

# **DRIVING TESTS for the APPROVAL of AUTOMATICALLY COMMANDED STEERING FUNCTIONS**

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## **ABSTRACT**

The UN Regulation No. 79 is going to be amended to allow automatically commanded steering functions (ACSF) at speeds above 10 km/h. Hence, requirements concerning the approval of automatically performed steering manoeuvres have to be set in order to allow safe use of automatic steering on public roads as well as improve overall road safety for the driver and the surroundings.

By order of the German Federal Ministry of Transport and Digital Infrastructure (BMVI), BAST developed and verified physical test procedures for automatic steering to be implemented in UN Regulation No. 79. The usability of currently available test tools was examined. The paper at hand describes these test procedures and presents results from verification tests.

The designated tests are divided in three sections: functionality tests, verifications for the transition of control and emergency tests. System functionality tests are automatic lane keeping, automatic lane change and an automatic abort of an initiated lane change due to traffic. Those tests check if the vehicle remains in its lane (under normal operating conditions), is able to perform safe automatic lane change manoeuvres and if it considers other road users during its manoeuvres. Transition tests examine the vehicle's behaviour when the driver fails to monitor the system and in situations when the system has to hand over the steering control back to the driver. For instance these tests provoke driver-in-the-loop requests by approaching system boundary limitations, like missing lane markings, surpassing maximum lateral acceleration in a bend or even a major system failure. Even further the driver and his inputs are monitored and if the system detects that he is overriding system actions or contrary want to quit the driving task and unfastens the seat belt, it has to shut down and put the human back into manually control and the responsibility of driving. The last series of test consists of two emergency situations in which the system has to react to a time critical event: A hard decelerating vehicle and a stationary vehicle in front both with no lane change possibility for the ACSF vehicle.

Some of the tests, especially the emergency manoeuvres, require special target vehicles and propulsion systems. Since no fully automatic steering vehicles are available, a current Mercedes E-Class with Mercedes' 'drive pilot' system was used. It was shown that the vehicle is automatically able to brake to a full stop towards a static Euro NCAP target from partial-automatic driving at 90 km/h, that it could brake towards a rapidly decelerating lead vehicle when travelling at 70 km/h, that it was able during partially automatic driving to remain in its lane in normal operation conditions and to perform a automatic (driver initiated) lane change while surveilling the driver's activities.

## INTRODUCTION

Except for corrective steering functions, automatic steering is currently only allowed at speeds up to 10 km/h according to UN Regulation No. 79. Progress in automotive engineering with regard to driver assistance systems and automation of driving tasks is that far that it would be technically feasible to implement automatically commanded steering functions also at higher vehicle speeds. Besides improvements in terms of comfort, these automated systems are expected to contribute to road traffic safety as well. However, this safety potential will only be exploited if automated steering systems are properly designed. Above all, possible new risks due to automated steering have to be addressed and reduced to a minimum. For these reasons, work is currently ongoing on UNECE level with the aim to amend the regulation dealing with provisions concerning the approval of steering equipment. These amendments of the UN Regulation No. 79 therefore are intended to cover normal driving situations, sudden unexpected critical events, transition to manual driving, driver availability and manoeuvres to reach a state of minimal risk. This includes physical test procedures for automatic steering that have to be implemented in the international regulations. This holds true for system functionality tests like automatic lane keeping or automatic lane change as well as for tests addressing transition situations in which the system has to hand over the steering task to the driver, and for emergency situations in which the system has to react instead of the driver. Some of the tests, especially the emergency manoeuvres, require special target vehicles and propulsion systems. BASt was asked by the German Federal Ministry of Transport and Digital Infrastructure (BMVI) to check whether the currently available test tools are usable and to verify the projected test procedures as a whole. The current paper characterizes the tests planned to be implemented in the UN Regulation No. 79 (Part 1). Afterwards, the conduction of demonstration tests for ACSF functionality, transition and emergency scenarios with a production car is reported and results of the feasibility of these tests scenarios are presented (Part 2). Since no fully automatic steering vehicles are available until today, a current Mercedes E-Class with Mercedes' 'drive pilot' system was used for the feasibility tests. Test conduction requires coordinating up to four vehicles including a motorcycle in strict tolerances.

## PART 1: TESTS INTENDED TO BE IMPLEMENTED IN UN REGULATION NO. 79

To enable automated driving in UN Regulation No. 79, it is necessary to remove the restriction for automatically commanded steering, which means to delete the 10 km/h limit and replace it by new adapted requirements.

There is one essential prerequisite for the development of new performance requirements for automated steering: The driver is still obliged to monitor the driving at all times. This condition follows the principle that it is not allowed for the driver to turn away from the driving task and be distracted.

Another prerequisite is that the automated steering function shall be designed such that the driver can always override or switch off the system. While proposing requirements, care should be taken that automated steering is at least as safe as manual steering. This leads to a catalogue of needs for the demanded functionalities of the system.

- The system shall safely do what it is designed for (safe operation of the use case).
- The conditions for activation have to be defined.
- Precautions for functional safety in the case of a failure have to be taken.
- Special emphasis must be laid on the design of a safe transition from automated steering back to manual steering.

To ensure these requirements, physical test procedures for automatic steering need to be implemented in UN Regulation No. 79 [1]. Systems for automatically commanded steering are planned to be subdivided in five categories. These categories and their short descriptions are listed in Table 1.

**Table 1. ACSF categories and descriptions [2]**

ACSF category	Description of functionality
A	Low speed manoeuvring: Park assist / Remote Controlled Parking
B1	Lane Keeping: Lateral control with hands on the steering control
B2	Lane Keeping: Lateral control with hands off the steering control
C	Lane change: Lane change commanded by the driver
D	Lane change: System indicates possibility, driver confirms
E	Lane change: Lane change is performed automatically by the system

Category A describes systems in the low speed range up to 10 km/h. This could be e.g. systems for automatic parking manoeuvres, with or without remote control. Parking systems (category A) are already allowed and therefore not discussed further. The major distinction of the other systems is between lane keeping and lane change functionality. Category B specifies lane keeping, category C to E will describe lane changing functions with different capabilities of the system to scan the surrounding [2]. Therefore category C to E systems will cover different ranges of functionalities, resulting in different technical requirements.

For all the categories different test cases are or will be developed based on the framework, scope and terms of reference given by GRRF and WP.29 [3]. As mentioned above the designated tests are divided in three sections, functionality tests, transition tests and emergency tests [4,5]. Category C, D and E systems always need to include a B1 or B2 system:

**Table 2. Intended ACSF test cases per category to be implemented in UN Regulation No. 79**

Test ID	Description
FU1	Lane keeping for B1 and B2
FU2	Abort of lane change for D and E
FU3	Lane change for C, D and E
TR0	Holding steering control for B1
TR1	Lateral acceleration exceeded for B2
TR2	Missing lane marking for B2
TR3	Driver unfastened for B2 and C
TR4	Failure for B2
TR5	Taking over manual control for B1 and B2
EM1	Braking with moving/decelerating target for B2
EM2	Braking with stationary target for B2

Category C and D need to be combined with a B1 or possibly B2 system and category E with a B2 system as a basis for the lane change functionality. Therefore the related test cases for the B1 or B2 system are also applicable for the C, D and E systems. An overview over the intended test cases and their addressed categories to be implemented in UN Regulation No. 79 is given in Table 2. The Technical Service will be responsible for the homologation tests of the UN Regulation No. 79.

### FUNCTIONALITY TESTS

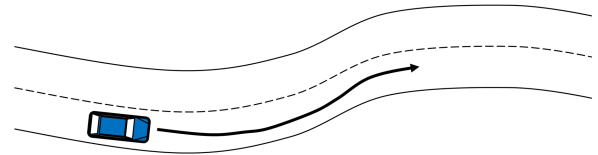
System functionality tests are automatic lane keeping, automatic lane change and an automatic

abort of an initiated lane change due to traffic. Additionally a lateral acceleration test for B1 and B2 systems will be required. Those tests check if the vehicle remains in its lane under normal operating conditions, is able to perform safe automatic lane change manoeuvres and if it considers other road users during its manoeuvres. Beside the tested criteria more information about the full system functionality will be delivered by the vehicle manufacturer to the Technical Service.

#### FU1 test: Lane keeping test

The lane keeping functional test will be required by all B1 and B2 systems and therefore effectively for all ACSF other than category A.

The vehicle speed shall remain during the test in the range of the operational speed for the system function ( $v_{min}$  up to  $v_{max}$  as specified by the manufacturer). The test should be carried out with different speeds if the lateral vehicle acceleration induced by the system ( $a_{y,max}$ ) changes with the speed. The driver should not apply any force on the steering and drive with a constant speed on a curved track (80% - 90% of  $a_{y,max}$ ) with lane markings (Figure 1). The vehicle fulfils the test requirements if it always stays in its lane.



**Figure 1. Sketch for the FU1 test**

An additional maximum lateral acceleration test will be required to check if  $a_{y,max}$  is below the limits specified in the Regulation of  $3 \text{ m/s}^2$  for M1, N1 vehicles and  $2.5 \text{ m/s}^2$  for M2, M3, N2, N3 vehicles.

This test is similar to the FU1 test. The lateral acceleration now is intended to reach more than  $a_{y,max} + 0.3 \text{ m/s}^2$  e.g. by travelling with a higher speed through the curve from FU1. The test requirements are fulfilled if the vehicle acceleration stays within the specified limits.

#### FU2 test: Test for the abort of lane change

The test for the abort of lane change is planned to be requested for all D and E systems.

The vehicle will be driven on a straight track with two or more lanes with road markings with a speed of 70 km/h. Two other vehicles of category M1 or target vehicles drive in the same lane ahead and behind the ACSF vehicle with the same speed. The time gap between the vehicles should be  $1.9 \text{ s} \pm 0.1 \text{ s}$  or the ACSF vehicle adjusts its time

gap to the front itself. The desired speed of the test vehicle will then be set such, that a lane change would be induced to pass the vehicle ahead, e.g. 20 km/h higher. The execution of the lane change will be always suppressed for safety reasons of the testing. The willingness to carry out a lane change ("yes" or "no") will be recorded. A motorcycle of category L3 approaches from behind on an adjacent lane with a speed of 120 km/h and with a lateral distance to the lane marking sitting between the motorcycle and the vehicle of  $1\text{ m} \pm 0.25\text{ m}$  (Figure 2). The test will be passed if the willingness to carry out a lane change switches from "yes" to "no" before the distance between the vehicle and the motorcycle falls below 68 m and remains "no" until the motorcycle has passed the vehicle completely. The proposed formula to determine this threshold is:

$$s_r [m] = (\Delta v \cdot t_r) + \frac{\Delta v^2}{2 \cdot a_b} + v_{VUT} \cdot t_d$$

The distance of 68 m ( $s_r$ ) follows from the above proposed equation with a 1.2 s reaction time ( $t_r$ ) for the motorcycle driver, followed by a maximum demand for  $3\text{ m/s}^2$  deceleration ( $a_b$ ) of the motorcycle from a speed of 120 km/h ( $\Delta v = 50\text{ km/h}$ ) and a resulting minimum distance-time of the motorcycle to the ACSF vehicle of 1 s ( $t_d$ ) when reaching the 70 km/h.

In case the willingness to carry out a lane change is "no" at any time, the test should be repeated without a vehicle behind the test vehicle. If it still stays "no", the test shall be repeated with reduced motorcycle speeds in steps of 10 km/h until the willingness to carry out a lane change is "yes" before the motorcycle approaches. System functionality thus should be limited.

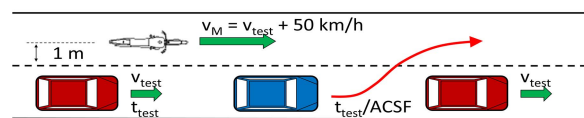


Figure 2. Sketch for the FU2 test

### FU3 test: Test for lane change

The test for the capability to perform a lane change is intended to be fulfilled by all C, D and E systems. The test set up is identical to the FU2 test but without an approaching motorcycle and the vehicle behind the ACSF vehicle. The desired speed of the test vehicle again will be set e.g. 20 km/h higher, that a lane change would be induced to pass the vehicle ahead (Figure 3). The requirements to fulfil the test are that the lane change manoeuvre will be completed without

crossing the outer lane markings and the vehicle shall ensure a time gap of  $1.9\text{ s} \pm 0.1\text{ s}$  to the overtaken vehicle after a second lane change manoeuvre back into the initial lane.

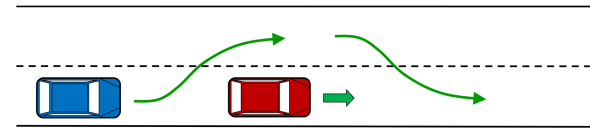


Figure 3. Sketch for the FU3 test

### TRANSITION TESTS

The transition tests examine the vehicle's behaviour when the driver fails to monitor the system and in situations when the system has to hand over the steering control back to the driver within an appropriate period of time. These tests provoke driver-in-the-loop requests by approaching system boundary limitations, for instance missing line markings, exceeding maximum lateral accelerations in a bend, failures in the system, driver not holding the steering control, overriding by the driver and when the driver unfastens the seat belt.

#### TR0 test: Hands on test

The hands on test is intended to be fulfilled by B1 systems and checks whether the driver is holding the steering control device.

The vehicle should be driven with a speed between  $v_{smin} + 10\text{ km/h}$  and  $v_{smin} + 20\text{ km/h}$  on a track with lane markings with released steering control until the ACSF is deactivated by the system. The selected track must provide enough space that it allows driving with activated ACSF for at least 65 s without any driver intervention. The test should be repeated with a vehicle test speed between  $v_{smax} - 20\text{ km/h}$  and  $v_{smax} - 10\text{ km/h}$  (max. 130 km/h). The test will be fulfilled if an optical warning signal (Figure 4) is given at the latest 15 s after the steering control has been released, the optical warning signal is at the latest after 30 s full or partly red and an additional acoustic warning signal is given and remains until ACSF is deactivated. The ACSF shall be deactivated at the latest 30 s after the acoustic warning signal has started, with a different acoustic emergency signal of at least 5 s.

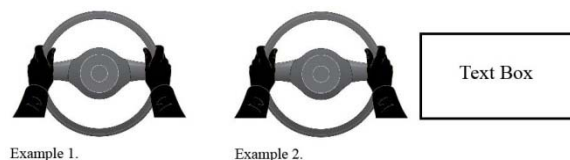


Figure 4. Examples of the optical warning signal to hold the steering control

### TR1 test: Transition due to exceeding lateral acceleration

The TR1 test is intended to be fulfilled by B2 systems and checks whether the system informs the driver in time to take over control again when the lateral acceleration limit is going to be exceeded or manages to prevent from exceeding the lateral acceleration limit.

The vehicle will be driven on a track with road markings at a test speed of 80 km/h or 10 km/h below  $v_{smax}$  whatever is lower. The track should have a section in which the lateral acceleration of the vehicle would be more than  $(a_{y,smax} + 0.5) \text{ m/s}^2$  for a length of at least 150 m (Figure 5). The test driver of the vehicle should not take over steering control again until the minimal risk manoeuvre is finished.

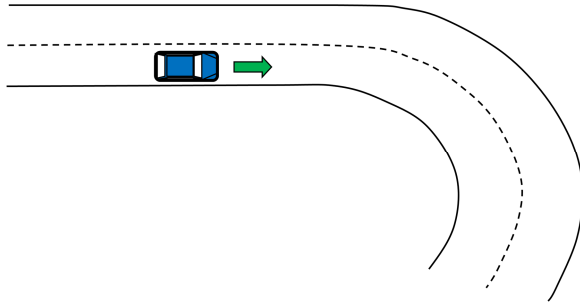


Figure 5. Sketch for the TR1 test

The test will be passed if a transition demand is given not later than at least when the lateral acceleration exceeds  $a_{y,smax}$  by more than  $0.3 \text{ m/s}^2$  and the vehicle does not cross any lane marking for 4 s after the transition demand and a minimal risk manoeuvre (as specified by the vehicle manufacturer) was initiated not later than 4 s after the transition demand with the hazard lights activated not later than 4 s after the start of the minimal risk manoeuvre. A second possibility to pass the test would be if no transition demand is initiated during the test and the vehicle reduces speed by itself so that  $a_{y,smax}$  was not exceeded for more than 1 s and the vehicle do not cross any lane marking. The 4 s time interval is a result of a driving simulator study from the National Traffic Safety and Environment Laboratory [6].

### TR2 test: Transition due to missing lane marking

The TR2 test is also intended to be fulfilled by B2 systems and checks whether the system informs the driver in time to take over control again when a lane marking is missing and the system is not able to cope with it. The vehicle will be driven on a track with road markings at a test speed of 80 km/h

or 10 km/h below  $v_{smax}$  whatever is lower. The track shall have a section in which the side lane marking is missing on one side with a length of at least 150 m and in which the lateral acceleration of the vehicle would be less than  $a_{y,smax}$  and more than  $0.5 \text{ m/s}^2$  (Figure 6). Here again the driver should not take over steering control again until the minimal risk manoeuvre is finished.

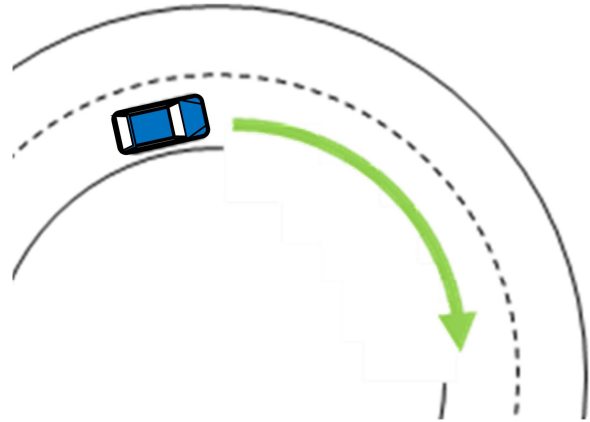


Figure 6. Sketch for the TR2 test

The test will be fulfilled if the transition demand is given at the latest when the vehicle entered the section with missing lane marking and the vehicle does not cross any lane marking and stays in the initial path for 4 s after the transition demand and a minimal risk manoeuvre is initiated as described in the TR1 test. Here again a second possibility to pass the test would be if no transition demand is initiated during the test and the vehicle follows the initial path for the complete section with missing lane marking without crossing any lane marking or leaving the road.

### TR3 test: Transition due to unfastening the seat belt

The TR3 test is also intended to be fulfilled by B2 systems and should prevent from misuse of the system by the driver with leaving his seat while driving.

The vehicle should be driven on a track with curvatures with road markings at a speed of  $v_{smax} - 10 \text{ km/h}$ . Subsequently, the driver shall unfasten the seat belt / or the seat belt sensor shall be cut off at the beginning of driving in the curvature. The test would be fulfilled if a transition demand is given when the unfastened seat belt was detected. The warning signal should continue until the driver steers again and the vehicle should not cross any lane marking for at least 4 s after the transition demand and a minimal risk manoeuvre is initiated as described in the TR1 test.

#### TR4 test: Transition due to failure

The TR4 test is also intended to be fulfilled by B2 systems and checks whether the system informs the driver in time to take over control again when a sensor of the system has a failure. The vehicle should be driven on a track with road markings at a test speed of 10 km/h below  $v_{smax}$ . The track should have a section with a length of at least 200 m in which the lateral acceleration of the vehicle would be less than  $a_{y,smax}$  and more than  $0.5 \text{ m/s}^2$  (Figure 7). A single sensor failure (e.g. for the lane marking detection) of the automatic steering function will be induced.

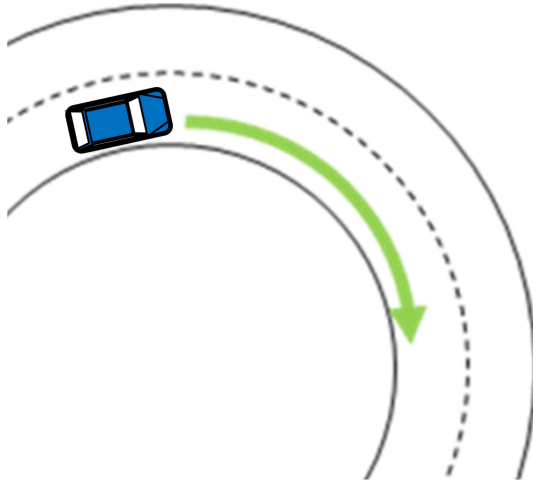


Figure 7. Sketch for the TR4 and TR5 test

The test will be passed if the failure warning and the transition demand were given immediately (not later than 0.5 s) after the sensor failure was induced and the vehicle should not cross any lane marking and a minimal risk manoeuvre is initiated as described in the TR1 test.

#### TR5 test: Driver takes over test

The TR5 test is similar to the TR4 and intended to be fulfilled by B2 systems and checks whether it is possible for the driver to take over control again when a sensor of the system has a failure. The vehicle should be driven on a track with road markings at a test speed of 70 km/h or ( $v_{smax} - 20 \text{ km/h}$ ) whatever is lower. The track shall have a section with a length of at least 200 m in which the lateral acceleration of the vehicle would be less than  $a_{y,smax}$  and more than  $0.5 \text{ m/s}^2$  (Figure 7). Again a single sensor failure (e.g. for the lane marking detection) will be induced. The driver should override the ACSF by steering after the transition demand and the minimal risk manoeuvre as described in the TR1 test was initiated. The test will be fulfilled if the ACSF is

deactivated automatically, the minimal risk manoeuvre is aborted and hazard warning signal is deactivated after the driver overrides the ACSF.

#### Overriding force test

There is an additional overriding force test foreseen to be fulfilled by all B1 and B2 systems and therefore by all ACSF. The vehicle should be driven in the range from  $v_{smin}$  up to  $v_{smax}$  without any steering input (e.g. by removing the hands from the steering control) with a constant speed on a curved track (80% - 90% of  $a_{y,smax}$ ) with lane markings. The driver should then steer to override the system intervention and leave the lane. The test is fulfilled if the force to override the steering is less than 50 N.

#### EMERGENCY TESTS

The last series of test consists of two emergency situations in which the system has to react to a time critical event: 1<sup>st</sup> a hard decelerating vehicle and 2<sup>nd</sup> a stationary vehicle in front, both with no lane change possibility for the ACSF vehicle.

#### EM1 test: Protective deceleration with a moving and decelerating target

The vehicle will be driven behind a target vehicle. The vehicle and the target vehicle shall drive aligned within the lane markings on a track with road markings at a speed of 70 km/h. The time gap between the test vehicle and the target vehicle will be selected by the vehicle itself but should not be more than 2.4 s. The target vehicle decelerates at a certain point with  $6 \text{ m/s}^2$  (Figure 8). The vehicle should not carry out a lane change to avoid a collision and therefore any adjacent lanes to the lane the vehicle is driving in should be physically blocked. The test will be passed if the ACSF vehicle does not collide with the target vehicle.

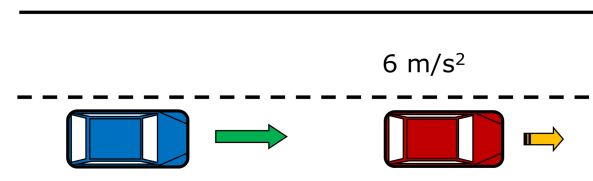


Figure 8. Sketch for the EM1 test

#### EM2 test: Protective deceleration with a stationary target

The vehicle will be driven on a track with road markings at a test speed of 10 km/h below  $v_{smax}$ . The vehicle shall approach a target vehicle being at standstill and being placed in the centre of the lane (Figure 9). Again the vehicle should not carry out a lane change to avoid a collision and any other lane



adjacent to the lane the vehicle is driving in should be blocked as in the EM1 test. The demanded requirement is the same as for EM1.

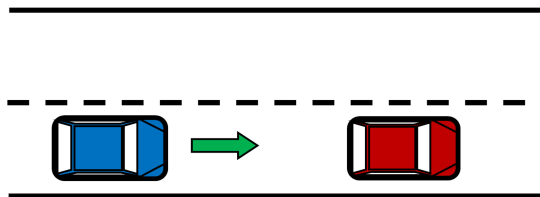


Figure 9. Sketch for the EM2 test

## PART 2: DRIVING EXPERIMENTS AND RESULTS

A vehicle providing full ACSF capability was not available on the market at the time the tests were scheduled in September 2016. To get a first impression of the feasibility and practicality of the planned ACSF – tests, a production car equipped with modern assistance systems promising to cover most functionalities was selected: Mercedes-Benz E Class W213 production year 2016, referred to as vehicle under test (VUT). Since it was not an actual ACSF vehicle, not the entire test catalogue could be completed. It was not intended in any case to assess the performance of this vehicle. The aim was only to get an impression of the feasibility and practicality of the planned ACSF – tests.



Figure 10. Measuring equipment of the motorcycle

The basis for the conducted tests was the draft test specification for ACSF categories B1, B2 and E (status from September 2016). The vehicle's lane change function was geo-fenced via GPS and digital maps to highways only and therefore the use of the function was prohibited on test tracks. Driving on public road was the only option for the

FU3 tests. FU1, TR0/1 and EM1 and EM2 were conducted at the Aldenhoven Testing Center (ATC) of RWTH Aachen University GmbH, while the FU2 test was conducted at DEKRA Automobil Test Center Klettwitz, since at this test track motorcycles are allowed for testing and in addition it does provide a 2 km long straight track.

All vehicles' dynamic parameters (positions, angles, speeds, and accelerations) were recorded via an inertial measuring unit (IMU) combined with differential GPS data (Figure 10). This allows position accuracy up to 1 cm [7].

## FUNCTIONALITY TESTS

### FU1 test

The FU1 test needs three to four fully marked lane curves with different radius to be able to maintain the identical lateral acceleration on the requested three to four test speeds.

To reduce effort for this first impression only one speed - radius combination was assessed. The speed was maintained through the vehicle's cruise control function, while the correct values for speed and acceleration were checked via the IMU.

The assessment of line crossing was done via a relatively small action video camera mounted above the front tire pointing towards the ground. A simple visual check is enough to evaluate if the car overruns the marking (Figure 11).



Figure 11. FU1 Test via video data

### FU2 test

As mentioned before, the FU2 conduction requires the participation of a motorcycle, as well as a straight track of approximately 2 km length with at least two fully marked lanes. For safety reasons it has to be ensured that enough lateral space is available. The motorcycle must be able to steer away from its initial path in the case the VUT would still overtake. The test vehicle convoy consisted of a leading vehicle (Mercedes Benz

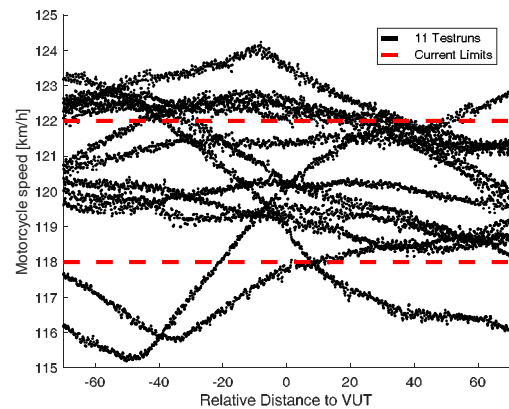
Sprinter T1N), the VUT (Mercedes Benz E-Class) and a rear view blocking vehicle (VW Passat B6). The leading vehicle is responsible for the test speed since the VUT and the following vehicle are set up to maintain a specific distance through the active cruise control which includes distance control. Any instability in the speed of the leading vehicle has an effect on the entire convoy. The leading vehicle only needs a GPS-Speed indication to set up the correct target speed which was then held by the build in speed control unit (70 km/h for this test). Once all three vehicles were in line and the distance and speed control smoothed out, the motorcycle approached from behind. The VUT had a live position, speed and relative distance display. This allowed the VUT test driver to initiate the overtaking command at the exact moment (Figure 12). The driver of the VUT was permanently in contact with the driver of the motorcycle via mobile phone to share commands like test start or test abortion.



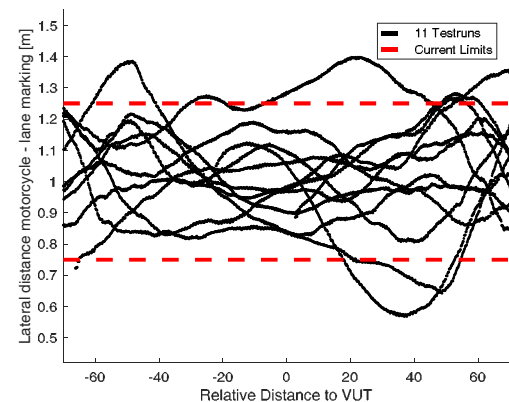
**Figure 12. FU2 convoy with motorcycle**

In this particular situation the car did not obey to or refused the lane change command since the functionally inhibited by geo-fencing, as stated above. Advantageously the test procedure could therefore be exercised and analysed without exposing the motorcycle driver to any danger. To reduce the effort for the motorcycle driver to maintain the correct distance of 1 m from the right sided lane marking while driving with the speed of 120 km/h some additional markings were temporarily put on the tarmac. Along the 2 km straight a yellow chalk line with 1 m  $\pm$  1 cm distance to the lane marking had been set up. The motorcycle had an additional display for a GPS-speed indication and together with several training runs, tolerances could be maintained as tight as possible for manual speed control. The manual

speed and path control of the motorcycle is analysed in a window of -70 m to +70 m (= -5 s to +5 s TTC) relative to the VUT (position reference is the VUT, positive value means the motorcycle is ahead of the VUT). The speed was held at 120 km/h with a tolerance of  $\pm$ 5 km/h (Figure 13). The lateral distance could be held in an interval of 1 m  $\pm$ 0.45 m (Figure 14). Both values exceed the current tolerances.



**Figure 13. Motorcycle speed**



**Figure 14. Lateral distance motorcycle to line**

A major improvement would be the use of a cruise control for the motorcycle. This would decisively reduce the multi task operation into a single task operation for the motorcycle driver to only maintain a correct lateral position. Alternatively the tolerance could be enlarged to the above mentioned values allowing the test to be fulfilled without too many invalid runs.

During the approach of the motorcycle from behind the driver of the VUT constantly monitored the longitudinal relative distance. Once it fell under 89 m the turn signal was set to initiate an overtaking command. That was obviously useless since the function was not active, but was executed



to examine the practicability. The 89 m threshold results from the 68 m defined above in the requirements with in addition the distance the requested three turn indicator blinks are emitted. The highest allowed blinking frequency is 2 Hz, which gives a minimum of 1.5 s for three complete blinking cycles, and together with the relative speed of 50 km/h the result is around 21 m [4]. Without any reaction of the VUT an assessment becomes obsolete, but it was shown and proven that the described procedure is feasible.

### FU3 test

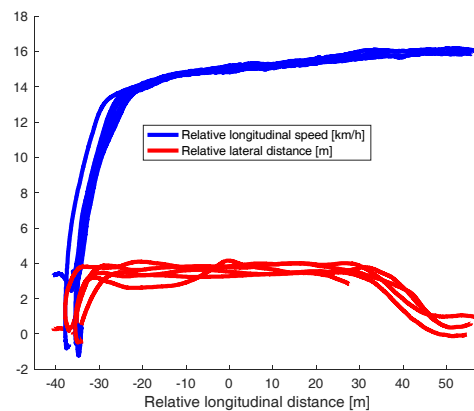
Due to geo-fencing, this test could not be performed on a test track. The street section had to be straight and approximately flat and should provide three lanes per direction to be able to drive safely with the leading vehicle constantly 100 km/h (GPS-Speed) without disturbing the other traffic to much. The selected highway was the Autobahn A 4 between Aachen and Cologne (Figure 15). Outside of a test track the use of the differential GPS was not possible but since relative positions were recorded and both cars' GPS units do suffer from the same atmospheric disturbances, the impact on the position tolerances is estimated to be below 0.5 m [7]. Otherwise the same measuring equipment was used as in the FU1 and FU2 tests.



**Figure 15. Leading vehicle for the FU3 test on a public road**

The active cruise control of the VUT was set to a speed of 120 km/h (shown in the instrument cluster). The overtaking command was initiated by triggering the turn indicator first fully to the left side to change to the overtaking lane and then once the leading vehicle was passed (synonymous with a relative distance of 10 m) the turn signal to the right side was fully triggered to bring the VUT back to its initial lane with a second lane change

manoeuvre. The demanded relative distance to the lead vehicle should be between 50 m and 55.5 m ( $1.9 \text{ s} \pm 0.1 \text{ s}$  at 100 km/h) before and after the overtaking manoeuvre. This relative distance complies with local traffic rules but was slightly elevated compared to normal real world driving. Together with the slow relative speed of only around 15 km/h the total overtaking time was long and other traffic participants showed their disagreement especially with the second lane change back after the overtaking manoeuvre. An additional shorter initial distance was selected within the possibilities of the active cruise control, resulting in a time gap of 1.26 s - 1.44 s (corresponding to a distance of 35 m - 40 m). Five test runs were conducted (see Figure 16). Note that the initial relative speed is not constantly starting at zero. This might be due to the system layout chosen by the manufacturer to maintain the desired distance.



**Figure 16. FU Test runs in comparison**

The mean lateral shift for all five lane changes is approximately 3.5 m (red line in Figure 16), which corresponds to the standard lane width of 3.5 m on an average three lane highway [7]. The VUT does accelerate quickly to gain a speed difference in the beginning of the overtaking and smoothes out while passing (blue line in Figure 16).

The VUT passed this test. The total time required for the overtaking maneuver was 23 s - 28 s (even with the shorter initial distance).

### TRANSITION TESTS

Due to the assistance systems with limited functionality fitted in the VUT, TR0 and partly TR1 could be conducted together. The absolute limit of  $a_{y,smax}$  was unknown but an assumption of  $a_{y,smax} = 1 \text{ m/s}^2$  was made after some verification runs. The setup of the VUT is equal to the FU1 test, besides an additional camera on the dashboard

to capture the optical warning which is shown in the head up display (Figure 17), and an audio trigger to record the acoustic warning. Both signals were synchronised and examined post test.



**Figure 17. Optical warning for the hands off detection in the head up display**

Via the cruise control option an indicated speed of 50 km/h, corresponding to a true speed of 47.1 km/h, was selected. The bend had a radius of 186.5 m with a total bend of just above 190°. The single test speed was chosen because of the available test track and to check several system features.

The vehicle also limited the speed itself in the bend to not generate higher lateral accelerations. This appeared to also fulfil the requirements for the TR1 test if conducted on a suitable test track for the required speed. The resulting lateral acceleration was between 0.75 m/s<sup>2</sup> and 1.1 m/s<sup>2</sup> and therefore confirmed the assumed  $a_{y,max}$ . The system did also fulfil the demanded warning signals by emitting the optical and acoustical warnings as requested by the ACSF tests (draft ACSF test procedures September 2016: optical warning within 30 s and different optical warning with an additional acoustical warning within 60 s; after Jan. 2017 the values have changed to 15 s and 30 s) when driving hands off on the test track.

## EMERGENCY TESTS

### EM1 test

Because of the similarity between the emergency tests and the current Euro NCAP active safety protocols (AEB Inter-Urban Test 2016), most of the test tools for these tests were directly derived from Euro NCAP. The inflatable target simulates the rear end of on a VW Touran (optically and with the radar cross section) and is towed on a trailer by a vehicle (Mercedes E240 W210) equipped with driving robots and position measuring equipment with differential GPS. This allows relative tight tolerances for the position and speed control as well as precise relative position calculation (similar to FU2). In addition, this equipment applies the requested 6 m/s<sup>2</sup> brake deceleration on the towing vehicle, ensuring the

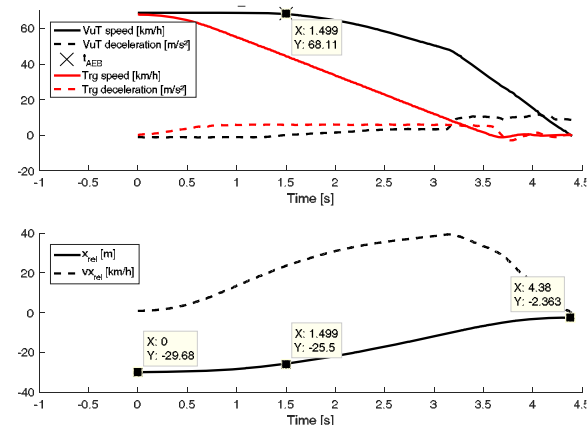
correct force is applied to the brakes with a brake robot.

The major distinction to the Euro NCAP procedures is the required presence of road markings (enabling ACSF lane keeping), the higher test velocity (70 km/h vs. 50 km/h) and the missing driving robots in the VUT. The target is mounted on a trailer formed by two parallel rails that allow the target to move along if the VUT fails the test and the target would be impacted. The rails are so narrow that they clear the tires of the VUT giving some room for an emergency stop and abort the test run (Figure 18).



**Figure 18. Euro NCAP target trailer**

The VUT did perform very well on this test and did not hit the target. The initial distance was 29.68 m with a test speed of 68.11 km/h. The distance at standstill was 2.36 m with brake activation at 25.5 m distance (Figure 19), which equals to a TTC time of 1.35 s. The requested tolerances could be met without problems.



**Figure 19. EM1 Performance ( $t = 0$ , target brakes)**

### EM2 test

EM1 and EM2 share the same background. The EM2 test is also derived from the current Euro NCAP active safety protocols (AEB City Test 2016), but also with lane markings (for the same

reasons as above to make the ACSF working without the need of driving robots) and higher test velocities.

To prevent the system to calculate its AEB intervention with a possible last second lane change, which would reduce the system performance, and to provoke a dead stop, two vehicles were parked at the adjacent lanes (Mercedes Benz Sprinter T1N on the left side and Mercedes Benz E240 W210 on the right side). The target (without the trailer) was put in the middle of the marked lane (Figure 20).



Figure 20. Target and lane blocking vehicles

The lane blocking vehicles were positioned 1 m next to the line marking and for safety reasons 7 m longitudinally ahead of the target to be away of the possible impact zone into the target.

Tests were conducted with a speed of 70 km/h, 80 km/h and 90 km/h. Remarkable is that with increasing speed the brake strategy of the VUT went from an early but smooth deceleration to a two stage deceleration with a hard emergency brake up to 9.8 m/s<sup>2</sup> at the end (Figure 21). The car did show good performance with no impact at all test speeds (Table 3. EM2 PerformanceTable 3).

Table 3. EM2 Performance

Test speed [km/h]	Speed at AEB activation [km/h]	TTC at AEB activation [s]	Distance to target at stop [m]
70	69.64	2.8	1.53
80	79.38	1.8	2.83
90	89.51	2.1	1.85

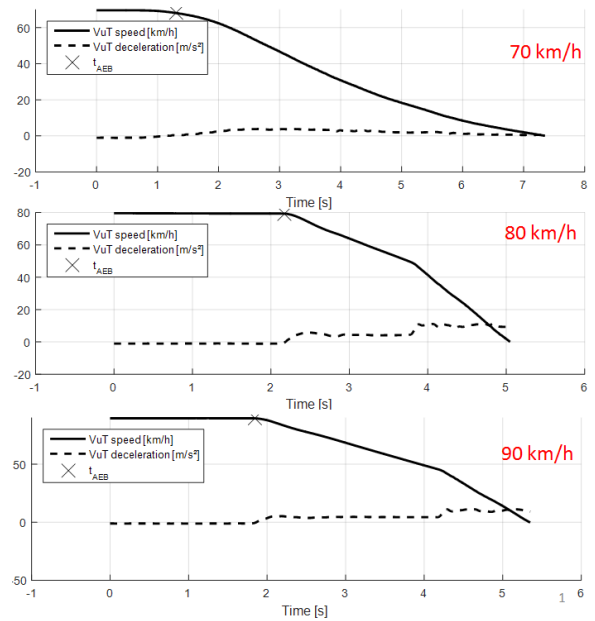


Figure 21. Deceleration curves at 70 km/h, 80 km/h and 90 km/h

To avoid damage to the test tools the high speed tests (up to 120 km/h) have not been carried out, since it was stated clearly by the manufacturer that an impact will happen. In such a case or if no information about system limitations is known an alternative strategy must be formulated to avoid damages at the VUT or the test equipment (target): The test could be automatically aborted by applying full brake force (e.g. with an additional installed braking robot) at a dedicated limit for the TTC. The suggested formula to determine the threshold is:

$$TTC [s] = \frac{v}{2\mu g} + 0.3 s$$

While the first summand is the physical limit to a dead stop the second summand (0.3 s) is a buffer to cover the time lags due to: brake robot activation, building up of hydraulic pressure, closing the gap between brake lining and disc, build up tire slip and the diving of the vehicle body.

## CONCLUSION

A test series was conducted in order to examine the feasibility of currently available test tools and to verify the projected UN Regulation No. 79 test procedures for ACSF as a whole. Since no fully automatic steering vehicles are currently available, a current Mercedes E-Class with Mercedes' 'drive pilot' system has been used. Since this was not an ACSF vehicle, the entire test catalogue could not

be tested. Anyway it was not intended to assess the performance of this vehicle and the aim was to get a first impression of the feasibility and practicality of the planned ACSF – tests.

The functionality test FU1 for the lane keeping capability was possible to be performed and a pass/fail-assessment for crossing lane markings is possible with a simple referenced wheel camera combined with a UTC time reference for the data synchronization with the vehicle speed and the lateral acceleration. The trials of the FU2 test for the abort of lane change showed that the test procedure is possible with a manually driven motorcycle on an adequate long test track, but the designated tolerances for the motorcycle speed and the lateral position might have to be extended to avoid too much invalid trials. The FU3 test was only possible to be performed on public roads because the chosen vehicle system was able to recognize the type of road via GPS and was restricted to operate the lane change function only on these roads. Therefore testing on a proving ground was not possible for this test.

From all transition tests the TR0 and partly the TR1 was able to be performed. All other transition demands were not covered and needed by the functionality of the installed system. These missing transition tests have to be tested as soon as a vehicle with the appropriate system functionality is available.

The emergency tests could be conducted with the designed specifications. The EM1 tests are a modification of the current Euro NCAP braking tests with a higher speed of 70 km/h instead of the 50 km/h. The tests can be performed with current target and propulsion systems. The target vehicle needs to be equipped with a brake robot to ensure the exact brake profile. The EM2 tests are stationary tests with speed up to 120 km/h. The tests have been conducted only up to 90 km/h approaching speed and not with the designated test speed of 10 km/h below  $v_{smax}$  because of system limitation. If the test is not passed, impacts with more than 50 km/h need to be avoided to protect the target and the VUT. Therefore the abort of the test by automatically applying full brake force (e.g. with an additionally installed braking robot) at a dedicated limit for the TTC could be a solution to protect the VUT and the target. This limit can be calculated and determined for the used test track.

BASt has carried out demonstration tests for ACSF functionality and emergency scenarios. In principle all performed scenarios can be tested using state-of-the-art test tools (e.g. target systems, measurement equipment).

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