Development of a Test Procedure for Driver Assist Systems Addressing Accidents Between Right Turning Trucks and Straight Driving Cyclists

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ABSTRACT

Accidents between right turning trucks and straight riding cyclists often show massive consequences. Accident severity is much higher than in other accidents. The situation is critical especially due to the fact that, in spite of the six mirrors that are mandatory for ensuring a minimum field of sight for the truck drivers, cyclists in some situations cannot be seen or are not seen by the driver. Either the cyclist is overlooked or is in a blind spot area that results from the turning manoeuvre of the truck and its articulation if it is a truck trailer or truck semitrailer combination.
At present driver assistance systems are discussed that can support the driver in the turning situation by giving a warning when cyclists are riding parallel to the truck just before or in the turning manoeuvre. Such systems would generally bear a high potential to avoid accidents of right turning trucks and cyclists no matter if they ride on the road or on a parallel bicycle path. However, performance requirements for such turning assist systems or even test procedures do not exist yet. This paper describes the development of a testing method and requirements for turning assist systems for trucks.
The starting point of each development of test procedures is an analysis of accident data. A general study of accident figures determines the size of the problem. In-depth accident data is evaluated case by case in order to find out which are representative critical situations. These findings serve to determine characteristic parameters (e.g. boundary conditions, trajectories of truck and cyclist, speeds during the critical situation, impact points). Based on these parameters and technical feasibility by current sensor and actuator technology, representative test scenarios and pass/fail-criteria are defined.
The outcome of the study is an overview of the accident situation between right turning trucks and straight driving cyclists in Germany as well as a corresponding test procedure for driver assistance systems that at this first stage will be informing or warning the driver. This test procedure is meant to be the basis for an international discussion on introducing turning assist systems in vehicle regulations.

INTRODUCTION

The share of accidents at crossings and intersections between right turning trucks and cyclists that move straight is rather low with regard to other accident types. However these accidents are particularly severe if the cyclist is hit and as a consequence overrun. Such cases always cause high public awareness due to the appalling implications for the victim as well as for the involved truck driver so that countermeasures are searched for a long time.
Already in the year 2004 the German Federal Highway Research Institute (BASt) published a study on the risk for pedestrians and cyclists at crossings due to right turning trucks [DEKRA (2004)] which was carried out by DEKRA accident research on behalf of BASt. This report especially depicted the lacking fields of vision for the truck driver to the front and to the right side (for left hand traffic).
In the meantime improvements for the direct field of vision and for the indirect vision via mirrors have been implemented with the aim to reduce blind spots to a minimum. With the European directive 2003/97/EC a larger field of vision became mandatory so that a truck normally has to be equipped with six mirrors in order to cover the required areas of the field of view. In addition the European directive 2007/38/EC was entered into force. Trucks above 3.5 t with their first registration in the year 2000 or later had to be retrofitted with corresponding mirrors on the right side until end of March 2009.
The mirrors however are only able to serve as useful remedy in eliminating blind spots if they are adjusted correctly if the driver looks into the mirror and if he, depending on what he has detected, takes the appropriate action with regard to the following driving manoeuvre.
Another project on behalf of BASt [TU BERLIN (2014)] ("Blind spot – conflict between right turning truck and straight driving cyclist") considered, which issues in terms of the construction and operation of a junction are relevant if we look at blind spot accidents or road traffic safety. In addition it was examined in a simulator study if driver assistance systems could possibly contribute to alleviate the conflict in question. As main results, the regarded accidents were widely spread over built-up areas and both traffic participants (truck and cyclist) were mostly moving previous to the collision. Thus there was no standstill at the junction before the accident happened.
At present there is an ongoing discussion on turning assist systems, which warn the truck driver in the turning situation if a cyclist might be overlooked. Accident research of German insurers [HUMMEL et al. (2011)]

estimated ex-ante that a generic and best performing turning assist system (if the whole truck fleet is equipped) which scans the areas in front of and at the right side of the truck and which warns the driver or hinders the truck to move on would avoid about 40 % of the truck-pedestrian and truck-cyclist accidents.
However, there are no performance requirements for turning assist systems and on how they are supposed to operate yet. But the presence of such requirements would be a prerequisite for a possible promotion of systems and the basis for a possible mandatory installation by legislation.

Starting Point

Since there is no turning assist system on the market up to now it is on the one hand difficult to assess to which extent a system would be able to mitigate a certain critical turning situation and on the other hand to develop performance requirements which a system would have to fulfil. At least truck manufacturers revealed that systems are at stage of development.
The aim to avoid and mitigate the accidents with severe consequences between right turning trucks and cyclists is also pursued by the German Ministry of Transport and Digital Infrastructure (BMVI). How to tackle the problem of those blind spot accidents and if turning assist systems might help was also discussed with relevant stakeholders at round tables in April 2012 and May 2014 initiated by BMVI. It is planned to make a proposal for regulating a test procedure for turning assist systems on international level to introduce requirements in vehicle type approval regulations. For that purpose BASt was assigned by BMVI to develop a corresponding test procedure based on existing knowledge and taking in to account the state of the art technology, accident figures and circumstances of the accidents in question.
Thus BASt is actively developing a test method for turning assist systems for trucks since mid of the year 2014 addressing the following tasks:
At the beginning a thorough analysis of recorded accidents has to be carried out in order to identify the essential situations and accident constellations from which parameters for the test method have to be derived:

- Are vulnerable road users who become injured or killed by right turning trucks mostly cyclists or do pedestrians also have to be paid attention to?
- Is it allowed to restrict a testing procedure to daytime lighting conditions or do also accidents during night-time have to be taken into account?
- Initial speeds and collision speeds of cyclist and truck are of interest.
- How do cyclist and truck behave relatively with regard to their trajectory?
- Which typical turning radii are taken by trucks?
- What are typical lateral distances between truck and cyclist?
- Do obstructions for the view of the truck driver play any role?
- Should a testing procedure focus on trucks above 7.5 t or should lighter trucks be included as well?

The answers to these questions will deliver findings that allow to establish a few representative test cases for which boundary conditions, test parameters and criteria for pass/fail can be fixed.

ACCIDENT ANALYSIS

In 2010, 1,994 cyclists were killed in road accidents in the EU-24 countries, this represented 6.8 % of all road fatalities. For comparison: 381 cyclists were killed in road accidents in Germany in 2010 and 406 in 2012, which corresponds to 10.4 % (2010) and 11.3 % (2012) of all road fatalities, respectively [CANDAPPA N. et al. (2012)].

Road traffic accidents between heavy goods vehicles (HGVs over 3.5 tons maximum permissible gross vehicle weight) and cyclists resulted in 296 fatalities for 2010, as shown in Figure 1.

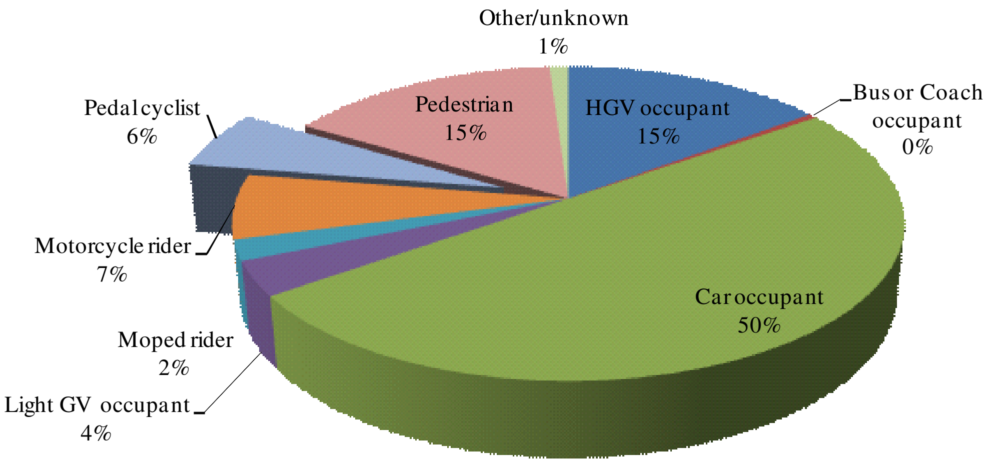


Figure 1: **Fatalities in accidents involving HGVs and in accidents involving buses or coaches, by road user type (Data: EU-24; 2010 (for EE, NI, NL and SE from 2009); Source: CARE Database/EC)**

It is not possible to identify the exact number and severity of this accident situation in the German national road accident statistics because the conflict situation "blind spot" is not explicitly quantified. Therefore, an extrapolation [SCHRECK & PÖPPEL-DECKER (2014)] for the year 2012 was carried out to regarding the relevance of the conflict situation. The extrapolation shows that around 640 injury accidents resulting in 23 fatalities and another 118 seriously injured cyclists are due to the accident situation between right-turning trucks and driving straight cyclists. In the same configuration, the number of injured, severely injured and killed pedestrians is a magnitude lower (55 injured, 16 sesiously injured, 4 fatalities), so pedestrians will be neglected for the following considerations.

Thus, accidents involving right turning trucks represent 1 % of all bicycle accidents, and about 6 % of cyclists killed. It became clear that the "light" trucks, as defined as vehicles weighing less than 7.5 tones permissible gross weight, only slightly contribute to the serious accidents. In 549 collisions with "light" trucks, one cyclist was killed. 90 % of the accidents with killed cyclists in "blind spot" situations are accidents with "heavy" trucks (more than 7.5 tones permissible gross weight). So, in every 10 injury accidents between a "heavy" truck and a cyclist in a "blind spot" situation on average about one cyclist is killed. That shows the accident severity in terms of seriously or fatally injured cyclists that are involved are much higher than in accidents of other traffic participants in other accident situations.

Within the research project this paper is based on ([SCHRECK & SEINIGER (2014)]), accidents are analyzed in detail. The study uses police-reported accident data from the German Federal Statistical Office. Furthermore the German In-Depth Accident Study (GIDAS) and the German Insurers accident database (database UDV) was used. For the detailed analysis of accidents in GIDAS and in the database UDV, 120 accidents were available.

Accident databases GIDAS and UDV allowed for the detailed analysis of the speeds of the truck and bicycle, the driving behavior of the truck before and during the collision, the driving characteristics of the truck before the collision with respect to the infrastructure and the type of junction. The point of collision of the cyclist hitting the truck and potential visual obstructions in the infrastructure were available as well. Figure 2 shows as an example for the evaluation of accident data the difference in speed between trucks and cyclists, absolute speeds as well as relative speeds.

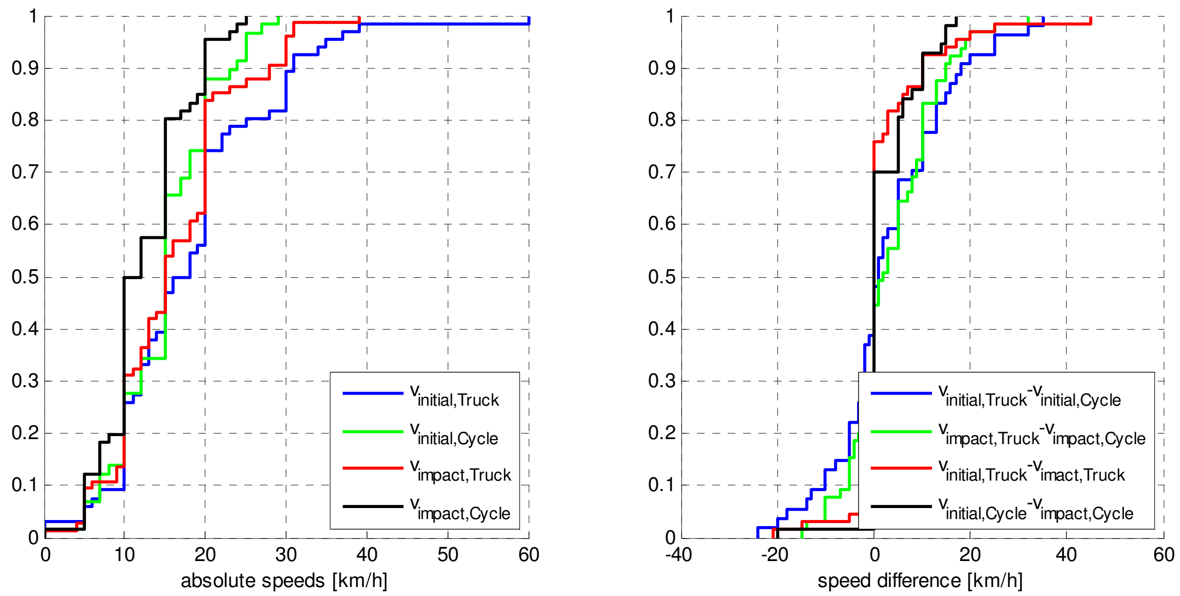


Figure 2: **Speeds and speed difference [km/h] between trucks and cyclists [SCHRECK & SEINIGER (2014)]**

Main findings from the accident analysis are:

- Truck speeds are below 30 km/h in more than 90% of all cases (as shown in Figure 2)
- Bicycle speeds are below 20 km/h in more than 80% of all cases (as shown in Figure 2)
- Bicycle and truck did not change their speeds during the accident in about two thirds of all cases.
- Visual obstruction and / or bad visibility due to weather (night, rain etc.) was not found to be an important factor.

With these results, it was possible to classify the accidents roughly into four scenarios. Figure 3 shows a sketch of this classification of the information collected, with the speed and track behavior of the truck and the lateral distance between truck and cyclist.

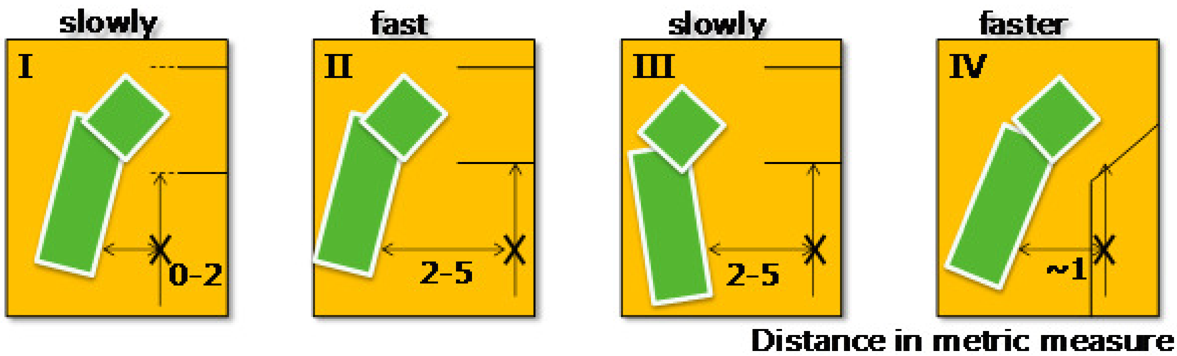


Figure 3: **Accident scenarios [SCHRECK & SEINIGER (2014)]**

DEDUCTION OF TEST CASES

The benefits of a turning assistance system for trucks based on the accident increases with increasing overlap between the standards set by the requirements of the test method for the system and the conditions in the accident situations.

Once a parameter space for typical accidents between trucks and cyclists is outlined, the greatest possible coverage of this parameter space by as few as possible test cases needs to be achieved.

Due to the missing experience with a turning assistance, the use of emergency braking for safety reasons (possible false activations) is initially not advisable. High-intensity information (warnings) are in the course of a driving situation only justified if the probability for an accident is high - otherwise vehicle drivers tend to ignore or disable the system alerts.

In general, driver reactions to any information (high or low threshold / warning or information) can be expected only after a reaction time. This response time is much longer than the time required to avoid the accident in many situations - the accident cannot be avoided despite the warning.
A (low threshold) informational assistance system, however, can be activated sufficiently early, as it helps the driver rather than annoys him. Such an approach provides a useful solution if the information is made available to the driver in an appropriate manner. The identification of an appropriate transfer of information in terms of human machine interaction is not part of this work.
Since the information given by turning assistance systems needs to be reliable, effective recognition of the objects is required. Specifications for sensors, viewing angles, and detection times can be derived from this detection requirement.
The definition of relevant detection areas is done via a parametric kinematics model of the truck and bicycle trajectories during an accident, and taking into account the needed reaction times (of the driver) and stopping distances (of the truck). Test cases then are defined in such a manner that the whole detection area around the truck is covered by as little as possible test cases.
An accident between truck and bicycle happens when the collision partners are at a time in the same place, so the trajectories of bicycle and any give point of the truck intersect in space and time. In first approximation, the bicycle motion can be described by a straight line. The movement of the truck is divided into two basic movements: first, it is a straight line as well, parallel to bicycle movement line, which at a certain time changes towards a turn. The turn is considered to have a constant radius for reasons of simplicity. Both trajectories intersect at the theoretical collision. Accident analyses show that obstructions of sight, night and bad weather are not an essential factor for these accidents.
The following parameters have been derived from accidentology:

- Driving speed truck: v_{Truck} = 10, 20, 30 km / h
- Driving speed bike: v_{Cycle} ranges from 10 to 20 km / h
- Lateral distance of the initial trajectories (with respect to the right edge of the truck): A = 1.5 to 4.5 m
- Truck turning radius R = 5, 10, 25 m
- Maximum lateral acceleration of the truck: $a_y < 3{,}2$ m/s²
- Impact location of the bike onto the truck: L = 0 to 6 m
- Required reaction time after driver information: 1,4 s
- Braking performance of driver after reaction time: 6 m/s²

A sketch of the situation is shown in *Figure 4*.

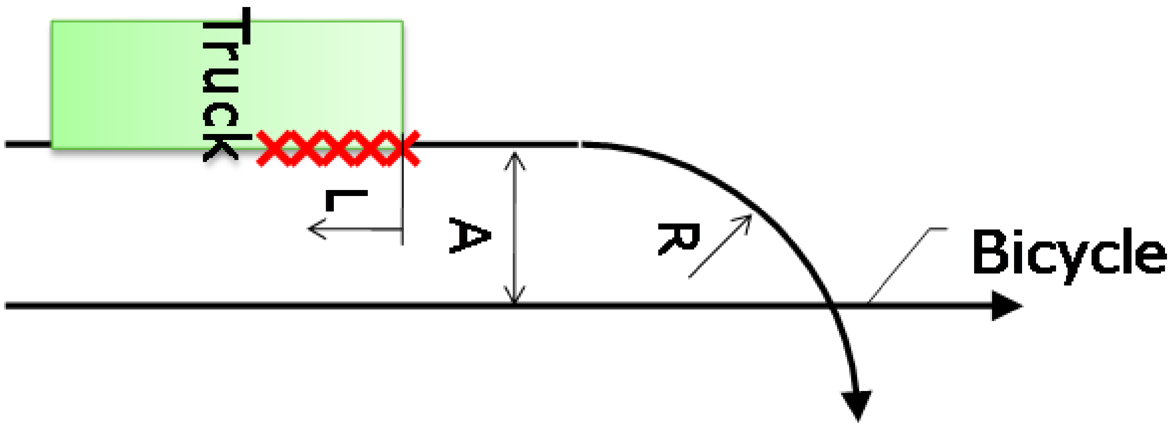
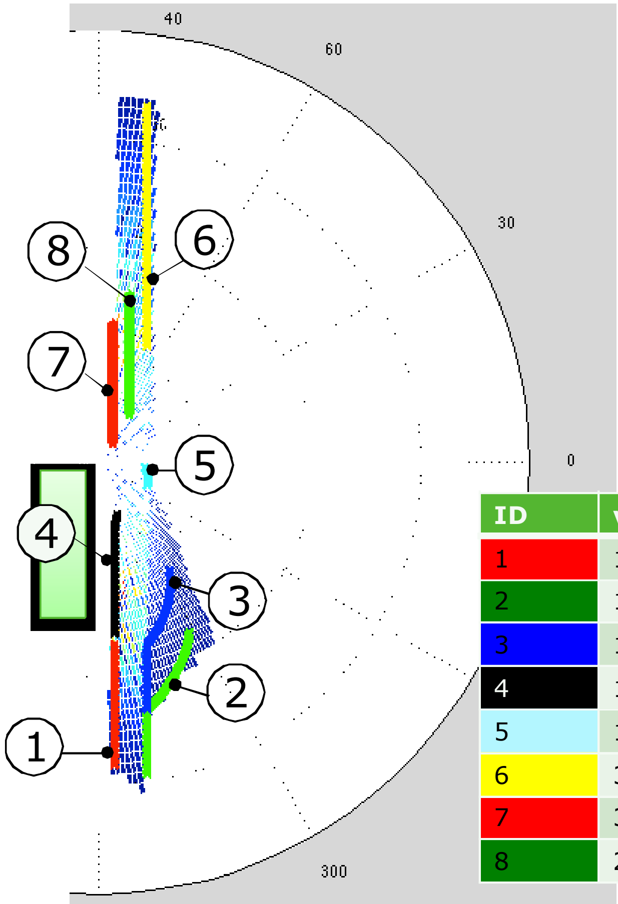


Figure 4. **Sketch summarizing the relevant parameters describing the accident situation.**

The necessary viewing area of a sensor is the hull around all bicycle trajectories relative to the front inner corner of the truck. All bicycle trajectories are determined assuming a full combination of all parameters, until the time when warning or information is still feasible, and starting with for instance 4 s time to go for both vehicles up to the theoretical collision.



ID	v_{Truck}	v_{Cycle}	R	A	L
1	10	20	5	1,5	6
2	10	20	10	4,5	6
3	10	20	10	4,5	3
4	10	20	10	1,5	0
5	10	10	5	4,5	0
6	30	10	25	4,5	0
7	30	20	25	1,5	6
8	20	10	10	3	0

Figure 5. **Bicycle trajectories relative to the front inner corner of the truck (=center of polar diagram), and proposed test cases (ID = 1 to 8). Field size in the polar diagram is 1m and 1°.**

The required viewing area as well as appropriate test cases to check bicycle detection in the viewing area are shown in Figure 5. Note that in theory a bicycle detection at the end of the nearer end of the trajectory satisfies the necessary detection criterion; it is not required to inform the driver already at the point where the bicycle is at the far end of the trajectory (which corresponds to 4 seconds TTC before the last possible information).

TESTING

Concept

Purpose of testing is to verify whether the system informs the driver, at least at the latest time at which avoidance is still possible, defined by the braking performance, driver reaction time and kinematics as laid out in the preceeding section.
This means that an object which sufficiently appears to any sensor technology as a cycle needs to be moved and synchronized to the truck according to the proposed test cases.
Since an information must be given at a time when the accident is still comfortably avoidable, all tests can be conducted without impacts, thus allowing for the use of a real bicycle (and possibly human dummy) rather than a specific bicycle dummy.

Test Tools and Equipment

For tests of pedestrian emergency braking in cars using the Euro NCAP test procedure, a propulsion system for the pedestrian dummy is used. This system can determine the speed of a vehicle over several light barriers and thus synchronize the movement of the dummy very closely with the moving vehicle, so the development of test tools does not need to start from scratch. Measurement equipment in the truck is not required. For cost reasons, it may be useful to establish a simplified test tool and not to use the said motion system - but for feasibility studies and the identification of the tolerable error in testing it is a suitable tool.
While the propulsion system is commercially available, testing with parallel trajectories requires a few modifications, which have been prototypically established at BASt.

The bicycle is guided by the motion system, therefore a review of the trajectory is not required. For checking the trajectory of the truck itself, an alley from pylons or "Botts' Dots" can be used to visually determine whether the vehicle had maintained the required trajectory.
Video recording and time synchronizing equipment might be required to check whether the information was given at an appropriate time.

Necessary Modifications to the Propulsion System

In a first step, the use of a pedestrian propulsion system, for instance "4active systems surfboard" (see Figure 6) could be used. This system is state of the art and will be used by several test labs for Euro NCAP AEB pedestrian testing (starting in 2016).

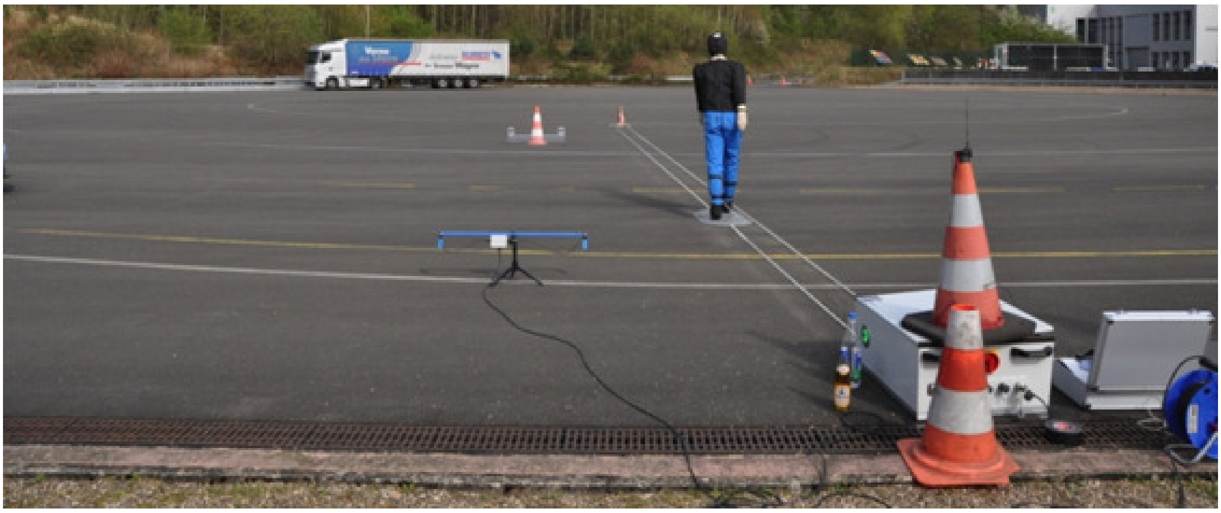


***Figure 6.* 4active systems "Surfboard" dummy propulsion system.**

This propulsion system has been designed to test with a crossing pedestrian. Magnets fit the pedestrian dummy to a platform. The platform is driven by a circular timing belt that of course requires bearings on both sides. When testing longitudinal scenarios (as is the case for the turning assistance systems), counter bearing or drive mechanism might disturb the vehicle's sensors, and since the belt is used in a circle, the available dummy displacement is not sufficient.
BASt therefore developed a method to use the propulsion system with a linear belt. This removes any bearing out of the sight of the vehicle sensors and doubles the effective belt length but also takes away lateral positional accuracy and requires manual transportation of the dummy to its' origin during testing.
A mechanism to fit a bicycle to the propulsion system also required and currently under development.

Test Track Requirements

As for all testing, a test track is required; it needs to be sufficiently large to fit all test cases. A typical test will consist of an acceleration phase for the truck (phase 1), a phase where the truck is moving alone at a stabilized speed (phase 2), and a phase where the bicycle movement is synchronized to the truck speed (phase 3). The space demand on the test track for phase 3 can be calculated from the kinematics of test cases as defined in *Figure 5*: the maximum space requirement is 44 m x 4.5 m excluding the size of the truck. The proposed tests therefore can be conducted even on small test tracks.

SUMMARY AND PERSPECTIVE

Turning maneuvers with collisions between trucks turning right and cyclists usually have serious consequences for the vulnerable road user. In the past the safety of vulnerable road users was raised by an improvement of the truck driver's vision by increasing the number of mirrors and by equipping trucks with side underrun protection. Since turning accidents still happen and driver assistance systems have been introduced in a lot of vehicle segments it seems to be obvious to use such assistance to address turning accidents between trucks and cyclists.
In order to stimulate system development, e. g. by means of incentives or legislation, performance requirements and corresponding test procedures are necessary. Aim of the work carried out by BASt therefore was to develop such requirements and a possible test method.
Starting from an in depth analysis of accidents, parameters and circumstances being characteristic in accidents with cyclists and right turning trucks were identified. Data at hand shows that the velocity is up to 30 km/h for the truck and up to 20 km/h for the bicycle. At the beginning of the critical situation the truck and the cyclist move parallel with a lateral distance of 1.5 m up to 4.5 m. Although there is no precise information about curve

radii it can be assumed that the inner side of the truck propagates predominantly on a radius between 5 m and 10 m since accidents occur in built-up areas. However, there can be junctions with triangular traffic islands where the radius is up to 25 m. Obstructions for the view of the truck driver were present only in a few cases. Also bad weather conditions or darkness hold only for a small fraction of accidents.
Considering driving dynamics in terms of reaction time and stopping distance for the given initial conditions leads to the conclusion that only an early and not annoying driver information can serve as effective function that assists the driver avoiding the accidents. For automatic braking being a massive intervention too less experience has been gained so far. Well known high priority warnings that are given at a late point in time would have no effect since the driver reaction time lasts that long that an emergency braking manoeuvre would start too late. So those variables and parameters that allow for comfortable braking can be used in a kinematic model to calculate the areas around the truck that have to be covered by a sensing system which has to detect cyclists in such a way that the driver is informed about the cyclist in time. Within the parameter range those special parameter combinations can be selected as test cases which cover the necessary sensing area with as less test cases as possible. A method to identify these test cases and the resulting test cases that are proposed for the test procedure were described in detail. A proposal how to effectively execute driving tests by using existing test tools coming from testing of automatic emergency braking systems to protect crossing pedestrians was described as well.
After having fixed the set of test cases and parameters a validation phase has to follow. For that purpose trucks equipped with turning assist system have to be used. It has to be examined if the system is able to inform the driver when necessary and how far it is still annoying due to possibly given false warnings.
It can be expected that a turning assist system that fulfils the requirements and tests elaborated in this study will have a very positive influence on accident figures concerning right turning trucks and cyclists.

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