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Turning accidents between cars and trucks and cyclists driving straight ahead

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Abstract

Two projects contain the conflict between turning vehicles and straight ahead driving cyclists. One out of four of all accidents in Germany are accidents with bicycles. In Addition, most of the accidents end with heavy or deathly personal injury. Especially accidents with right turning trucks and straight ahead driving cyclist are on one hand rarely but on the other hand very dangerous because of gravity results of an accident. Finally one of the main problems is the conflict during the driving by green traffic light. Furthermore the obstructed view is a big problem for this accident constellation.

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Keywords: Accident analysis, cycling, turning accidents, infrastructure, behavior observation, blind spot; traffic safety

1. Introduction

In 2014 nearly 27% of all accidents with personal damage in German built-up areas are accidents with cyclists involved as reported in Statistisches Bundesamt (2015). Most of these accidents led to severe injuries or fatalities. Turning accidents make around 20% of all cyclist involved accidents and are the second leading accident cause after turn into or crossing accidents. These results are covered by several studies conducted to similar topics, e.g. Alrutz et al. (2009), Angenendt et al. (2005), Schnüll et al. (1992).

The right of way is regulated by law as turning cars have to give way to straight on driving cyclists. Nevertheless, the most frequently accident cause is "making mistakes while turning". An accident analysis and a behavior analysis

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should detect reasons for such mistakes. Related deficiencies could be on infrastructure-side, on on-board-side or on behavior-side.

These deficiencies and accident causes were analyzed by two separate research projects. In one project, financed by the German Insurers Accident Research (UDV) as part of the German Insurance Association (GDV), research has been conducted on conflicts between left and right turning vehicles and cyclists driving straight on. The other project, financed by the Federal Highway Research Institute (BASt), focused mainly on the special conflict between right turning trucks and cyclists driving straight ahead.

2. Methodology

Both projects started with an overview of the current state of science. Subsequently suitable German cities were researched and selected. Therefore, provided accident data and local observations were used to define infrastructure attributes (Figure 1).

On one hand the German cities Darmstadt, Erfurt, Magdeburg and Muenster were selected and data between the years 2007 and 2009 was used for further analysis. Personal and telephone interviews and a behavior observation were part of the project after an accidents analysis. On the other hand, the German cities Berlin, Darmstadt, Magdeburg und Muenster were selected and data ranging from the years 2006 to 2011 used for further research. After an accident analysis driving tests in a truck simulator were conducted to evaluate the gaze movement before and during the turning process. In addition to that driving tests with and without a turning assistant were included. The results should identify infrastructural, board and driver-side measures and recommendations to reduce these turning-conflicts.

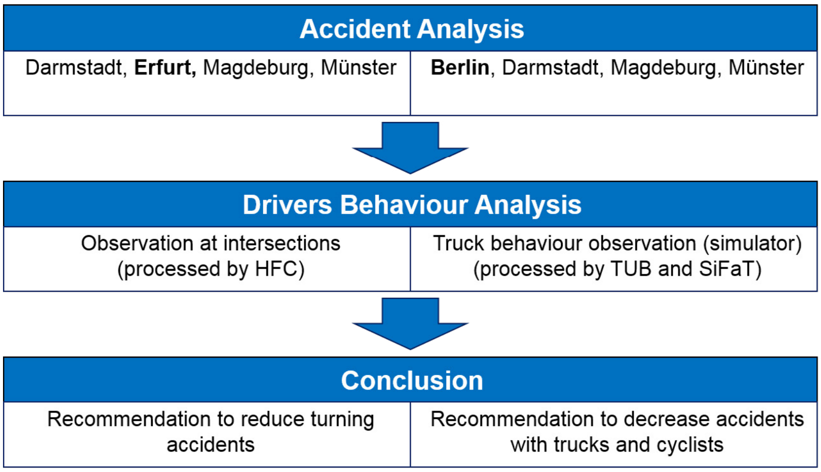

Figure 1: Methodology

To compare the different infrastructure characteristics and the circumstances of accidents a classification of intersection types is essential. These classifications are selected according to infrastructure features like availability of traffic lights, on- or off-road bicycle lanes and separation distance of bicycle lanes (Figure 2).

with traffic light	off-road cycle lane	with marked cycle crossing	separation distance up to 2m
			separation distance 2m to 4m
			separation distance more than 4m
	on-road cycle lane	with marked cycle crossing	
		without marked cycle crossing	
	mixed traffic (no bicycle lane)		
without traffic light	off-road cycle lane	with marked cycle crossing	separation distance up to 2m
			separation distance 2m to 4m
			separation distance more than 4m
	on-road cycle lane	with marked cycle crossing	
		without marked cycle crossing	
	mixed traffic (no bicycle lane)		

Figure 2: Classification of infrastructure characteristics

3. Literature review

According to the recommendations for bicycle infrastructure or the guidelines of signalization few measures to prevent these conflicts were stated so far. Possible measures include that for example the bicycle stop line is marked in front of the car stop line (FGSV 2010, a) and that cyclists receive green light before other vehicles (FGSV 2010, b). These measures lead to a better detection of waiting cyclists at intersections even though it reduces only those conflicts which occur at the beginning of a green phase or when traffic participants need to stop because of a red light. No benefits are shown during green phases when vehicles approach the intersection with continuous drive. The same results apply to fixed mirror systems like Trixi®-Mirrors (Figure 3). These mirrors are mounted on traffic poles and support especially truck drivers to gain a better view on cyclists.

Results from Schnüll et al. (1992) indicate that at intersections bicycle lanes routed directly next to the vehicle lane provide a higher safety level than those which are further separated. With increasing distance between the vehicle and the bicycle lane the accident severity increases too. It is important to note that the opposite results apply for left turning accidents. The severity is increasing with an increasing distance between the vehicle and the bicycle lane. In general, the recommendations of bicycle infrastructure (FGSV 2010, a) suggest a distance between the cycle and the vehicle lane at intersections not more than 0.5 meters. For the special constellation of conflicts with right turning trucks and straight on driving cyclists the extent of cycle crossing no specific recommendations can be given. Different evasion movements conducted by the cyclist lead to contrary safety measures as described by Niewöhner and Berg (2004). In case the cyclist approaches the truck within a sharp angle the probability is higher that if a collision occurs the cyclist is falling down away from the truck. Additional mirrors can help preventing such collisions. In opposite if the approaching angle is wider a collision might cause less severe damage but the probability that the cyclist is falling down towards the truck increases. In such cases a direct view through the vehicle windows provides a higher chance to detect cyclists than additionally mounted mirrors. The size of the direct field of vision depends on several factors such as vehicle characteristics, tallness of the truck driver and tallness of the cyclist. An advantage by a minor extent of cycle crossing is a taper angel of collision.

Figure 2: Trixi®-Mirror at an intersection in Darmstadt

Source: Technical University Berlin

The establishment of the various mirror systems in the European Union has been processed in the past. Due to these results trucks have to implement in addition to the main outside mirrors a wide-angle-mirror, a near-area-mirror and a front mirror to minimize the blind spot area.

Niewöhner and Berg (2004) extracted two main scenarios for the accident collective of right turning trucks, straight driving cyclists and pedestrians and truck drivers stopping traffic-related before the turn. As soon as the traffic continuous to run, the truck moves and starts the right turn while a cyclist is approaching undetected due to the blind spot. In the other scenario the truck driver and the cyclist both need to stop at a red traffic light. After switching to the green light both continue their ride.

4. Accident analysis

Due to various data bases and observation periods the accident analysis for each project was conducted separately, according to the bending process and to the involved people. Starting with the general evaluation of turning maneuvers and followed by the specific analysis of the right turning trucks.

4.1. Right and left turning accidents

The first research project covers the four German cities Darmstadt, Erfurt, Magdeburg and Muenster with data from 2007 to 2009. In total 79,756 accidents are listed where only a small proportion of 1.1% (873) are accidents with turning vehicles. Nearly 80% (693) of these turning accidents led to personal damages (fatalities, seriously and slightly injury).

Overall 91% of these accidents are caused by automotive drivers. In detail up to 94,5% are caused by "mistakes during turning". For those cases where cyclists are partly to blame around 52% used the wrong way, 20% are caused by "another mistake" and 11% are caused ignoring traffic lights.

Male cyclists are more often included in an accident (60%) than female cyclists (40%). Concerning their driving performance there is no increased risk for male or female cyclists. The gender analysis of the vehicle drivers provides nearly the same results. 61% of the accidents involved male vehicle drivers and 39% females. Regarding their traffic volumes, the numbers for each gender compensate each other as female drivers share 35% driving kilometers causing 39% of the accidents. When it comes to analyzing the results by age cyclists between 21 and 34 years provide a two times higher risk than other age groups. Vehicle drivers have a two times higher risk of being involved in a turning accident between the age of 18-20 and 65-75+ year.

The analysis of the temporal distribution outlines hydrographs of days, weeks and years. Based on these most accidents happen during the cycle season from March to October. Furthermore, most accidents happen during the week. At weekends the amount of accidents decreases due to lower traffic volumes. In addition to that, most accidents happen between 6 am and 8 pm with the highest amount of accidents during the morning and afternoon rush hour. During the night and early morning hour fewer accidents occur. Variations between the different cities are nearly non-existing. Also the analysis concerning the light and weather conditions are negligible. Basically most accidents happen during daylight (81%) and on dry roadways (80%). Only few accidents happen during twilight and darkness or on wet and icy roadways.

Influence of infrastructure to the accidents

After analyzing 318 selected intersections it can be summarized that if there is no separate bicycle lane available banned driving on pavements increases by 36% at intersections with and 27% at junctions without traffic light. Furthermore, driving on pavements in the wrong direction by an average of 15% and even more if there is no separate bicycle lane available (64% at intersections with traffic lights and 33% at junctions without traffic lights).

Microscopic infrastructure analysis

In addition to the analysis of the accident data on-site inspections of 150 intersections were carried out to find more clues regarding accident causes. Therefore, characteristics like which kind of cycle facility, infrastructural guidance of the bicycle lane next to the road, condition and execution of the crossing, presence of traffic lights or occurrence of an obstructive view have been analyzed.

Generally said, one third are left turning accidents and two thirds are accidents with right turning vehicles. Furthermore, nearly three out of four accidents happened at intersections with traffic lights (n=150). As shown in Figure 4, most intersections signal two-phases, which means that cyclists and vehicle drivers receive green light at same time.

Slopes were detected in15% of the analyzed crossings and 6% provide a large radius. Both characteristics can lead to higher vehicle speed. Another 6% of the intersections were perceived as large and inconclusive. A further 3% of the junctions have shown outworn markings for the cycle crossing. In addition to the analyzed intersections with accidents, junctions without accidents have been reviewed. At these 17 equivalents none of those characteristics has been found.

At 41% of the intersections sight disabilities were identified. This obstructive view could be provoked because of parking vehicles, trees, bus stations etc. The obstructive view is higher with an increasing distance from the bicycle lane to the vehicle lane. When the bicycle lane is two to four meters besides the vehicle lane, 69% of intersections underlie obstructive vision. If the bicycle lane is more than four meters away, a sight disability of 61% is endogenous.

The proportion of accidents with right turning trucks covers less than 10% when the turning maneuvers between vehicles and bicycles are basic population. That means that nearly every 10th turning accidents between vehicles and cyclists happened with truck involvement and needs a special investigation.

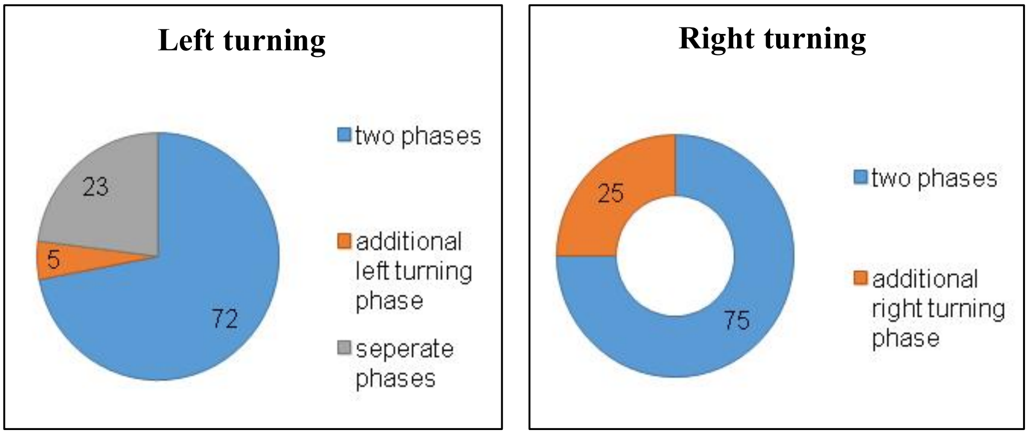

Figure 3: Number of phases at investigated intersections

4.2. Accidents with right turning truck

Accidents with right turning trucks and cyclists straight on driving do not interfere often (755 cases) but if conflicts happen they lead to sever damages (nearly 80% with personal injury). Fatalities make about 2% (16 cases) of those accidents, nearly 10% (74 cases) cause severe injuries and over 67% (508 cases) involve slightly injured persons. The remaining 20% are accidents with material damage.

As Figure 5 shows, most accidents happen with vans / delivery trucks / trucks without trailers. Just 8% of the turning accidents with trucks are accidents with heavy semitrailer trucks. Concerning the severity of such accidents, those with semitrailer trucks result in more serious damages than those with vans or delivery trucks. In about every 5th accident with severely injured persons and every 3rd accident with fatalities a semitrailer truck was involved (Figure 5, right).

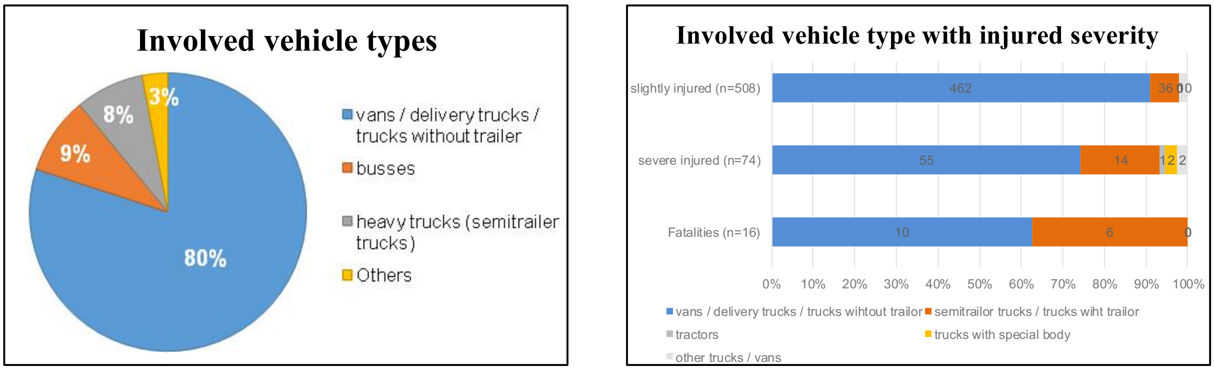

Figure 4: Involved vehicle types at accidents (left) and involved vehicle types with injury severity (right)

The main cause of 96% of these accidents are trucks where the most common reason was an incident turning maneuver. Cyclists make the main cause for only 3% of the accidents. Thereby the wrong usage of roadways is the most frequent reason to provoke an accident. Another 4.6% are caused because of driving in the opposite direction.

These data were deleted subsequently because driving in the opposite direction does not provoke typical blind spot problems relating to right turning trucks and cyclists driving straight ahead. Only 1% of accidents happened because cyclists violated a red traffic light.

The main problem seems to be the first scenario of Niewöhner and Berg (2004) (page 4) that none of the drivers previously came from a standing position. That means cyclists and vehicle drivers pass through the intersection without the need to stop. This could lead to scenarios were the cyclist is located in the blind spot of the truck and both vehicles approach the intersection with almost the same speed.
The scenario were both drivers have to stop traffic-related before they continue on is not a problem for this accident collective. Therefor the large amount of mirrors and the direct view through the windows seems to be very useful.

Male cyclists are more often included in accidents (61%) in Berlin than female cyclists (39%). Concerning their driving performance there is no increased risk for male or female cyclists. Male cyclists in the cities Darmstadt, Magdeburg and Muenster are less often included in an accident (48%) than female cyclists (52%). Concerning driving kilometers female cyclists even have an increased risk to be involved in a conflict (42% of the driving kilometers) than male cyclists (58%). The gender analysis of the truck drivers contains nearly the same results. Male truck drivers make 91% of the accidents while female drivers cover only 3% (another 6% are unable to attribute because of hit and run accidents). Based on the institute of employment market and occupational research, the division between male and female truck drivers in 2010 was 96% to 4%. There exists no additional differentiation regarding their driving kilometers. The age-related analysis results an increased risk for cyclists between 21 and 34 years and in Berlin ancillary the 35-44 years old cyclists. Vehicle drivers have a raised risk according to their driving kilometers in the age of 18-24 (nearly double the risk of other age groups) and 25-34 (around one third).

Microscopic infrastructure analysis

For the analysis, all intersections in the cities Darmstadt, Magdeburg and Muenster and a sample amount of 242 from 567 in Berlin were analyzed in detail. In total 43% of the 343 investigated intersections have an obstructive view through parking vehicles, bus stops or plants (nearly the same amount as mentioned in the analysis in chapter 4.1). Figure 6 shows an example of an obstructive view caused by trees and parking vehicles and the distribution of the characteristics. These sight disabilities can occur in addition to blind spots from trucks.

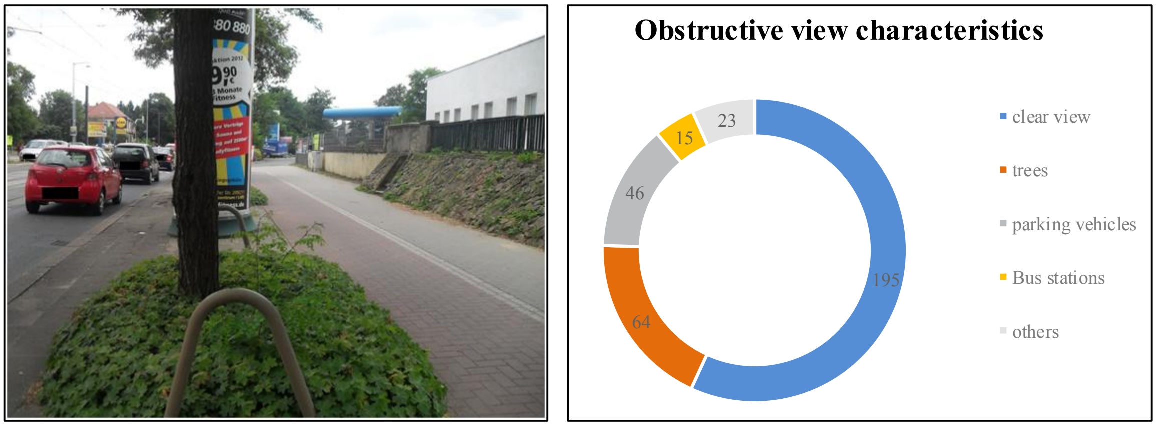

Figure 5: Obstructive view in Magdeburg(left) and distribution of the obstructive view characteristics (n=343) (right)

Source: Technical University Berlin

An additional detailed analysis at selected intersections has been conducted. Most junctions provide no infrastructure or operational deficits. There are rather random individual accidents at many different single intersections. Therefore, no black spots can be determined and no general recommendations can be given.

5. Drivers behavior analysis

Additional behavior analysis was conducted because of the extremely rare event of accidents. On one hand, the behavior and conflict between the turning vehicles and cyclists driving straight ahead and on the other hand, there were analyzed the behavior of truck drivers in a simulator with and without a simulated turn-off assistant.

5.1. Behavior and conflicts

Altogether 43 intersections were selected to be monitored via cameras. The selection procedure was based on the evaluated infrastructure characteristics. Every intersection was surveyed for 3 hours, either during the morning rush hour from 7 to 10 am or during the afternoon peak from 2 to 5 pm. Afterwards the videos were evaluated manually by estimating every single situation. Thereby interactions and conflicts were analyzed at intersections with and without (equivalent) accidents. Comparing this two attributes, at equivalent intersections a conflict involvement rate of 6.5% has been obtained (Table 1). At accident-prone junctions a higher conflict involvement rate of 10.7% has been determined. (Kolrep-Rometsch et al. 2013)

		equivalent	accident-prone
observated intersections		17	26
amount of interaction		118	590
amount of conflicts	total	8	63
	average	0.5	2.4
	standard deviation	0.8	2.5
conflict involvement rate		**6.8%**	**10.7%**

Table 1: Comparison of intersections with (accident-prone) and without (equivalent) accidents

Source: Kolrep-Rometsch et al. (2013)

Furthermore, several traffic behaviors such as indicate rate, speed reduction and shoulder check were captured for every occurrence independent from conflict or non-conflict situations. The indicate rate was in both cases high (98% in general and 96% in a conflict). Reducing the speed while turning happened more often overall (91%) than in a conflict (70%). The look over the right shoulder before turning right occurs less often in a conflict (67%) than in general (82%). (Kolrep-Rometsch et al. 2013)

The evaluation of the signalization phases provides more interesting results which can be seen in table 2. The most common situation is that both drivers start driving again after stopping at a red traffic light. However, the conflict rate case is the lowest (3.2%) for this case. On the contrary, the conflict rate is the highest (39.8%) if the vehicle driver starts driving after a red traffic light and the bicycle rider passes through without stopping. In addition to that, the conflict involvement rate is six times higher if the cars are turning in a convoy (38.8%) than a single vehicle turns right (6.1%). (Kolrep-Rometsch et al. 2013)

Concerning traffic regulations there exist different perceptions. On one hand most drivers know that cyclists driving straight on have priority and right turning vehicles have to give way (97.3%). On the other hand, the knowledge about the obligatory using of bicycle lanes is insufficient. Just 14% of the vehicle drivers and bicycle riders know that a bicycle lane is only mandatory to use once a traffic sign is mounted. If there is no road sign cyclists can choose between driving at the vehicle lane or on the separate bicycle lane. (Kolrep-Rometsch et al. 2013)

Vehicle driver	starting to drive after stopping at a *red traffic light*		pass through *without* stopping	
Bicycle rider	starting to drive after stopping at a *red traffic light*	pass through *without* stopping	starting to drive after stopping at a *red traffic light*	pass through *without* stopping
Conflict involvement rate	3.2%	29.8%	11.1%	10.4%
Total number of situation	250	84	9	202

Table 2: Conflict involvement rate concerning the signalisation phase

Source: Kolrep-Rometsch et al. (2013)

5.2. Behavior and turn-off assistant

As part of the driving simulator study routes have been implemented which are different regarding their infrastructure design. The driving and gaze behavior during the right turning of 48 study participants were analysed. In addition to that, the influence of a turn-off assistant was tested, which informed half of the drivers in turning situations by an audible and visual warning (Figure 7) when a cyclist was approaching. The other half of driving tests happened without any assistant system. Comparing the turning situations with and without simulated turn-off assistant, hardly any differences could be found in the driving parameters or gaze data.

Figure 6: Turn-off assistant in a simulator

Source: Technical University Berlin

Because of the coding and the different way of driving in some cases an interaction between right turning trucks and straight on driving cyclists could not be ensured. For example, if the speed of the truck driver is more or less than planned, the interaction did not happen because either the cyclist crossed already the intersection or the cyclist was located behind the truck driver. Another Problem was the minor number of evaluable trips because of simulator illness. (Richter et al. 2015)

The lowest speed was detected when cyclists do not have their own bicycle lane. Furthermore, the speed is lower if the distance between the bicycle and the vehicle lane is decreasing. Even the relative gaze frequency to the cyclist through the right window is increasing when the distance between the lanes is decreasing. Concerning the gaze behavior into the mirrors there were no abnormalities. None cycling infrastructure is suspicious to that token. (Richter et al. 2015)

6. Recommendations and measures for turning accidents

Based on the accident and drivers behavior analysis following recommendations for infrastructure design can be given which are partly already included in German guidelines. A rather small distance between the bicycle and the vehicle lane at intersections should be preferred because of the increasing obstructive view with increasing distance between vehicle lanes which is verified by both the microscopic analyses and the behavior analyses. In addition to that, intersections should be clearly, quickly recognizable and comprehensibly designed. The marking of bicycle crossings should be obvious and if required additionally marked red (e.g. high accident rate or high traffic intensity). Obstructions (e.g. parking vehicles, trees, advertising panels etc.) should be avoided. In general regulations which can lead to conflicts among traffic participants should be avoided. For example, vehicle drivers should not need to expect cyclist driving on the pavement and therefore additional traffic signs which grant cyclists the usage of the pavement should be avoided. A signalization providing separate phases for cyclists driving straight and right turning streams is recommended if the traffic volume of vehicles or cyclists is high or an obstructive view exists. Furthermore, when the speed of vehicles and cyclists is high because of a downhill road or a big radius, a separated signalization is suggested. This is a promising way to reduce accidents, even those who happened because of the continual drive. A signalization with separated phases is required if there exists more than one turning lane for vehicles (FGSV 2010, b). Therefore, it is necessary to implement the standards which are given in the guidelines. In most cases junctions display some compromises which can be responsible for accidents or conflicts.

It can be captured that the truck drivers already several mirroring systems which should be on one hand on the right position and on the other hand the gaze to the mirrors which helps in the right moment to detect a cyclist. Nevertheless, it needs to be considered that every additional mirror enlarges the field of indirect view but reduces the field of direct view. Furthermore, every further mirror claims an extra attention for the truck drivers. Therefore, a mandatory implementation of additional mirror systems on trucks should be avoided.

The fixed mirrors at intersections are only suitable for the special situation when the truck and the bicycle rider have to stop at a red traffic light. However, this represents a minor problem at the accident collective of right turning trucks and cyclist driving straight. Although the direct costs for a mirror are rather small, within the areal distribution of those accidents the cost would be very high. Nevertheless, at black spot intersections that measure could certainly contribute to reduce the number of accidents.

Moreover, an ancillary measure is the sensitization of all traffic participants because of the analyzed data that highlights the increasing risk of involving in an accident if the shoulder check is missing. In many cases the bicycle riders do not realize the danger and insist on their right of way, regardless of the problem that in some cases the car or truck driver cannot see the cyclists. Furthermore, a high attention should be paid to the danger of blind spots in driver trainings, especially for truck drivers. In addition to that, an enhanced awareness for cyclists should be trained even if they have the right of way. Further explanations for the obligatory usage of the bicycle lanes have to be suggested because of the questionnaire results. A considerate handling in traffic may affect higher safety.

As general result of all the parts of the study is can be said that risks increase when cyclists and vehicle drivers do not need to make traffic-related stops (red traffic light). Most accidents happen during continuous drive (without stopping) and also the conflict rate is much higher (Table 2) compared to situations including stops at the red traffic light. If the cyclists are covered in the blind spot area while driving, the truck driver has limited chances to detect the cyclist while turning which leads to dangerous situations on both sides. The measures included in the German guidelines are more or less for conflicts including intersection stops. In the future there is a strong need for measures preventing turning accidents for green light phases when right turning vehicles and cyclists going straight pass through the intersection without the need to stop traffic-related.

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