Investigation of bicycle accidents involving collisions with the opening door of parking vehicles and demands for a suitable driver assistance system.

M. Jänsch, D. Otte, H. Johannsen

Abstract

Vulnerable road users play an increasingly important role in traffic safety work as the severity of their injuries often are higher than for those travelling in a car or truck. Thus safety devices implemented in cars should not only protect the car occupants but also vulnerable collision opponents in a crash. When looking at accidents where bicyclists have collided with a car one certain accident scenario seems to be more frequent than expected: A bicyclist riding along a road with longitudinally parked cars, suddenly the door of a parked car opens and the bicyclist either collides with the open door or falls when attempting to avoid the collision. The objective of this study is to display the injuries of cyclists in such accident situations and to analyze trajectories and time related accident frame parameters for the suggestion of an appropriate driver assistance system on passenger cars to reduce the number of such accident situation. Further the estimation of the effectiveness of such an assistance system is done within the chosen sample of real world accidents. The study is based on the analysis of real word crashes using the data of the German in depth Accident Study (GIDAS) by means of weighting, an extrapolation of the accident situation in Germany is provided.

Keywords bicycle accidents, door impact, injury mechanisms, vulnerable road users

I. INTRODUCTION

Accidents where a cyclist collides with an opening door of a parked car are not among the most common traffic accidents but appear to be occurring needlessly often when taking into account, that the car is not even moving. These accidents have a share of 3% of all bicycle accidents in the German In-Depth Accident Study database and they are of great concern to the cyclists because they are usually caused by the vehicle passenger while the cyclist, the vulnerable road user, is injured.

The conflict of a cyclist with an opening car door was the subject of some previous studies based on statistical data from various authorities or insurance companies around the globe to point out that these accidents are more common as expected. In contrast the objective of this study is to analyze these accidents more profoundly describing the accident situation in more detail and to propose technical methods to prevent the accidents. The protection for bicyclists by passenger cars, equipped with technical systems, as collision partners is mainly focused on collisions with moving cars. This study focuses on the particular accident situation where drivers or passengers of parked vehicles open doors and jeopardize the safety of passing cyclists. The causes of the accidents are analyzed and a possible assistance system to avoid these accidents is proposed, based on information from the reconstruction of such accidents

II. METHODS

This study is based on the analysis of real word crashes using the data in GIDAS. GIDAS is an in-depth accident database with comprehensive information about the accident occurrence, the vehicle information as well as personal information such as causation and injury information. By means of an accident reconstruction the course of events, speeds and reaction points of the participants are determined. The methodology used is an on-scene investigation of a representative subsample of accidents where injuries were sustained in the regions of Hannover and Dresden which is well suited to represent the German accident situation [1]. The

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theoretical framework for the analysis of human causes in this study is given with Accident Causation Analysis System (ACAS) which is a hierarchical classification scheme of five categories of basic human functions and errors present in the emergence of an accident during the pre-accident phase [2]. This information is available for cases collected by the Accident Research Unit at the Hannover Medical School, which represent a subsample of the chosen GIDAS cases.

The GIDAS database contains 225 cases of bicycle accidents with injuries since the year 2000 which occurred as a result of an impact against an opened car door. For the selection, accident types were used (Fig. 1 and Fig. 2). By means of analyzing the GIDAS in-depth accident database, relevant accidents cases were identified and the scenarios and causes of such accidents, as well as the injuries and injury mechanisms are described. Subsequently the sequence of events for each accident is determined by accident reconstruction and impact speeds are calculated. Based on this in-depth information an appropriate driver assistance system for passenger cars is suggested to prevent these accidents from happening.

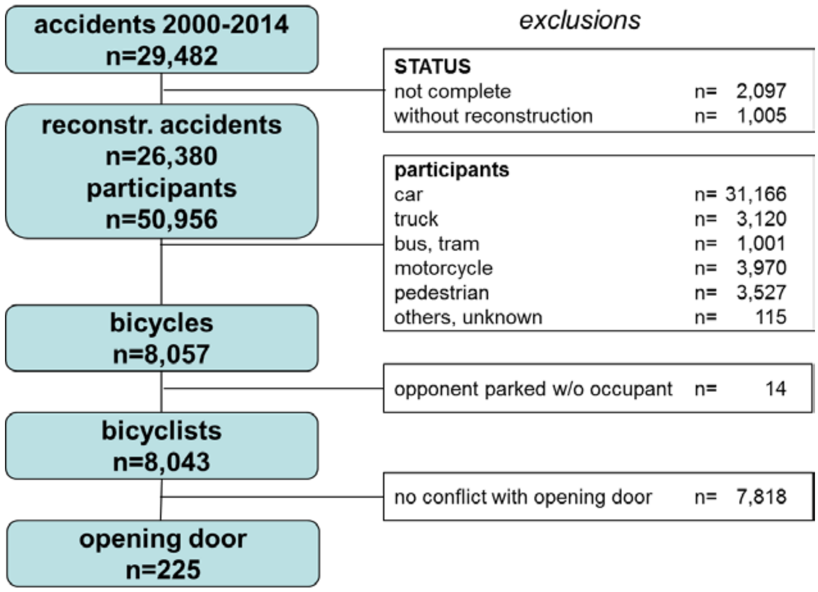

Fig. 1 Sample frame of available GIDAS data for this accident analyzes**.**

III. RESULTS

Bicycle accidents with opening car doors

Initially the accident type according to the Gesamtverband der Deutschen Versicherungswirtschaft (GDV) which classifies accidents by the initial conflict situation which led to the crash, was evaluated. There are 7 main categories of accident type (driving accidents, accidents caused by turning-off the road, accident caused by turning into a road or by crossing it, accident caused by crossing pedestrian, accidents involving stationary vehicles, accident between vehicles moving along in the carriageway and *other* accidents) which are further specified by nearly 300 subtypes in those categories. The relevant accident types for this study are from the category 5 *accident with parking vehicles.* For the conflict of a moving road user with an opening door of a parked vehicle the relevant subtypes are 581 and 582 (Fig. 2) in which a bicycle (B) collided with an opening door of a parked vehicle (A), passing the vehicle either on the left side (type 581) or on the right side (type 582). For this study accidents were chosen, where participant A is a car or truck and participant B is a cyclist.

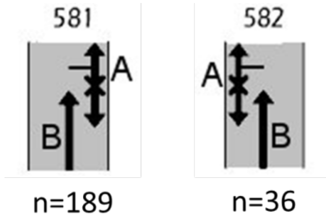

Fig. 2: Relevant accident types for this study: A bicycle (B) collides with an opening door of a parked vehicle (A), passing the vehicle either on the left side (type 581) or on the right side (type 582).

The GIDAS data are randomly collected based on a statistical sampling procedure representative for Germany. The above mentioned accident types *represent 3% of all bicycle accidents with injuries*. The vast majority of these accidents happened due to a conflict with a cyclist passing a vehicle on the left side (in 189 cases) while in only 36 cases a cyclist passed the car on the right side.

TABLE 1
DISTRIBUTION OF COLLISION OPPONENTS OF CYCLISTS WHO HAD A CONFLICT WITH AN OPENING CAR DOOR

Car	*Truck*	*Object (fall)*	*Other/multiple*
194	10	13	8

The collision opponents of the cyclists are displayed in Table 1. Mostly conflicts with an opening door of a car were observed. In only 13 cases the cyclist either fell without having contact with the door due to an evasive maneuver or subsequently collided with another object.

The analysis further showed that in most cases (80%) the cyclists had a conflict with an opening door of the driver (Fig 3). Just under 20% of the cyclists had a conflict with the front passenger door while the rear doors were rarely opened when a cyclists was approaching (1% each).

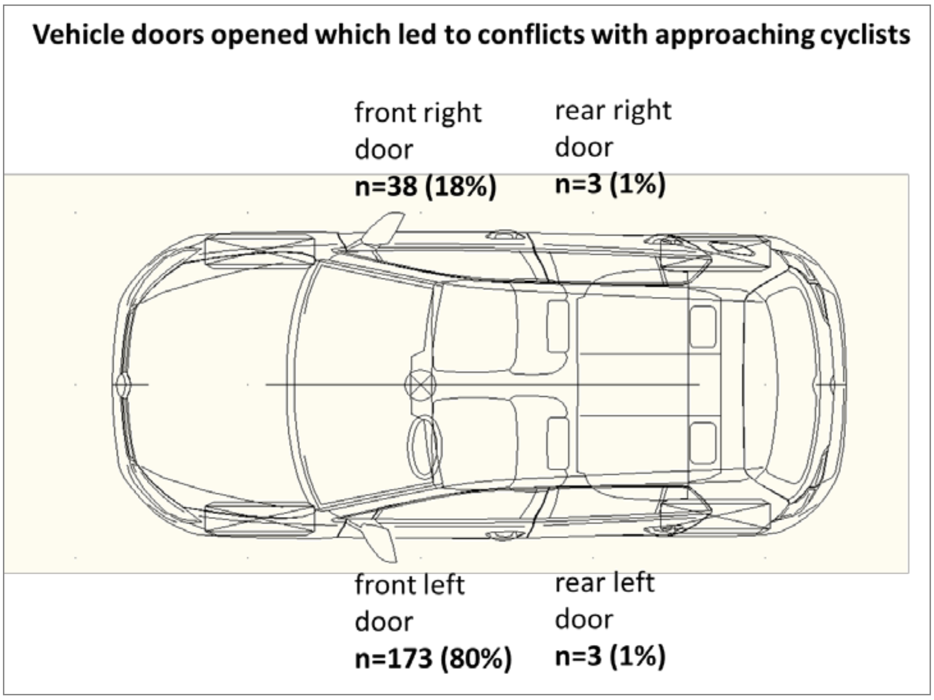

Fig. 3: Location of vehicle door which led to a conflict with a cyclist.

The conflict of a cyclist with on opening vehicle door can mainly be reduced to situation where the cyclist approached the vehicle from behind as in the vast majority of cases the cyclist approached the vehicle parallel to the vehicle from a 6 o’clock direction. In 1 case the cyclist approached the vehicle from behind at slight angle (coming from 5 o'clock) and in only 3 cases the cyclists approached the vehicle from the front (coming from 12 o'clock).

Injury situation

The sample of this study consists only of injury accidents where, due to the nature of the chosen accident types, in all cases the cyclist was the participant that was injured. The maximum injury severity of all body parts MAIS [3] of the 219 cyclists with known injuries that had a conflict with an opening car door is shown in Fig. 3 in comparison to all injured cyclists in the GIDAS database.

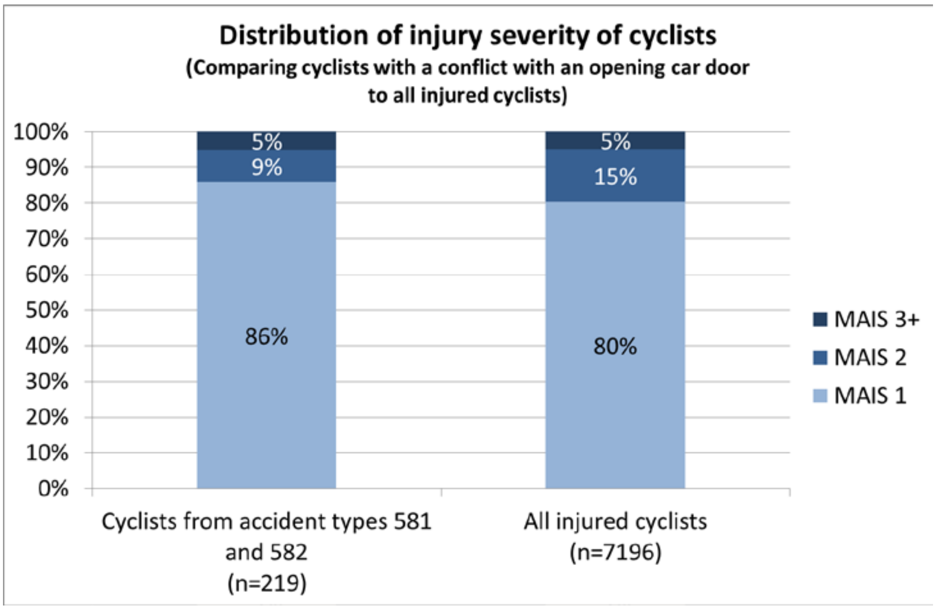

Fig. 4: Distribution of the severity of injuries sustained by cyclists who had a conflict with an opening car door compared to all injured cyclists.

In both groups the majority of cyclists only suffered minor injuries (MAIS 1) while injured cyclists who had an accident due to a conflict with an opening vehicle door seem to sustain slight injuries more often (86%) than all injured cyclists (80%). In exchange the group of all injured cyclists was more often moderately injured (MAIS 2) at 15% more often than the cyclists who had accidents with vehicle doors (9%). Serious injuries (MAIS 3+) were found in 5% of the cases in both groups. So the accidents with opening doors do not cause particularly severe or serious injuries, however it has to be noted that 4 of the 219 cyclists suffered fatal injuries.

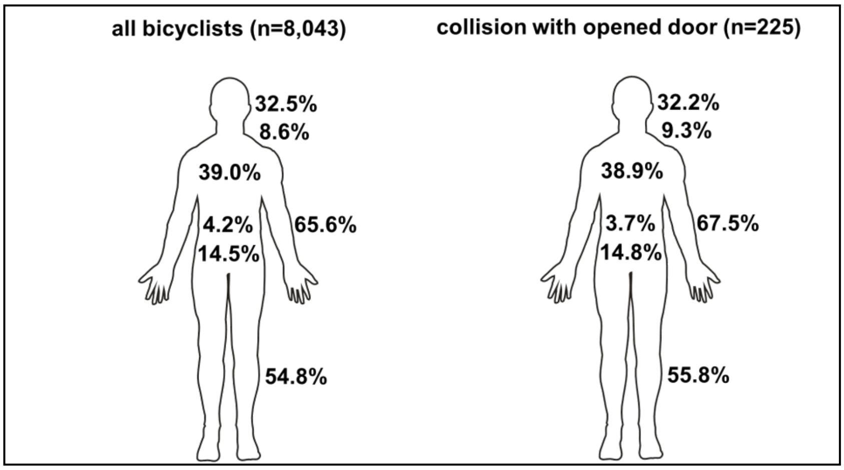

Fig. 5: Injured body parts of cyclists comparing accidents with an opening vehicle door to all cyclist accidents.

An analysis of the injured body regions (Fig. 4) shows no significant difference between the cyclists who had an accident due to a conflict with an opening vehicle door and all injured cyclists. For both groups of cyclists the upper and lower extremities are most frequently injured (legs over 50%, arms over 65%) when looking at all injury severities.

TABLE 2
DISTRIBUTION OF BODY REGIONS WITH SERIOUS INJURES (AIS 3+) OF CYCLISTS THAT HAD A CONFLICT WITH AN OPENING DOOR

Head	*Neck*	*Thorax*	*Arms*	*Abdomen*	*Pelvis*	*Legs*
4	0	1	0	0	1	5

When looking at the serious injuries (AIS 3+) (Table 2) the distribution of the injured body regions shows that mostly the head and the legs are seriously injured in the cyclists who had a conflict with an opening door. Of the 219 cyclists with known injuries it is known that only a minority of 22 cyclists had been wearing a bicycle helmet while 176 cyclists had not worn a helmet at the time of the accident (in 21 cases the helmet usage was unknown). It is interesting to see that of the 72 cyclists with head injuries only 5 of the helmet users had sustained injuries to the head and that no head injury was more severe than a minor injury (AIS 1) among the helmet users.

The 104 head and facial injuries which were documented in the analyzed cases were sustained by contact with:

- the road surface in 92 cases,
- the door of the opponents vehicle in 8 cases,
- other parts of the opponents vehicle in 3 cases,
- the own bicycle in 1 case.

Here there seems to be a potential to decrease the amount of head injuries by eliminating sharp door edges but the main source of head injuries at these bicycle accidents is the secondary collision of the cyclist with the ground.

Next to the head, serious injuries (AIS 3+) were also sustained to the lower extremities in 5 cases (tibia, femur and femoral neck fractures) and to the thorax and pelvis in one case each. In all of these cases the collision with the road surface had caused the injuries with one exception where the collision with the door handle caused a fracture of the femoral neck.

Accident reconstruction

All accidents that are available in the GIDAS database are reconstructed to calculate the initial speeds of the accident participants, as well as the time and the distance traveled from the point of reaction to the collision, among others. There are however certain difficulties involved in calculating these types of accidents, as often no detailed information about the traveling speed of the cyclist, the point of rest of the bicycle or damages which indicate the collision energy are available. Values like the initial traveling speed of the cyclist as seen in the graph of the cumulated frequency in Fig. 4 are often estimated. Therefore the graph shows some inconsistencies at 10, 15 and 20 km/h. About half of the cyclists among the 168 cyclists where information on the traveling speed was available were traveling no faster than 15 km/h. About 90% of the riders were traveling at a speed of 20 km/h or less. A resulting stopping distance for the cyclist before colliding with the door calculates to less than 11 m.

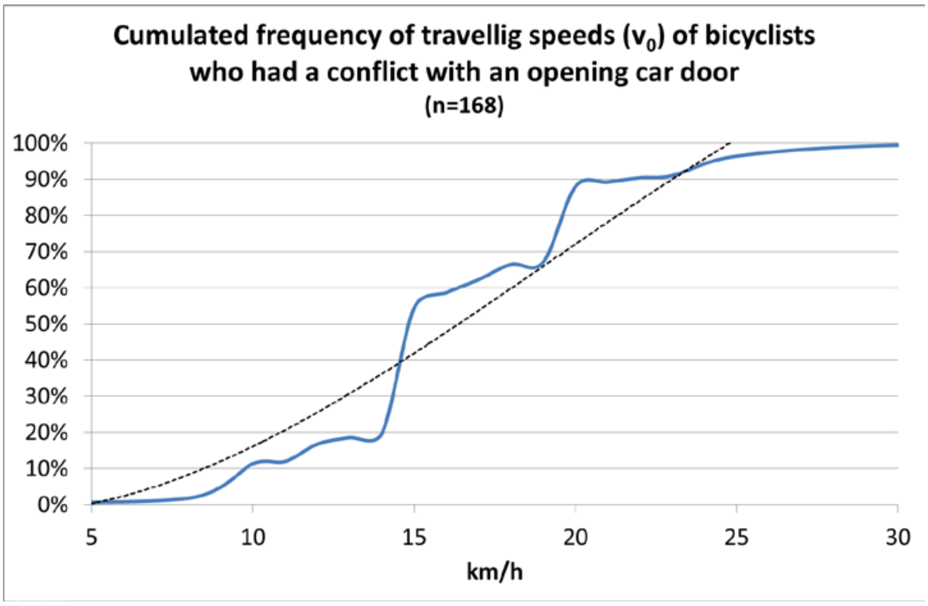

Fig. 6: Cumulated frequency of the travelling speed v_0 (initial speed) of cyclists with trend curve (dotted line).

For 87 cases the distance of the cyclist from the point of reaction to the point of collision, which is often based on estimated traveling speeds, was determined (Fig. 6). The step in the graph at 4.2 m corresponds to the frequent travelling speed of 15 km/h seen in Fig. 5 combined with a reaction time of about one second. This lead to the conclusion that with a technical system, which can identify cyclists at a distance of about 4m behind the vehicle, about half of the approaching cyclists could have been detected to warn the vehicle passenger not to open the door. If the detection range is extended to about 6 meters some 90% of the approaching cyclists could be detected in time.

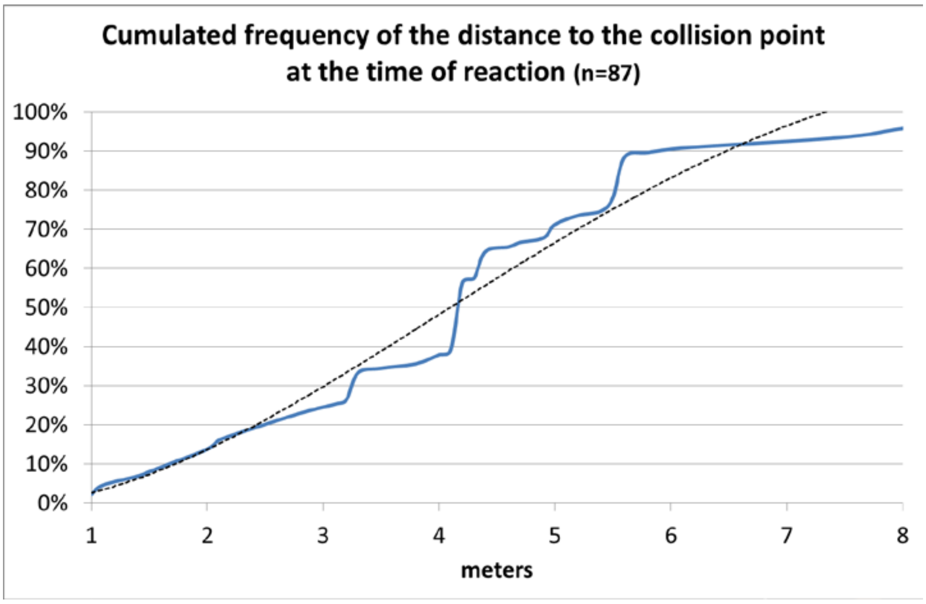

Fig. 7: Cumulated frequency of the distance from the point of reaction to the point of collision for 87 cyclists who had collided with an opening vehicle door (trend curve as dotted line).

Accident causes

The causes of the accidents are described by using the methodology of the Accident Causation Analysis System developed by Hannover Medical School [4]. The identification of the accident causes is done by means of a structured interview of the accident participants or witnesses on scene or at hospital. If no interview is possible in some cases the information collected from police reports or expert opinion of the accidents researchers is the base for the causation coding.

ACAS collects accidents causation factors with a focus on the human causes, which are now identified and classified in 5 categories instead of seven.

The 5 categories of human factors are:

- information access
- information admission
- information evaluation
- planning
- operation

Except for the first category (information access) the following four categories refer to a chronological sequence of human basic functions, which were active during the pre-crash phase in the situation of the accident emergence and in which failures of the road user were identified and thus contributed to the causation. It has to be noted that, if relevant, multiple causation factors can be assigned to one accident participant. In addition accident participants who are not the main cause of the accident may also have been assigned causation factors. This was the case for 10 cyclists. In total a subsample of 57 cases of the 225 cases are available with ACAS codes, as this information is only available from the cases of the Hanover accident research unit and only for cases from 2008 or later.

Causation factors of vehicle occupants

Out of all the accident participants who opened the door there were 58 causation factors identified, which were all human factors. Fig. 7 displays the distribution of the human factors of to the 5 categories of human causes.

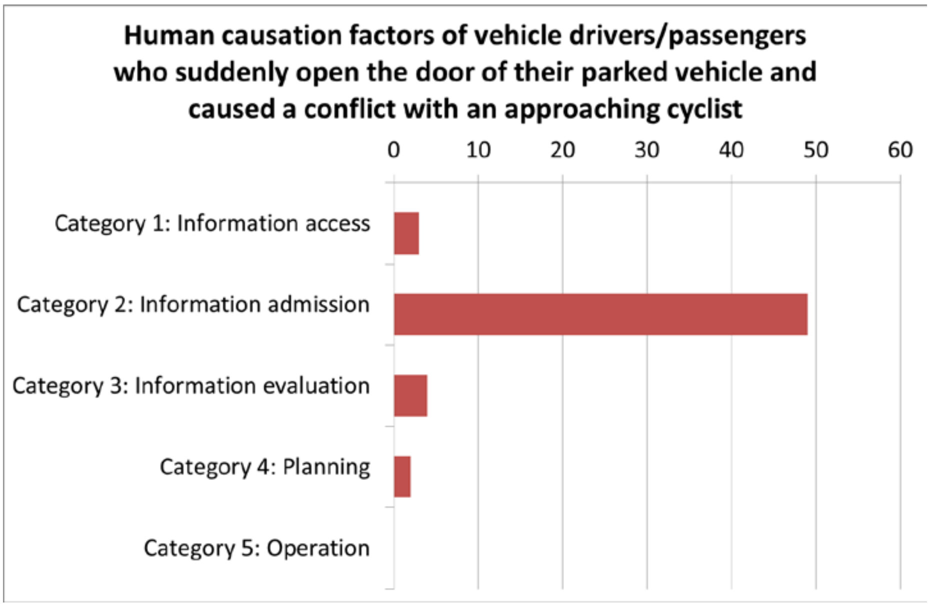

Fig. 8: Human failure categories of vehicle drivers or passengers who suddenly opened the door of their parked vehicle and caused a conflict with an approaching cyclist.

In the majority of cases the vehicle driver or the passenger in the car would have been able to see the approaching cyclist as in only 3 cases there were difficulties with the information access (category 1) due to darkness, heavy rain or strong sun. The majority of human failures were recognized to be from the category of information admission (49 failures such as missed reassuring view). Four failures were found in the category of information evaluation (*wrong expectation concerning the behavior of other road users* in 2 cases and *misjudging the distance of the cyclist* in 2 cases). Two failures were planning errors (category 4) where the vehicle door was opened due to a wrong decision, knowing that a cyclist was approaching. None of the accidents were caused due to an operation error such as slipping off the door handle or opening the door wider than intended.

Causation factors of cyclists

In 9 cases the cyclist also contributed to the emergence of the accident where detailed causation information is available and was thus also given a causation factor. In all cases human failures were involved:

- In 2 cases the cyclist had the wrong focus of attention.
- In 2 cases the cyclist's expectation concerning the behavior of other road users was wrong and he passed the driver's door at close distance although having seen the car entering the parking space.
- In 4 cases the cyclist was thought to have passed too close to the vehicles in front.
- In 1 case the cyclist fell due to wrong braking maneuver (over braking) and falling off the bicycle as a result of the avoidance maneuver.

Consequently these accidents mainly happened because the vehicle occupants did not look towards the cyclist when opening the door. Visibility problems due to visual obstruction i.e., from bodywork or pillars of the vehicle were not found to be a major factor in these accidents.

IV. CONCLUSIONS

Accidents where cyclists are in conflict with an opening vehicle door occur in about 3% of all bicycle accidents and are therefore relatively rare in the German accident situation. Even if there is no striking difference to all other accident events of cyclists in the general injury severity, fatal injuries do occur from these accidents.

This implies further action for preventing these accident situations. Using weighting factors the injury situation of the GIDAS cases of this type of accident can be projected to the German accident situation. 3.7% of minor injuries in cyclists, 2.2% of the severely injured cyclists (24h in hospital) and 6.4% of the killed cyclists are caused by accidents based on a conflict with an opening vehicle door. In the year 2013 in Germany 354 cyclists were killed, 13,204 cyclists were severely injured and 57,775 cyclists were slightly injured [5]. According to the results of this study, this type of accident accounts for over 20 killed cyclists, 290 severely injured cyclists and over 2,000 slightly injured cyclists when using the GIDAS cases from the last 15 years as a basis for the calculation.

The analysis of these accidents revealed that the distribution of the injuries on the body parts of cyclists in an accident with an opening door is very much the same as the distribution of the injuries on all cyclists. Serious injuries however are especially found to the head and the legs. Even though most injuries are sustained by the secondary collision of the cyclist with the road surface, there seems to be a potential to decrease the amount of serious injuries by eliminating sharp edges of the vehicle doors. Most accidents result in a collision between the cyclist and the open door compared to accidents where the cyclist falls due to an evasive maneuver.

The accidents mainly happen because the vehicle occupants are not making sure that the road is clear before opening the door. Visibility problems due to visual obstruction i.e., from bodywork or pillars of the vehicle were not found to be a major factor in these accidents. Thus to avoid these accidents it is sensible to warn the vehicle occupants about approaching cyclists. With a technical system, which can identify cyclists laterally behind the vehicle this kind of accident could be avoided. The study reveals that about half of the approaching cyclists could have been detected according to the reconstruction of the accidents at a distance of about 4 m behind the vehicle. If the detection range is extended to about 6 m some 90% of the approaching cyclists could be detected in time to warn vehicle occupants not to open the vehicles door. At a distance of 11 m or more the majority of cyclists (90%) would have the possibility to stop before a collision at an assumed traveling speed of 20 km/h.

Consequently an assistance system which informs the driver of the vehicle and all passengers about the danger of an approaching cyclist has the potential to significantly reduce accidents based on a conflict with an opening car door. Such system could also be used for any other type of road user i.e., motorcyclists coming from the same direction. Similar assistance systems such as blind spot detection systems are found in cars already and would have to be adapted to detect approaching vehicles when the car is parked. To avoid opening the door an acoustic signal could warn the occupants and temporarily lock the specific vehicle door and as such avoid opening the door. Another system implemented on the part of the cyclist could also be used for avoidance of such accidents. The bicycle helmet has a great potential for the implementation of such driver assistance systems where the car communicates to the helmet of the cyclist that the car has recently parked and no doors had been opened yet. This information could be passed on the cyclist via acoustic warning from the helmet.

Apart from the cyclists (which were the topic of this study) the potential to decrease accidents of vulnerable road users is higher in reality because the conflict with an opening vehicle door applies also to riders of powered two wheelers which pass parked cars. Due to the higher traveling speeds however an assistance system would have to be adapted to scan larger distances behind the vehicle.

V. Acknowledgement

For the present study, accident data from German In-Depth Accident Study (GIDAS) was used. GIDAS, the largest in-depth accident study in Germany, is funded by the Federal Highway Research Institute (BASt) and the German Research Association for Automotive Technology (FAT), a department of the German Association of the Automotive Industry (VDA). Use of the data is restricted to the participants of the project. Further information can be found at http://www.gidas.org.

VI. References

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