A Draft Regulation for Driver Assist Systems addressing Truck-Cyclist Blind Spot Accidents

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ABSTRACT

Accidents between right turning trucks and straight driving cyclists often show massive consequences. Accident severity in terms of seriously or fatally injured cyclists that are involved is much higher than in accidents of other traffic participants in other situations. It seems clear that adding additional mirrors will very likely not improve the situation. At ESV 2015, a methodology to derive test procedures and first test cases as well as requirements for a driver assist system to address blind spot accidents has been presented.
However, it was unclear if and how testing of these cases is feasible, to what extent characteristics of different truck concepts (e.g. articulated vehicles, rigid vehicles) influence the test conduction and outcome, and what tolerances should be selected for the different variables. This work is important for the acceptance of a draft regulation in the UN working group on general safety.
In the meantime, three test series using a single tractor vehicle, a tractor-semitrailer combination and a rigid vehicle have been conducted. The test tools (e.g. surrogate devices) have been refined. A fully crashable, commercially available bicycle dummy has been tested. If used correct, this dummy does follow a straight line quite precisely and it does not cause any damage to the truck under test in case of accidental impact. The dummy specifications are freely available.
During testing, the different vehicle categories resulted in different trajectories being driven. Articulated vehicle combinations did first execute a turn into the opposite direction, and on the other hand, single tractor vehicles did behave comparable to passenger cars. A possible solution to take these behaviors into account is to require the vehicles to drive through a corridor that is narrow for a precise straight-driving phase and extends during the turn.
Other investigated parameters are the dummy and vehicle speed tolerances.

The results from this research make it possible to draft a regulation for a driver assistance system that helps to avoid blind spot accidents: test cases have been refined, their feasibility has been checked, and corridors for the vehicles and for important parameters (e.g. test speeds) have been set.
The test procedure is applicable to all types of heavy goods vehicles. In combination with the accidentology (ESV 2015 paper), the work provides the basis for a regulation for such an assistance system.

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 required.

Advanced driver assistance systems (ADAS) are state of the art for current passenger cars. These systems can already interpret traffic situations and appropriately warn the driver or even intervene, for instance by activating brakes or steering.

Several aftermarket solutions with differing characteristics have been on the market for quite some time, but by the time of writing, only one truck manufacturer offers a turning assistance system for its own vehicles. Almost all other important truck manufacturers and tier-one suppliers are either developing systems or have been showing demonstrators in the last years.

The system characteristics (including sensors and ranges) and information-warning-intervention (IWI) concepts differ heavily between these different systems. The following Table 1 gives an overview.

The technology overview shows that there are no common information-warning-intervention concepts or system characteristics, yet all those systems are available as driver assistance systems for right-turning trucks. From a traffic safety point of view, it would be essential to set minimum requirements for those systems in order to address the majority of accidents.

To support this, Germany has committed itself to draft an international regulation on UN ECE level for advanced driver assistance systems for right-turning trucks that especially target blind-spot accidents. This draft regulation sets requirements for these systems and can be the basis for making turning assistance systems mandatory, should lawmakers choose to do so.

Activities concerning fundamental research on typical accident configurations, trajectories and speed relations between truck and cyclist were presented at ESV 2015 (see paper 15-0286 [1]), but since then, the status has progressed: Test procedures have been developed, verified with driving tests, presented to the United Nations, and finally a proposal for the international regulation has been submitted.

This paper will give a short summary about the previous results, describe the draft regulation that BASt has developed on behalf of the Federal Ministry of Transport and show the results from validation tests.

Details on general requirements, accidentology and derivation of the use cases can be found in the previous paper.

PREVIOUS WORK

Accidentology

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

Table 1: Overview of driver assistance systems for right-turning trucks

System (Year)	Technical Maturity	Sensor concept	IWI concept
MAN MoTiV (2000) [2]	Demonstrator, discontinued	LASER scanner, region unknown	Unknown
Mercedes Benz Blind-Spot Assist (2016) [3]	Announced for production	RADAR, viewing region from rear of articulated truck up to 2 m in front	Information, Warning, not coupled to turn signal activation
Volvo Intersafe-2 (2011) [4]	Demonstrator	Sensor fusion of 5 LASER scanner, several ultrasonic sensors, mono camera, covering the side of the truck up to 15 m in front	Information, Warning, (coupling to turn signal unknown)
Fuel Defend Side-Warn (2014) [5]	Aftermarket	4 ultrasonic sensors covering side of vehicle only	Warning, coupled to turn signal activation, up to 26 km/h
FusionProc CycleEye [6]	Aftermarket	RADAR and Camera	Warning/Information (unknown)
Safety Shield Systems CycleSafetyShield [7]	Aftermarket	Multiple Cameras covering side and front	Warning/Information (unknown)
Sentinel BikeHotspot [8]	Aftermarket	Ultrasonic sensors	Warning (internal and external) up to 16 km/h

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.

Assistance Concept

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 maneuver would start too late.

A (low threshold) informational assistance system, however, can be activated sufficiently early, even if this happens often, 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 - specifically at a time when the truck driver is still able to avoid crossing the bicycle trajectory by braking comfortably (e.g. with a reaction within 1.4 seconds to the warning and a brake deceleration of 5 m/s²).

It is also anticipated that various traffic situations might require an information given at a time when the truck has not shown any turn intention yet and is still driving straight ahead - especially when the bicyclist rides very close to the truck. These cases could happen relatively often and would - in case of a high-intensity warning system - generate far too much warnings and provoke a deactivation.

But even if the information is given at a low-annoyance-level, the system should exclude at least static objects - otherwise an urban area would effectively generate information events all the time.

Derivation of test cases

The variables and parameters that allow for comfortable braking as well as the accident parameters (e.g. speeds, distances etc.) 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 set of cases has been derived, as shown in Figure 1, with the parameters as shown in Table 1.

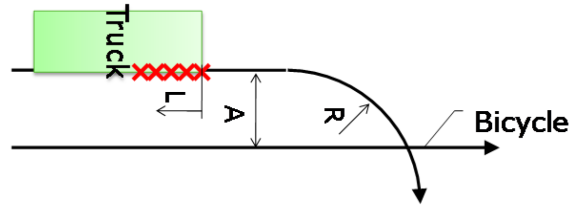

Figure 1: Sketch of test cases

Table 1: Test Cases

Test case No.	v_{Truck} [km/h]	v_{Cycle} [km/h]	R [m]	A [m]	L [m]
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	20	10	25	4,5	0
7	20	20	25	4,5	6

TEST PROCEDURE AND TOOLS

Purpose of testing is to verify whether the system informs the driver, at least at the latest time at which avoidance is still possible (=Last Point of Information LPI), defined by the braking performance, driver reaction time and kinematics as laid out in the preceding 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 (true-positive tests). Additional false-positive tests are required to ensure the system does not inform the driver about static objects. This can be a simple check for non-activation, for instance with large cones or poles next to the truck.

For tests of pedestrian emergency braking in cars using the Euro NCAP test methodology [9], a propulsion system for the pedestrian dummy is used [10]. The dummy (in this case the bicycle) is pulled using a tooth belt. This system is commercially available and meanwhile also usable for testing with parallel trajectories. A fitting bicycle dummy, impactable up to 60 km/h, is in the process of being finalized [11]. For the first set of verification tests, the tools had not been upgraded by the manufacturer, so own modifications and a non-impactable dummy had to be used, see Figure 2.

Figure 2: Dummy

Figure 3: Dummy propulsion system

This system can determine the speed of a vehicle via Differential Global Positioning System (DGPS) and synchronize the movement of the dummy very closely with the moving vehicle. The synchronization is split into a continuously controlled phase, where the dummy speed is controlled to achieve a specific impact position, and a second constant speed phase where the dummy speed is maintained regardless of the truck's speed, and typically the phases change 2 seconds before the calculated impact. The necessary software modifications for an adaption to longitudinal blind spot scenarios have been successfully implemented.

While the use of driving robots in testing is possible for passenger car tests, it is not recommended for truck testing just yet, since the turn trajectory of trucks differs for different sizes and trailer types. A more realistic way to define the turn is to mark inner boundaries for the truck path with cones, see Figure 4.

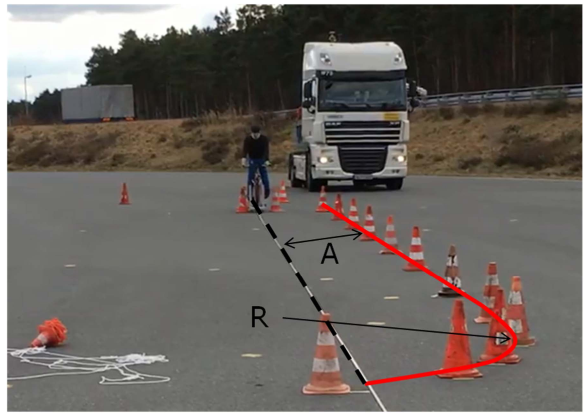

Figure 4: Test layout on test track

VERIFICATION TESTS

The purpose of the tests is to simulate a traffic situation where a collision between truck and bicyclist will occur if both accident partners would continue their movement, and to check whether the assistance system is able to classify a traffic situation correctly as critical and inform the driver at the appropriate times.

Test accuracy

Inaccuracies in speeds and trajectory following could lead to a situation where no accident would happen, for instance when the truck's speed is too low and the bicycle has passed the truck trajectory before the truck has arrived at the impact point. This situation would occur when the synchronization of movement does not function correctly. Anticipated issues in test conduction therefore are the precision of the truck's trajectory and speed during test conduction (since the truck is manually driven, not robot-controlled), as well as the functionality of the bicycle's synchronization and the accuracy of the bicycle speeds.

Figure 5 shows a plot for an exemplary test run of test case 6 (R = 25 m, truck at 20 km/h, bicycle at 10 km/h, large lateral separation of 4.5 m). Shown is bicycle (dotted line) and truck trajectory (desired: red, actual: black). A cross marks the last point of information on the truck trajectory lines, and the green circle shows the point where a prototype system would have initialed a warning. The star marks the truck's position when the bicycle motion starts.

Note that during the verification test runs, the bicycle dummy’s motion was initiated at a time-to-collision of 4 seconds, but the test results have shown that this is not sufficient for conduction of all test cases. A higher value of 8 seconds is proposed in the draft regulation document.

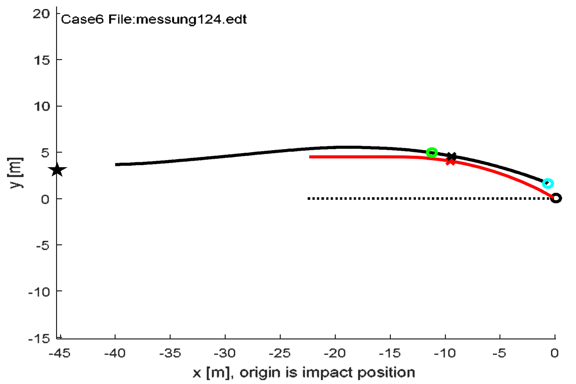

Figure 5: Trajectory (black) and desired trajectory (red) of front right vehicle corner, and trajectory of bicycle (dashed), example for test case 6. Crosses mark the last point of information.

The conducted verification tests show that path and speeds can in principle be maintained within reasonable tolerances: A speed tolerance of ± 2 km/h is easily achievable, see Figure 6.

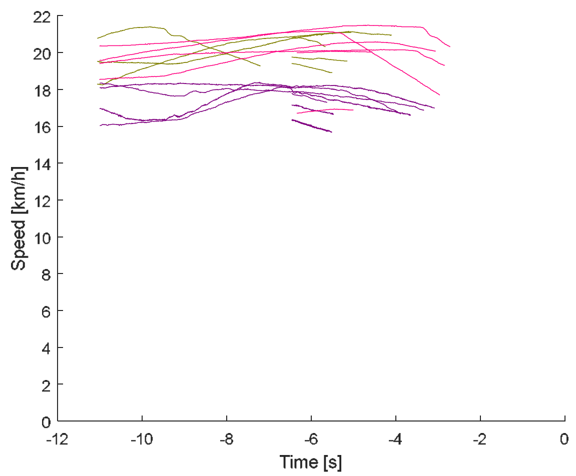

Figure 6: Achieved speed tolerances (example for 20 km/h truck speed)

For the vehicle trajectory, specified corridors should be maintained during the test runs. Besides the driver's ability to follow a defined trajectory, the vehicle configuration is an important factor: long, articulated vehicle combinations will be driven differently in bends than long or short rigid vehicles.
Figures 7 and 8 show this: The thin lines mark the trajectory of the front right corner of the truck; the ocre respectively violet areas mark the range covered by the body of the vehicle.
Short rigid vehicles will very likely follow the inner curb of the bend, see for instance measurement results in Figure 7, and articulated vehicle combinations might need to turn first to the opposite of the bend to move the trailer away from the inner curb, and then negotiate the bend with a much tighter radius, see Figure 8.
This behavior needs to be taken into account in the formulation of the upcoming regulation.

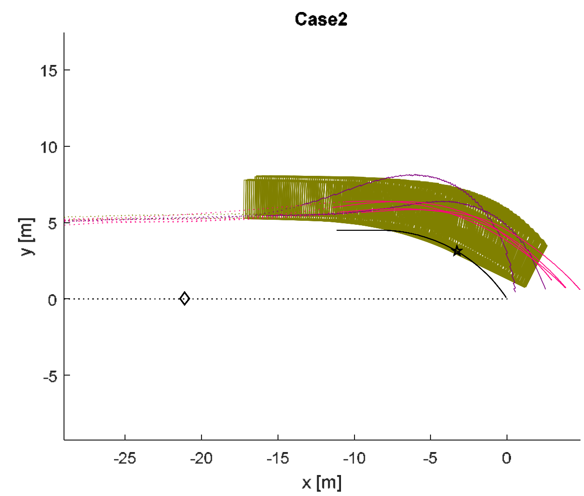

Figure 7: Trajectory of a short vehicle

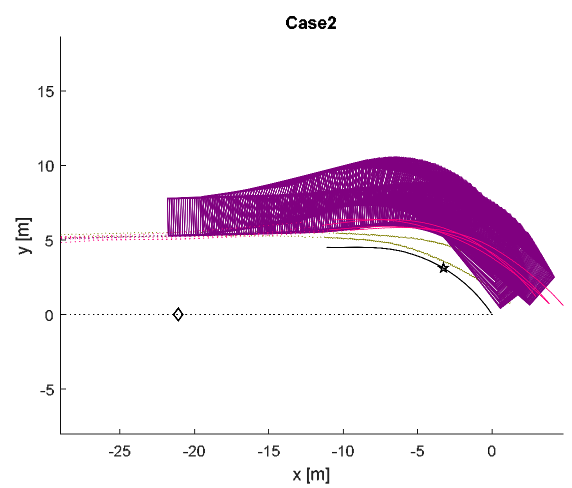

Figure 8: Trajectory of an articulated vehicle combination

REGULATION

This section of the paper is intended to give an overview over the concepts of the draft regulation as submitted to the UN GRSG for the April 2017 session. Changes to the initial text are expected during that session, but this naturally cannot be reflected in this text yet.

The test procedure contained within the draft regulation is following this concept:

- The proposed test procedure as defined in the draft regulation defines parametric corridors that the vehicle needs to follow with a speed tolerance of ± 2 km/h., see Figure 9 and Table 10.
- The synchronization of vehicle and dummy object is introduced by defining a longitudinal distance (including a tolerance of in total ± 1 m) between dummy and vehicle when the vehicle is at those specific points, plus a speed tolerance of ± 0.5 km/h for the dummy movement.
- Since turn signal use might not happen in accidents, the turn signals are explicitly not operated during the test runs.
- The pass or fail of the test will be determined by checking if the information signal was given before or after a virtual line crossing the test track.
- A simple check for false positives is done with a regular road sign and cone markings around the test corridor that should not lead to an information signal being given, if the truck performs the test without a bicycle.

Further details are presented in [12] and [13].

CONCLUSION

A set of test cases had previously been defined by calculating all bicycle positions relative to the truck and filling this necessary "sensor field of view" with as few as possible test cases, taking into account the accident characteristics derived from accidentology. The result is a suite of 7 different test cases.

For testing, commercially available test tools for passenger car automatic emergency braking (AEB) systems can be used. Verification tests for the test suite had been successfully carried out. Acceptable tolerances for the truck trajectory and truck speeds as well as tolerances for the dummy movement are defined, and a draft regulation had been submitted to GRSG for discussion at the April 2017 session.

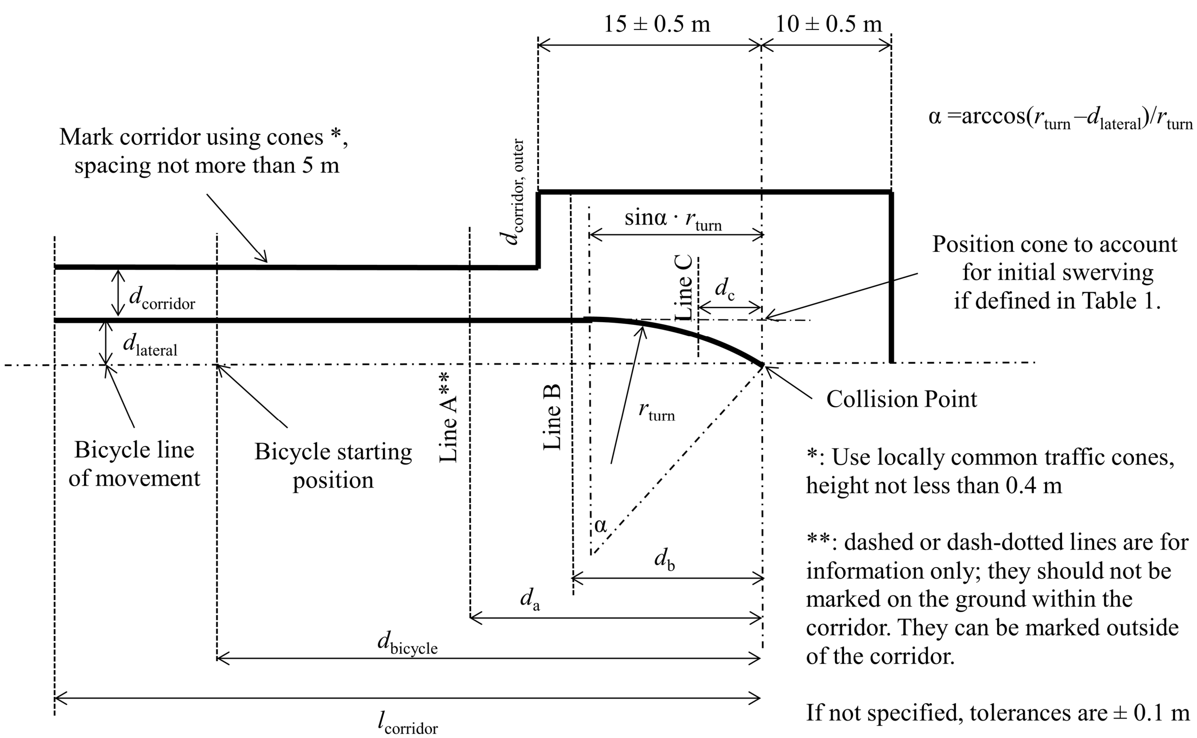

Figure 9: Test Layout

Table 10: Test configurations. Note that test cases marked with a * are comparable to tests without, but with a tighter corridor to provoke a different driving style. All kinds of vehicles are expected to perform all 12 test cases.

<table>
<tr><th>New Test Case</th><th>Orig. Test Case</th><th>r_{turn}</th><th>$v_{vehicle}$ [km/h]</th><th>$v_{Bicycle}$ [km/h]</th><th>$d_{lateral}$ [m]</th><th>d_a [m]</th><th>d_b [m]</th><th>d_c [m]</th><th>$d_{bicycle}$ [m]</th><th>$l_{corridor}$ [m]</th><th>$d_{corridor}$ [m]</th><th>$d_{corridor,outer}$ [m]</th><th>Include cone to account for initial swerving?</th></tr>
<tr><td>1</td><td>1</td><td>5</td><td>10</td><td>20</td><td rowspan="3">1.5</td><td rowspan="3">44.4</td><td>15.8</td><td>4.3</td><td rowspan="12">< 55</td><td rowspan="12">> 70</td><td rowspan="12">vehicle width + 1m</td><td>5</td><td>Yes</td></tr>
<tr><td>2</td><td>4</td><td>10</td><td>10</td><td>20</td><td>22</td><td>4.4</td><td>2</td><td>Yes</td></tr>
<tr><td>3</td><td>7</td><td>25</td><td>20</td><td>20</td><td>38.3</td><td>10.7</td><td>1</td><td>No</td></tr>
<tr><td>4</td><td>6</td><td>25</td><td>20</td><td>10</td><td rowspan="4">4.5</td><td rowspan="2">22.2</td><td>43.5</td><td>10</td><td>1</td><td>No</td></tr>
<tr><td>5</td><td>5</td><td>5</td><td>10</td><td>10</td><td>19.8</td><td>2.4</td><td>6</td><td>Yes</td></tr>
<tr><td>6</td><td>2</td><td rowspan="2">10</td><td rowspan="2">10</td><td rowspan="2">20</td><td rowspan="2">44.4</td><td>14.7</td><td rowspan="2">3.4</td><td>3</td><td>Yes</td></tr>
<tr><td>7</td><td>3</td><td>17.7</td><td>2</td><td>Yes</td></tr>
<tr><td>8</td><td>1*</td><td>5</td><td>10</td><td>20</td><td rowspan="2">1.5</td><td rowspan="2">44.4</td><td>15.8</td><td>4.3</td><td rowspan="5">1</td><td>No</td></tr>
<tr><td>9</td><td>4*</td><td>10</td><td>10</td><td>20</td><td>22</td><td>4.4</td><td>No</td></tr>
<tr><td>10</td><td>5*</td><td>5</td><td>10</td><td>10</td><td rowspan="3">4.5</td><td>22.2</td><td>19.8</td><td>2.4</td><td>No</td></tr>
<tr><td>11</td><td>2*</td><td>10</td><td>10</td><td>20</td><td rowspan="2">44.4</td><td>14.7</td><td rowspan="2">3.4</td><td>No</td></tr>
<tr><td>12</td><td>3*</td><td>10</td><td>10</td><td>20</td><td>17.7</td><td>No</td></tr>
</table>

Finally, 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. A draft of a regulation for a driver assistance system to avoid blind-spot accidents of right-turning trucks will be presented to UNECE afterwards as a first step on the road to make these systems mandatory.

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