion criteria). An explanation of the low frequency (below 10%) of the second use case within UTYP 321 regarding all injury severities (part II) provides the high initial velocity, resulting in higher injury severities. Since the initial velocities for the priority-to-right violation-scenarios (321_1 & 321_4) are equal, the low distribution of the fourth use case within UTYP 321 regarding severely and fatally injured cyclists only (part I) may be explained by the cyclist's direction. Nevertheless, priority-to-the-right violations tend to be more frequent for cyclists than for passenger cars [4].

Table 3. Identified use cases of car-to-cyclists crashes in GIDAS (2000-2013) in crossing scenarios at intersections (red arrows: cyclists, black arrows: car drivers)

Use case			Distribution[1] within UTYP [%]	Initial velocity [kph] M (SD)	Time of Day [%] Day| Dawn| Night	Obstruction [%] YES | NO
301_1		Part I	76	46.68 (12.57)	87 | 6 | 6	41 | 59
		Part II	63	43.98 (11.63)	79 | 5 | 16	35 | 65
301_2		Part I	24	21.86 (13.87)	60 | 30 | 10	10 | 90
		Part II	35	18.19 (11.55)	69 | 17 | 14	21 |79
302_1		Part I	86	14.00 (8.79)	50 | 17 | 33	33 | 67
		Part II	69	15.44 (10.13)	66 | 11 | 23	29 | 71
302_2		Part I	not considered			
		Part II	10	11.86 (4.71)	63 | 13 | 25	63 | 38
303		Part I	67	19.00 (12.73)	50 | 33 | 17	0 | 100
		Part II	72	15.82 (10.43)	72 | 9 | 19	15 |85
321_1		Part I	31	29.00 (9.81)	92 | 4 | 4	29 | 71
		Part II	38	25.85 (9.80)	94 | 4 | 2	33 | 67
321_2		Part I	29	53.94 (19.00)	73 | 9 | 18	23 | 77
		Part II	not considered			
321_3		Part I	19	18.23 (10.86)	67 | 26 | 7	50 | 50
		Part II	18	18.86 (12.59)	82 | 10 |8	34 | 66
321_4		Part I	not considered			
		Part II	17	26.65 (13.21)	78 | 8 | 14	39 | 61
341_1		Part I	55	13.21 (9.94)	68 | 10 | 23	14 | 86
		Part II	57	14.27 (10.84)	72 | 12 | 16	12 | 88
341_2		Part I	14	15.14 (10.00)	75 | 13 | 13	13 | 87
		Part II	14	12.72 (11.16)	77 | 9 | 14	14 | 86
342_1		Part I	66	13.65 (9.46)	87 | 10 | 4	33 | 67
		Part II	64	12.09 (9.19)	89 | 6 | 6	26 | 74
342_2		Part I	20	10.77 (8.06)	87 10 | 3	50 | 50
		Part II	24	37.67 (13.68)	91 | 5 | 4	42 | 58

[1]relative frequency of a use case within the UTYP

3) UTYP 341: Cyclists crossing from the left on the separate bike lane collided more often with passenger cars intending to turn right as with those, intending to turn left. This effect was already analyzed in former accident analyses. For both use cases, about 29% (part I) and 25% (part II) of the accidents happened during nighttime or dawn. View obstructions were only found in 13% of the accidents for both injury severity classes [4].

4) UTYP 342: An opposite effect was found for cyclists crossing from the right side on the separate bike lane (usually non-compliant with traffic regulation). For these accidents, most of the passenger cars intended to turn right (part I: 86% and part II: 88%) – often exiting a driveway or parking lot (part I: 20% and part II: 24%) or approaching a yield junction. Only 13.5% (part I) and 9.5% (part II) of these accidents happened during nighttime or dawn, whereas view obstructions were present for junctions in 33% of the cases for part I (part II: 26%) and even in 47% (part I) of the entrance/exit situations (part II: 29%).

Comparisons between use cases

1) 301_2 & 321_3: In both use cases, a passenger car intended to go straight at a junction (yield sign) and collided with a crossing cyclist from the left (301_2) or right side (321_3). For those cases only slight differences in the relevance of cyclists crossing from the left or right side were found, with a somewhat higher relevance for cyclists crossing from the right side regarding part I (0.35% vs. 0.21%) and for cyclists from the left side regarding part II (1.01% vs. 0.91%). For part I of the analysis, for both cases the distribution of 'Time of Day' was similar, but the distribution of obstruction was different (50% (321_3) vs. 10% (301_2)). In contrast, for part II of the analysis, for both cases the distribution of 'Obstruction' was similar, while the distribution of 'Time of Day' differs (distribution of dawn/night-accidents: 31% (301_2) vs. 18% (321_3)).

2) 301_1 & 321_2: These use cases are analogous with the situations in the previous comparison, but with a different traffic regulation (right-of-way for the passenger car). There were only slight differences between the relevance of situations, in which the cyclist was crossing from the right (0.73%) or left side (0.51%) regarding part I of the analysis, with a tendency towards cyclists crossing from the right side. Only 12% of those accidents (cyclist crossing from the right side; 301_1) happened during nighttime or dawn, but in 41% view obstructions were present. The opposite is the case for accidents with cyclist crossing from the left side. For part II of the analysis, the distribution of 321_2 (cyclist crossing from the left) was below 10% and therefore excluded from further analysis.

3) 301_1 & 321_3: In both use cases, a driver intended to go straight at an intersection, and collided with a cyclist crossing from the right side. From a sensor perspective, the use cases are identical. But there are different right-of-way rules apparent in these situations: for 301_1 the car was driving on a main road with right-of-way, while in 321_3 the driver approached a junction with a yield sign and hence, the cyclist had priority. For both injury severity classes (part I and II) the relevance of the scenario, in which the driver had priority, was about double as high (part I: 0.73; part II: 1.80) as in the scenario, in which the driver had to yield priority (part I: 0.35; part II: 0.91). Both use cases share a relatively high relevance of view obstructions (41% vs. 50%), as indicated in part I of the analysis. In addition, the initial velocities are very different for these use cases. If the driver had priority, the initial velocity is on average 46.7km/h (part I), dropping to 18.2km/h (part I) for those situations, in which the driver had to yield priority to the cyclist.

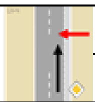
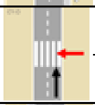
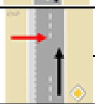
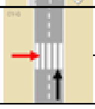
4) 301_2 & 321_2: These use cases represent the analogous scenarios as described in 3), with the cyclist crossing from the left side. Within these crossing from the left use cases, the same effect as described above for crossing from the right use cases can be found: the relevance of scenarios, in which the driver has priority (321_2), is twice as high (part I: 0.51) as for those (301_2), in which the driver had to give priority to the cyclist (part I: 0.21). However, there are differences in the relevance of view obstructions. Only 10% of all 301_2 cases included view obstructions compared with 23% in all 321_2 cases (part I). Furthermore, both use cases showed a higher relevance for nighttime/dawn (part I: 40% for 301_2, 27% for 321_2).

5) 341_1 & 342_1: These use cases represent the same situations, but with the difference that in the first one the passenger car collided with a cyclist from the left side and in the latter with a cyclist from the right side, each cycling on a separate bike lane. It should be noted, that in such situations the frequency to collide with a cyclist coming from the right side is three times higher than the frequency to collide with a cyclist coming from the left side (part I: 2.43% vs. 0.73%; part II: 15.19% vs. 4.17%) . As mentioned above in the comparisons within the accident types, on the one hand a high proportion of accidents happened during night or dawn, where the cyclist was coming from the left side. Presence of view obstruction, on the other hand, was found to have a higher distribution in those accidents in which the cyclist was coming from the right side.

3.2 Use cases for crossing scenarios outside intersections

Table 4 shows the identified use cases for crossing scenarios outside of intersections, i.e. those scenarios, in which the cyclist was crossing the street at some point outside of an intersection. The use cases are presented analogous to section 3.1. As mentioned in section 2, only use cases with a relevance greater or equal 10% are depicted.

Table 4. Identified use cases of car-to-cyclist crashes in GIDAS (2000-2013) in crossing scenarios outside of intersections (red arrows: cyclists, black arrows: car drivers)

Use case			Distribution[1] within UTYP [%]	Initial velocity [kph] M (SD)	Time of Day [%] Day | Dawn | Night	Obstruction [%] YES | NO
371_1		Part I	71	40.25 (21.2)	91 | 4 | 5	53 | 47
		Part II	70	37.67 (13.68)	91 | 4 | 5	52 | 48
371_2		Part I	22	52.30 (18.6)	94 | 6 | 0	24 | 76
		Part II	17	45.75 (20.94)	100 | 0 | 0	28 | 72
372_1		Part I	69	35.56 (12.19)	72 | 11 | 17	41 | 59
		Part II	54	33.75 (12.21)	90 | 4 | 6	53 | 47
372_2		Part I	31	39.38 (25.39)	50 | 25 | 25	0 | 100
		Part II	30	27.5 (17.59)	75 | 11 | 14	7 | 93

[1]relative frequency of a use case within the UTYP

Comparisons within accident types

1) UTYP 371: Two main use cases were identified for UTYP 371. In both use cases, a cyclist crosses the street from the right side, in the first use case without any crosswalk, in the second one at the crosswalk. The frequency of crossing scenarios with crosswalks (part I: 22%) is much lower as it is without crosswalks (part I: 71%), and yet lower for part II (17%). Interestingly, the initial velocity is with 52.3km/h higher for scenarios with crosswalk as for those without a crosswalk (40.3km/h) in part I of the analysis. In addition, a higher distribution of young cyclists is found for those situations without a crosswalk (part I: median cyclist age 14.5 years w/o crosswalk, 47 years w/ crosswalk), as well as a higher distribution of view obstructions (part I: 53%) compared to 24% in situations with crosswalks.

2) UTYP 372: Accident type 372 resulted in two use cases analogous to UTYP 371 with and without crosswalk, but with the cyclist crossing from the left. As for UTYP 371, the same tendencies were found in the data, showing a higher distribution of cases without crosswalks (part I: 69% vs. 31%) higher distribution of view obstructions (part I: 41% vs. 0%) in cases without crosswalks, as well as lower initial velocities (part I: 35.6km/h vs. 39.4km/h).

Comparisons between use cases

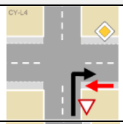
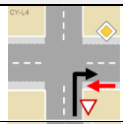
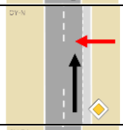
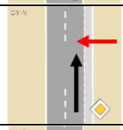
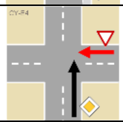
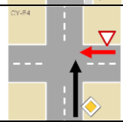
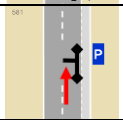
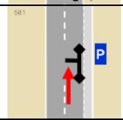
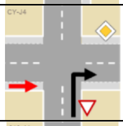
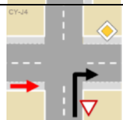
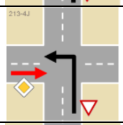
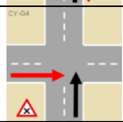
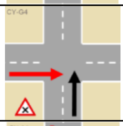
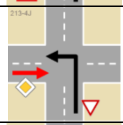
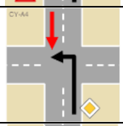
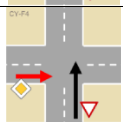
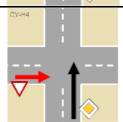
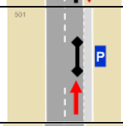
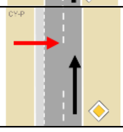
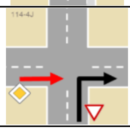
1) 371_1 & 372_1: Comparing the use cases, in which the cyclist was crossing the street without a crosswalk, the relevance of accidents with the cyclist crossing from the right is about three times higher as it is for those, in which the cyclist was crossing from the left (part I: 1.31% vs. 0.42%; part II: 3.14% vs. 1.47%). In addition, the initial velocity is about 5 km/h lower for crossing from the left scenarios (part I: 35.6km/h vs. 40.3km/h; part II: 33.8km/h vs. 37.7km/h).

2) 371_2 & 372_2: Scenarios with a cyclist crossing at a crosswalk also show a tendency towards crossing from the right side (part I: 0.40% vs. 0.19%; part II: 0.77% vs. 0.66%) and lower initial velocities for crossing from the left scenarios (part I: 39.4km/h vs. 52.3km/h; part II: 27.5km/h vs. 45.8km/h).

4 MOST RELEVANT USE CASES

Table 5 shows the ten most relevant use cases based on their ranking for part I and II of the analysis. The ranking is calculated as described in section 2, taking into account the relevance within one UTYP from the case-by-case analysis, the relevance of every UTYP based on DESTATIS and the socio-economic impact for the different injury severities.

Table 5. The ten most relevant use cases based on their ranking scores

Part I[1]	Ranking position	Part II[2]
	1	
	2	
	3	
	4	
	5	
	6	
	7	
	8	
	9	
	10	

[1]use cases identified from part I weighted by injury costs
[2]use cases identified from part II weighted by injury costs

Based on the ranking, the Top 5 use cases are identical for both injury severity classes (part I and II). Most of the Top 10 use cases are crossing scenarios (see Table 1). The three highest ranked use cases are situations, in which a cyclist is crossing from the right side. All of these scenarios include some type of non-compliant or unexpected behavior regarding traffic regulation for the cyclist (cycling against traffic direction on the sidewalk, crossing the street without a crosswalk, priority violation). In addition, those use cases all share a higher distribution for view obstructions (see section 3.1 for accident types 342 and 301 and section 3.2 for accident type 371). View obstructions also have a higher distribution in the use case, in which the cyclist was violating the priority-to-the-right rule (rank 7 for part I and rank 6 for part II). In contrast, view obstructions have a lower distribution for those situations, in which the driver was violating the cyclist's right-of-way. However, these situations tend to happen more often during nighttime or dawn.

5 DISCUSSION

The aim of the presented study was to analyze car-to-cyclist accidents from the driver's point of view. By taking the driver's task in a given infrastructure into account, this approach supplies more detailed information about the situations which the drivers faced. The results of the accident analysis confirm findings of previous studies (e.g.[5], [12], [15]) that crossing scenarios play a predominant role in car-to-cyclist accidents. Moreover, the results show that both the orientation of the cyclist and driver's task influence the distribution of those scenarios in so far as certain combinations led to a higher or lower distribution. In this context, two main findings will be highlighted:

1) Drivers collided more often with a cyclist from the right side in those situations, in which the cyclist violated road traffic regulations (e.g. cyclist crossing a main road/junction without paying attention to the passenger car or cyclist driving on the wrong side and intending to cross a junction from the right side, at which a passenger car intends to turn right). Interestingly, the frequency of collisions decreased in equivalent infrastructural situations, if either the orientation of the cyclist (e.g. cyclist is crossing a main road from the left side) or the driver's maneuver intention (e.g. passenger intending to turn left at an intersection while the cyclist is driving on the wrong side) was different as described above.

Regarding the situation, in which a cyclist is crossing at a junction from the right against the travel direction and the car intends to turn right, some of the differences already have been explained in previous studies by drivers' inappropriate expectations about a traffic situation (e.g. [6], [16], [17]). In this studies it was found, that these inappropriate expectations lead to an improper allocation of attention, so that the driver pays less attention to unexpected and less frequent events as he expects other road users to comply with road traffic regulations. As a consequence, drivers "fail to look" into the cyclist's direction, thus seeing the other traffic participant too late to avoid a collision. This explanation can also be applied to accident scenarios, in which the driver is driving along a main street or on a main arm of a junction and his/her right-of-way is violated by a cyclist, as drivers do not expect this event. If, in addition, the cyclist is crossing the street from the right side, the driver simply has less time to react to the cyclist from the right side compared to a cyclist from the left. Another contributing factor could be the higher distribution of view obstructions, accounting for 42% on average for part I and 39% on average for part II.

2) In situations, in which the driver had no right-of-way, collisions with a cyclist coming from the left side had a higher relevance compared to situations, in which the driver had right-of-way (e.g. (1) cyclist drives on a separate way with the intention to cross a junction from left, at which a passenger car intends to turn right or (2) cyclist drives on a main arm of a junction, at which a passenger car with no right of way intends to cross the main arm of this junction from the right). As mentioned above, it was also found that in this case the frequency of collisions decreased by varying either the orientation of the cyclist or the drivers' maneuver intention in the same infrastructural situations. Based on the driver's task in this environmental situations, the driver is required to look in the cyclist's direction, especially in those situations where the cyclist is driving on the street. As for these scenarios the percentage of view obstructions is quite low, while the percentage of accidents that happened during nighttime or dawn is somewhat higher (accounting for 43% for part I on average and 30% for part II on average), it may be assumed that drivers "look but fail to see" the other traffic participant. Most of these accidents happen during daytime; however, no further conclusions can be derived from the accident data as to why the driver might fail to see the cyclist. One possible hypothesis can be

that there is competing information in the driver's field of view with a higher salience (size, color, etc.) than the cyclist, which attracts and captures the driver's attention.

It has to be noted that all results were derived based on the analysis of GIDAS data that comprise crash information from Germany only. As this can't be representative for Europe, in-depth data from other countries was considered within PROSPECT but results were not ready in time to be included in this work and will presumably also not be able to provide overall insights regarding all European countries.

6 CONCLUSIONS

In conclusion, a case-by-case analysis was performed to identify the most relevant use cases in car-to-cyclist accidents in Germany from a driver's point of view. It was of particular importance to deduce hypotheses for reasons which would cause drivers to mismanage the situations that they faced. The results indicate two different potential mechanisms associated with most accident scenarios that are related to the environmental situation, the driver's task and the orientation of the cyclist. So called failed-to-look errors seem to be the leading cause in situations in which the cyclist's behavior is not in compliance with traffic rules. These situations are characterized by an unexpected or unpredictable behavior of the cyclist in so far as drivers can be seen as resource-saving systems, thus are not permanently anticipating rule violations by other road users. In contrast, technical systems are able to scan and evaluate the intention of other road users continuously without any need to split resources between the different tasks, enabling warnings or, if necessary, automatic brake or evasion maneuvers in case of potential hazards. In addition, a more detailed understanding of the driver's perception of the situation might help to reduce the number of false alarms by adapting algorithms especially for those situations, in which the data indicate an increased need for supporting the driver.

Furthermore, the results indicate look-but-fail-to-see errors in situations, in which drivers violate traffic rules and collide with a cyclist coming from the left. So far, however, only little knowledge is available about factors that contribute to the driver "overlooking" the cyclist, thus necessitating further investigations in order to acquire a better understanding of the driver's needs for support. Also, it should be noted that not only perceptual errors can cause such situations. Even if the driver had seen the cyclist, decision errors might lead to an accident, e.g. if the driver underestimates the cyclist's velocity.

Alternatively, the gained understanding of car-to-cyclist accident scenarios can also be used to improve traffic education for cyclists including especially the most common scenarios and to optimize infrastructure in order to minimize influencing factors within the road and junction layouts.

Regarding PROSPECT, the use cases presented above will be used to specify and develop advanced measures that will be implemented in the next generation of active safety systems. These new functionalities will be installed and tested in three demo car vehicles [18], with the aim to improve the sensing of vulnerable road users and to develop advanced system strategies.

Acknowledgements

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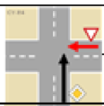
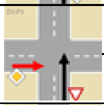
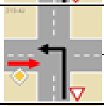
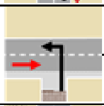
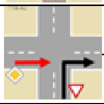
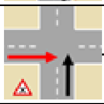
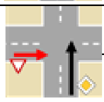
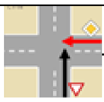
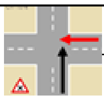
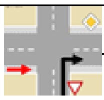
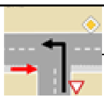
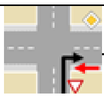
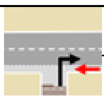
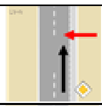
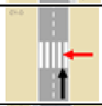
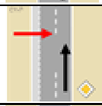
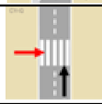
APPENDIX A

Use case			Relevance[1] [%]
301_1		Part I	0.73
		Part II	1.80
301_2		Part I	0.21
		Part II	1.01
302_1		Part I	0.28
		Part II	1.24
302_2		Part I	
		Part II	0.19
303		Part I	0.14
		Part II	1.10
321_1		Part I	0.56
		Part II	1.90
321_2		Part I	0.51
		Part II	
321_3		Part I	0.35
		Part II	0.91
321_4		Part I	
		Part II	0.84
341_1		Part I	0.73
		Part II	4.17
341_2		Part I	0.19
		Part II	1.03
342_1		Part I	2.43
		Part II	15.19
342_2		Part I	0.73
		Part II	5.69

[1]frequency of an use case with regard to all bicycle-to-car accidents (n=4272)

Use case			Relevance[1] [%]
371_1		Part I	1.31
		Part II	3.14
371_2		Part I	0.40
		Part II	0.77
372_1		Part I	0.42
		Part II	1.47
372_2		Part I	0.19
		Part II	0.66

[1]frequency of an use case with regard to all bicycle-to-car accidents (n=4272)