Testing and Evaluation Methods for ICT-based Safety Systems

Collaborative Project

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Executive Summary

eVALUE is addressing active safety functions and their capability to perform through two courses of action: defining and quantifying the requirements of a safety function under a relevant traffic accident scenario and developing the testing and evaluation methods for the active safety functions of vehicles.

WP2 aims at developing testing procedures based on the system descriptions and scenarios defined in WP1. The testing procedures will be integrated in WP3 and finally carried out and assessed in WP4.

D2.2 takes the output of D2.1 and, where scenarios, safety functions and test procedures are related, defines the basis for the test procedures further developed in the next work packages. The test procedures are drafted, taking into account the future "testing protocols" and the "assessment protocols".

The document is structured according to the scheme followed from the project start, where tests are classified into "Design Reviews", "Physical Testing" and "Laboratory Testing". The test procedures are also classified depending on clustering different safety functions: "Longitudinal Assistance", "Lateral Assistance" and "Stability".

Document Name

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Version Chart

Version	Date	Comment
0.0	20/04/09	Draft version created by IDIADA
0.1	25/05/09	Updated version, with all partners contribution
0.2	18/06/09	SP reviewed version
0.3	01/07/09	Draft updated version
0.4	07/07/09	Draft version reviewed by all partners
0.5	15/07/09	Final version reviewed by all partners
0.6	17/07/09	Final version accepted by all partners
1.0	22/07/09	Final version as submitted to the EC
2.0	15/11/10	Final version including EC comments

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Table of Contents

1 INTRODUCTION

1.1 Motivation

The general objective of eVALUE is to develop testing and evaluation procedures for Information and Communication Technologies (ICT)-based safety systems and, thereby, to increase public perception and customer acceptance of ICT-based safety systems and to support development of ICT-based safety systems at vehicle OEMs and suppliers.

The objective of Work Package 2 (WP2) in eVALUE is to provide specific test procedures for representative accident scenarios and integrate them into general procedures (WP3 objective) for global performance assessments and evaluations (WP4 objective). For this reason, WP2 is providing many test procedures that might overlap and need to be integrated in the future work packages.

In other words, the specific objective of WP2 is the definition, development and analysis of test and evaluation procedures for all different situations selected as the focus of eVALUE (defined in WP1).

This can be divided into 2 objectives:

- Assignment of testing procedures to accident scenarios.
- Definition and detailed development of testing and evaluation procedures for scenarios.

D2.1 fulfilled the first objective, while D2.2 is compiling all the results of WP2 and completing the remaining objective.

One of the major achievements shown in D2.2 is the definition of the safety indicators. For each of the three clusters (longitudinal domain, lateral domain and vehicle stability), a selection of variables able to show the performance of a vehicle under specific condition has been done. These safety indicators are aimed to be the basis of the test procedures, which are defined according to them.

1.2 Concepts followed

D2.2 describes the status of eVALUE after 18 months of work. For this reason, it is important to refresh which are the concepts followed within the project, regarding the approach, the types of tests and the test procedures. This chapter tries to compile this information.

Objectives
The main focus of the European research project "Testing and Evaluation Methods for ICT-based Safety Systems (eVALUE)" is to define objective methods for assessment of preventive safety systems. Performance test results presented to the public will help to promote the use of those systems. The project is based on safety systems used in today's vehicles and will investigate the future upcoming ICT-based systems. Aims are to identify evaluation and testing methods, especially for primary safety systems, with respect to the user needs, the environment and economic aspects. Tests are preformed with respect to verification and validation of the preventive safety of the vehicle.

- *Verification* is addressed by tests of a function towards its requirements and considers the course of events from creating a critical situation until system activation occurs. Available reference material in terms of e. g. ISO standards can be used.

- *Validation* is provided by tests for evaluating safety effects; investigation on whether a preventive safety function in a certain cluster "does what it is designed for", e. g.

increasing safety. For this purpose driver in the loop testing is required to consider both, the response from the vehicle and/or the driver. Less reference material is available for deriving these tests, for instance with respect to information on driver behaviour, indicators for reflecting safety performance (safety indicators) as well as methods and tools for including drivers in the tests.

Scenario based approach
The actions of the project have been defined following a scenario based approach, opposed to the system based approach.

- With the scenario-based approach, it is started from accident databases to make assumptions on the most relevant and critical accidents in order to develop test methods for these situations. The advantage is that the focus is the most crucial accident types, derived from real world accident data. Thus performance will be evaluated in traffic scenarios, not adapted to specific function. This approach might lead to that certain systems are found to contribute more than others in increasing safety in the particular situations addressed, which might stimulate development of these systems.
- With the system-based approach traffic scenarios are defined for specific systems, where each system is assigned to certain traffic scenarios. A consequence here is that the accident types are not prioritized or ranked after criticality or importance to end up in a few general test scenarios, independent of all safety systems. All systems are assigned a set of relevant traffic scenarios and these traffic scenarios are more specific and adapted to the systems they are addressing.

Clustering
The ICT-based safety systems have been classified into four domains. Each domain will have several test procedures. These test procedures might be relevant to test several safety functions.

- Longitudinal assistance: Adaptive Cruise Control, Forward Collision Warning and Collision Mitigation by Braking.
- Lateral assistance: Blind Spot Detection, Lane Departure Warning and Lane Keeping Assistant.
- Yaw/stability assistance: ABS and ESC.
- Additional assistance: is excluded from the eVALUE project

Test procedures
It is important to note that the test procedures will be developed from a scenario based point of view. It means that no test procedures will be defined for specific systems. Test procedures will be defined for clusters, represented by accident scenarios. The objective is the evaluation of the behaviour of a vehicle under representative accident conditions and avoiding tests which are designed for the validation and verification of a function of the vehicle.

Test procedures have been classified into:

- Design reviews
  It is a systematic, comprehensive, and documented analysis of a design to determine its capability and adequacy to meet its requirements. It is also suitable to identify present and potential problems.
- Laboratory tests
  This type of tests can be divided into system performance and human factors testing in a driving simulator. A laboratory test is carried out on a static environment and is meant to identify and determine the concepts, requirements, specifications and limitations of the safety systems and components in the subject vehicle, in order to create a set of valid test procedures for the physical vehicle tests. Driver in the loop is considered under this type of test on a simulator environment. The test results

derived from the laboratory test will set the range input parameters for the physical vehicle test.

- Physical tests
  The purpose of this type of test is to validate the complete vehicle's performance, following the scenario approach. In other words, the approach is not to test one particular ICT-based safety system, but to validate the whole vehicle's functional safety under different scenarios. The general approach of eVALUE, based in real accident scenarios, is emphasized in physical testing, where there is a clear implementation of real traffic scenarios.

For each cluster, representative accident scenarios have been defined and safety indicators have been identified. The test procedures will show how to test and assess these safety indicators under the related clusters.

Another important aspect is the differentiation between verification and validation.

1.3 Testing strategies for preventive safety systems

The primary goal with preventive safety systems is to increase the safety for the occupants in a vehicle as well as for other road users. The purpose with ICT-based safety systems is to detect a critical event and support the driver in the primary driving task by taking an action during the chain of events that follows. The support to the driver can be given in different ways depending on the type of system. An information or warning system aims at increasing the driver's attention and awareness of the critical situation. The outcome of the situation depends on the driver's response to the given warning or information. An intervening system will provide, possibly in addition to the warning, an active response from the vehicle; an intervention that aims at retaking control over the situation. The driver might be more or less aware that the intervening function is taking an action. The intervention can either be complementary or contradictory to the driver's action.

Regardless of the type of function, the purpose of preventive safety systems is to act at some point in the chain of events following a critical event in such a way so that the criticality of the events is minimized and the safety is increased.

Within the scope of eVALUE are warning, support and intervention systems. One of the challenges is how to consider driver's behaviour in the tests procedures.

ADAS vs. IVIS systems

Since the objective of D2.2 is to define testing and evaluation methods for ICT-based safety systems or preventive safety systems, it is important to find a suitable way to describe the targeted functions.

A general distinction is often made between ADAS (Advanced Driver Assistance System and IVIS (In-vehicle Information Systems). In general, there seems to be a consensus that ADAS refer to systems mainly intended to support the (primary) driving task, while IVIS are systems mainly supporting other (secondary) tasks.

In AIDE a framework, based on the hierarchical control model of driving ECOM (Extended Control Model) (AIDE D2.2.5 e.g. Hollnagel, Nåbo and Lau, 2003; Hollnagel and Woods, 2005; Engström and Hollnagel, 2005), was used, describing the functions in terms of the driving sub-task (i.e. which goal) that they support (where some systems may not support driving goals at all). In this context, it is more useful to talk about functions than systems, since a system may contain many functions of very different types. A tentative mapping of some example IVIS and ADAS functions onto the ECOM layers is illustrated in Figure 1. This taxonomy is intended as a complement, rather than as an alternative, to the more traditional taxonomy of IVIS and ADAS (AIDE D2.2.5 Floudas et al., 2004)

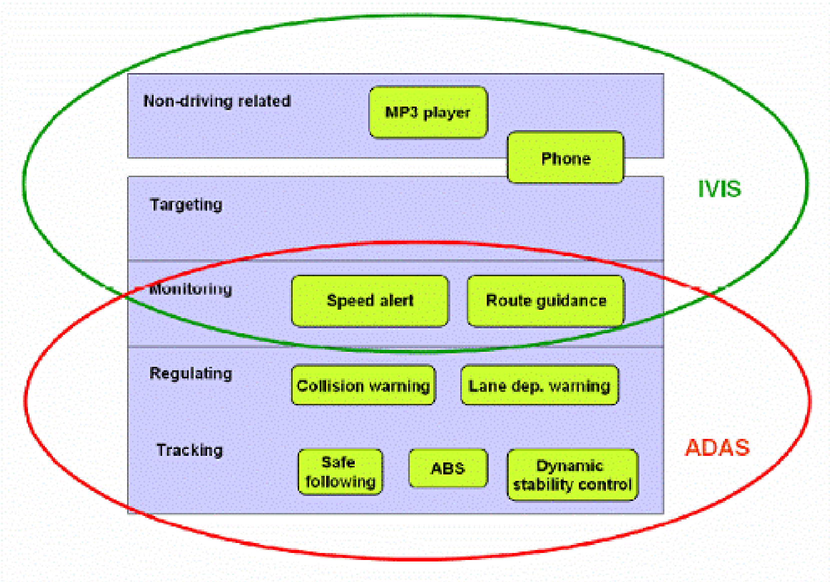

Figure 1: Proposed mapping of the ADAS/IVIS categories and some example functions onto the ECOM layers according to AIDE D2.2.5.

Concepts of performance testing

The evaluation of the functional performance of a preventive safety system needs to consider both the technical performance of the function as well as the overall safety effects of the function.

The technical performance tests aims at investigating whether the function equipped in the vehicle provides a correct behaviour with respect to technical specifications on what the function shall do. This can be referred to as verification tests against technical requirements. Evaluation of the overall safety effects of a function aims at investigating that the function fulfils its purpose; that is, given a certain output from a function the overall response produce the desired outcome in this case increased safety. This can be referred to as validation tests of the overall safety effects. Since no general established references for evaluating safety exist, is not trivial in what way to define assessment criteria for evaluating safety effects from a set of test results. An important part of the test strategy is therefore to define safety indicators that can be used for reflecting safety. Other important steps are to define the test objective and the hypothesis: what it is that eVALUE wants to test and which are the intended effects?

The driver's behaviour and response are essential when testing the safety effects of preventive safety systems, in particular for warning and information systems. Figure 2 presents the difference and connection between verification and validation, also previously presented in D1.2. Indicators for analysing the results will differ depending on whether the focus is verification or validation.

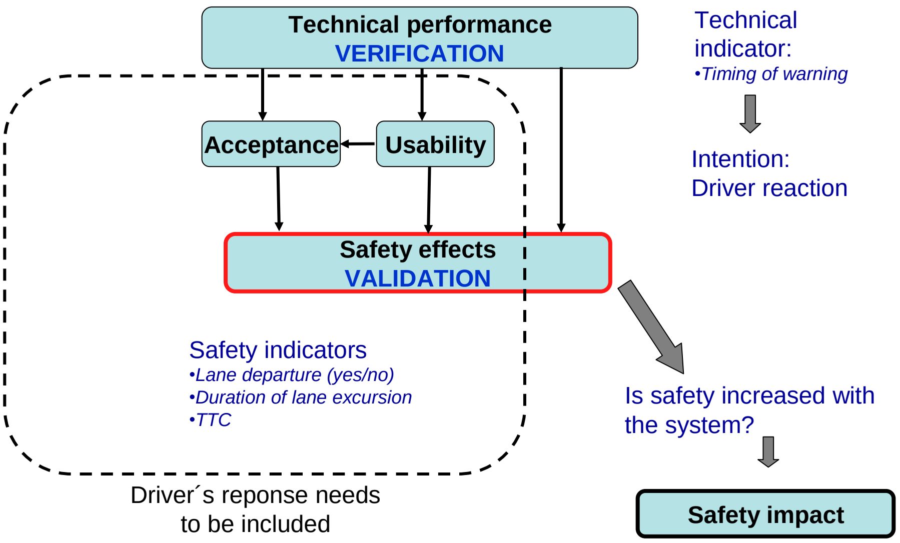

Figure 2: Validation vs. Verification

Driver in the loop testing

Depending on what safety system the vehicle is equipped with, the driver will be more or less involved in the vehicle's overall response. The overall outcome from an activation of a warning systems like Forward Collision Warning (FCW) system or Lane Departure Warning systems (LDW) entirely depends on the drivers reaction to the system and the driver's acceptance of the warning, while a supporting system as for example a Lane Keeping Assistance system (LKA) to largest extent relies on the driver's reaction, but might also have some intervening action from the vehicle itself, for instance by applying a torque in the steering wheel. For other preventive safety systems like ABS or ESP with autonomous intervention, the vehicle itself provides the complete corrective manoeuvre for taking control of the situation. However also in these situations and for the intervention systems, the driver's reaction during the critical event is of importance in order to understand in what way the driver can influence the overall outcome of the situation.

When performing validation tests with drivers one challenge is to define a reference or baseline for evaluating safety effects. When evaluating technical performance, it is most likely to have a certain specification on how the function will behave, for analysis of the results. Also when evaluating safety effects it is needed to have a reference for the test when analysing the data. This reference is often called baseline when performing driver tests.

One possibility for creating a baseline for comparison is to perform driver tests with and without the safety system equipped. A problem with this strategy is that it is not easy to create a critical situation in a real test environment without the safety system equipped for safety reasons. A recently published report from NHTSA; *Methodology for estimating safety benefits for Preproduction Driver Assistance Systems (Burgett et al, 2008)* presents a methodology for estimating safety effects using naturalistic driving data from a recently conducted field operational test (FOT), in combination with driver tests in similar situations as found in the FOT data, but with safety functions installed in the vehicles. This methodology is of great interest when considering driver tests in eVALUE.

A common way to validate warning or supporting systems with drivers is to use a driving simulator, in which you can create critical scenarios in a repeatable way with similar prerequisites for many drivers. To test these driver behavioural effects when driving with intervention systems in a driving simulator brings another dimension of complexity in a driving simulator since a representative vehicle dynamics model and characteristics for achieving the right prerequisites is needed for the tests.

Driver in the loop testing is further discussed in the chapter driving simulator tests. Most of the challenges with driver tests discussed in this chapter are also applicable for physical testing with drivers.

eVALUE scope

The eVALUE scope is mainly to investigate performance testing methods that can be carried out in a physical environment both with respect to verification and validation. Within WP3 testing protocols will be derived focusing on either verification or validation.

Verification tests are naturally performed in a physical environment, in which the vehicle and function acts under natural environmental conditions and vehicle dynamics prerequisites. Validation tests for evaluating safety effects might be performed in a physical environment or in a driving simulator depending on the purpose with the test and the type of system (warning, support or intervention).

Driver tests on test track and in driving simulator both have drawbacks and advantages. Test in a physical environment will provide a more realistic test environment but it will on the other hand be difficult to create critical scenarios for safety reasons. It will also be difficult to assure repeatability of the tests and tools for performing driver tests such as dummy vehicles might not appear realistic to the driver. In a driving simulator you might get other effects because of the virtual environment.

A current large research area is driver modelling which is an important and interesting input and complement to the eVALUE project for understanding driver’s behaviour. Other related research projects are the currently ongoing field operational test (FOT´s) projects which aim at collecting data on driver’s behaviour.

1.4 Status of the test procedures

Not all the test procedures have the same level of development and not all the types of test have the same number of test procedures. A scheme of what is provided in this deliverable is given as a reference.

- Design reviews
  - Test procedure for Definition of subject vehicles
    - Draft test protocol
    - Draft checklist for type of vehicle
    - Draft checklist for longitudinal functionality
    - Draft checklist for lateral functionality
    - Draft checklist for stability functionality
    - Draft checklist for external communication
  - Test procedure for Environmental conditions
    - Draft test protocol
    - Draft checklist for environmental conditions
  - Test procedure for HMI design
    - Draft test protocol
    - Draft checklist for HMI design

        - Test procedure for Functional safety
            - Draft test protocol
            - Draft checklist for functional safety
- Physical tests
    - Cluster 1
        - Description, implementation and assessment for the test procedure for deceleration of target vehicle
        - Description, implementation and assessment for the test procedure for approaching a slower or stationary target vehicle
        - Description, implementation and assessment for the test procedure for transversally moving target
    - Cluster 2
        - Description, implementation and assessment for the test procedure for lane and road departure
        - Description, implementation and assessment for the test procedure for lane change collision avoidance on a straight road
    - Cluster 3
        - Description, implementation and assessment for the test procedure for mu-split braking
        - Description, implementation and assessment for the test procedure for collision avoidance manoeuvre
        - Description, implementation and assessment for the test procedure for fast driving into a curve
        - Description, implementation and assessment for the test procedure for rollover
- Laboratory tests
    - Component tests
        - Specifications list for component tests
- Driving simulator tests
    - Specifications list for driving simulator tests

It is important to understand that WP2 has to provide a specification list of all the test procedures, which is already done in this document. The development of the final test procedures will be done in WP3 and WP4.

2 DESIGN REVIEW

A design review is a systematic, comprehensive and documented analysis of a design to determine its capability and adequacy to meet its requirements. A design review also serves to identify present and potential problems. Most parts of the design review are done studying the documentation and interviewing the manufacturer, but other parts of the work might be done investigating the vehicle.

2.1 Introduction

A design review may be performed with one out of three different objectives (see Figure 3) The first objective for a design review would be to familiarize with the subject vehicle. Efficient performance testing will require the test engineer to understand the safety functionality of the vehicle. The design principles of the ICT-based safety systems should also be understood, even if the performance testing does not explicitly address the performance of individual systems. Such a “get-to-know” design review would include a definition of the subject vehicle, an overview of longitudinal functionality, an overview of lateral functionality, an overview of stability functionality, and external communication needs.

The second objective for a design review would be to prepare a test. The test cases of the performance testing will partly be chosen depending on potential weaknesses of the system and on the already performed test by the manufacturer. An example of such a design review is for system performance in different environmental aspects (rain, snow, ice, darkness etc.). The performance at different environmental influences may be reviewed and assessed instead of thoroughly tested at the performance testing. The manufacturer must be able to show the efforts made during development testing of user behaviour and environmental conditions. “Normal conditions” (dry asphalt or concrete, flat road, approx 20 °C) would then suffice at the performance testing.

The third objective for a design review will be to actually perform an evaluation reaching a pass or a fail judgement. The design review will be part of the safety evaluation. The interface to the driver (human-machine interface, HMI) will probably be reviewed and assessed by a small number of experts. A time-consuming HMI test with a large number of drivers cannot be afforded at the performance testing. The focused HMI design review by experts will conclude if the HMI is “pass” or “fail” in the performance testing.

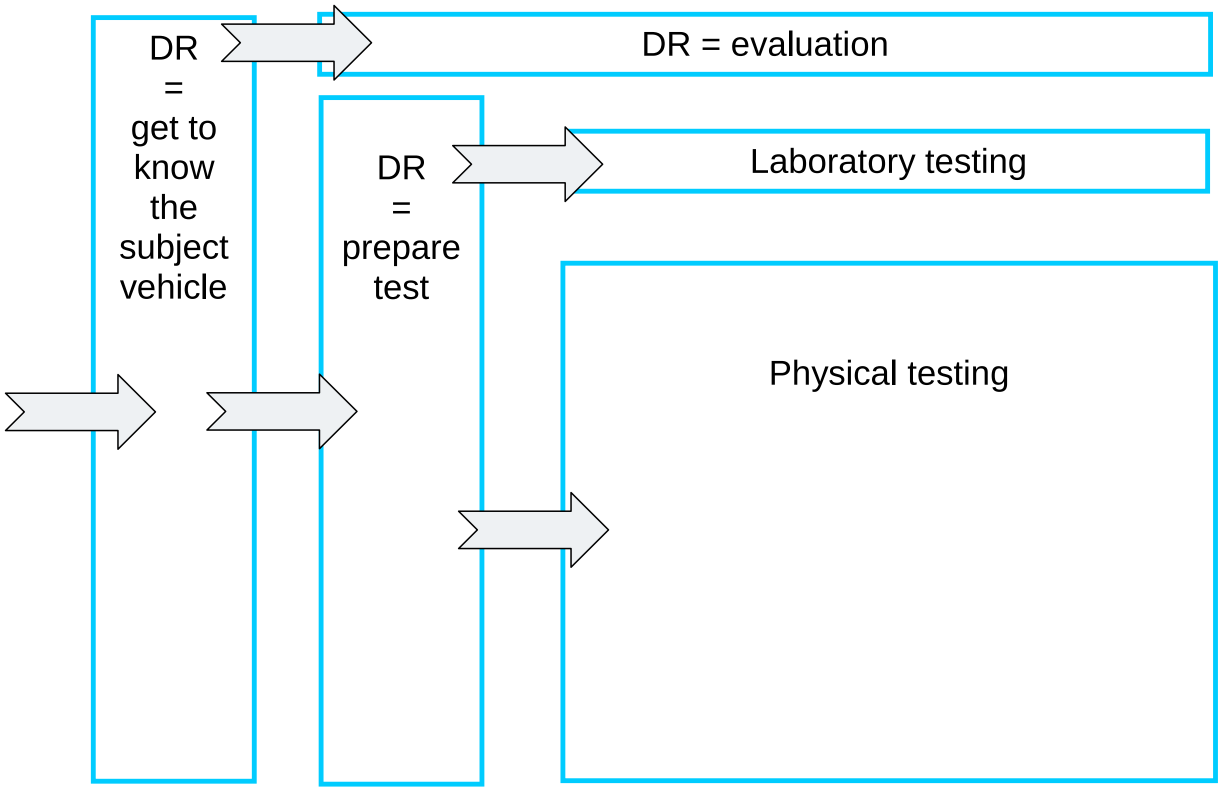

Figure 3: Objectives to perform a Design Review (DR)

2.2 Aims and goals with Design Reviews

As stated above, a design review is a practical document able to give some information about the vehicle to be tested and able to indicate some failures or bad practices implemented in the vehicle, a priori, before any test is implemented.

An issue related to Design Reviews is the need of having a close contact with the vehicle manufacturer. Some of the information required can be obtained by simply inspecting or driving the vehicle but, for some other, it is needed to contact the manufacturer. At some points, information might not be easy to get, because it could be sensitive, confidential or because the manufacturer would not find the necessity of sharing it. This issue is not completely in the scope of eVALUE and, at least, not at the level of WP2, but some concerns have been arisen. Thinking in a future 'eVALUE Test Programme, an effective manner could be defining a collaboration bonus, but this will be discussed in the next work packages.

2.3 Specifications for Design Review of Definition of Subject Vehicle

It is important to clearly identify the vehicle under test (i.e. the subject vehicle), especially if the vehicle is a prototype vehicle. All major characteristics of the vehicle influencing the performance testing must be noted. The challenge of identifying the vehicle under test is greater at performance testing than at testing of passive safety. Even small design modifications in the active safety systems may severely influence the performance.

A certain model of a road vehicle is normally produced in several different types. There will be differences in engine, chassis, brakes etc. Many of these differences will not be important for the performance testing. It will in many cases be possible to choose one type of vehicle for the performance testing, and to assume that the test results are valid also for other types of the same vehicle.

Evaluation of longitudinal, lateral, and stability safety functionalities require information about their characteristics and limits, e.g. the kind of sensor used and limits of its operation range. If the manufacturer has already done tests it is helpful to receive information about these tests to ensure that they are adapted to the system tested and the related standards.

The safety performance dependence on reliable external communication will also be reviewed. External communication includes positioning, vehicle-to-vehicle, and vehicle-to-roadside communication. Transmission anomalies, such as distortion and interference, can have a negative effect on the overall performance and it is consequently addressed in the review.

This testing protocol describes how to perform a design review to identify the type of vehicle, its safety functionalities, and possible dependence on external communication. The design review is necessary to specify the vehicle under test and all other types of the vehicle model intended to be covered by the performance test. It is also a necessary step for the test engineers familiarizing with the subject vehicle and its safety functionalities.

The results of the design review cannot be a pass or fail judgement, but simply a definition of the subject vehicle and its safety functionalities.

The result of the design review will be:

- a clear identification of the subject vehicle. The identification shall include a list of all active safety functions included.
- a list of all other types of the vehicle model for which the performance testing results will be regarded valid.
- if the characteristics of the system complies with the related standard
- if the testing protocol used matches with the requirements of the standard
- if the testing protocol used by the OEM provides repeatable test results
- influence of the availability of communication systems on the performance of the subject vehicle
- definition of safe-state in the occurrence of communication failures/faults
- performed test cases for communication shortcomings by the manufacturer

2.4 Specifications for Design Review of Environmental Conditions

Development of ICT-based safety systems requires extensive testing to understand how the vehicle is influenced by its environment. Temperature, light conditions, pollution, precipitation or road characteristics may influence the performance. Sensors, controllers, and actuators might be negatively affected by adverse environmental conditions. Development testing by the manufacturer will address all identified hazards.

Performance testing on the test track is often performed at normal environmental conditions. Due to the limited time and resources during performance testing, a design review could be used to validate which environmental conditions the vehicle can handle.

The objective is to verify that the design fulfils the requirements on operation during different environmental conditions. The important environmental influence factors must be identified, and the vehicle and its ICT-based safety functionality must be verified during different environmental conditions.

The result of the design review will be four conclusions:
- if environmental conditions are expected to influence the performance of the design to be tested.
- if the developer has specified requirements for environmental influence.
- if the developer has performed adequate tests of the environmental influence.
- if normal environmental conditions can be applied at performance testing on the test track.

2.5 Specifications for Design Review of HMI Design

Development of ICT-based safety systems requires extensive testing to understand how the vehicle and driver are influenced by the HMI design. Depending on level, the driver will be warned, supported, and/or intervened by the vehicle. Hence the interaction between the vehicle and the driver is important.

Performance testing on the test track is often performed using robots or professional drivers. Due to the limited time and resources during performance testing, a design review could be used to validate the appropriateness of the HMI design of the vehicle.

The HMI requirements specification and the user manual for the subject vehicle will be analysed. Status indication, visual warnings, visual information, haptic warnings and auditory warnings will be examined for the longitudinal, the lateral and the stability functionality. Also the intervention and combinations of warnings/interventions will be assessed.

The result of the design review will be four conclusions:
- if the HMI design is expected to influence the performance of the design to be tested.
- if the developer has specified requirements for HMI design.
- if the developer has performed adequate tests of the HMI design.
- if simulation experiments of the HMI design is necessary to complement performance testing on the test track.

2.6 Specifications for Design Review of Functional Safety

The components within vehicles are becoming more and more replaced by electronic devices which are taking over additional (safety) functionalities. The consequence is an increased complexity of safety requirements, preventive actions to avoid faulty states and failures of those components. Safety turns out to be one of the key issues as new functionalities as ADAS (Advanced Driver Assistance System), dynamics control and additional safety systems emerge.

Failure in ICT-based safety functions may cause risks. Meanwhile when designing such a system, the goal is to develop a system that provides the safety functions it is designed for under any probable situation. The design review of the functional safety shall address the safety principles applied and the safety measures implemented to avoid hazardous system states or operation modes. The development of ICT-based functions must be based on a requirement specification set-up adapted to the hazardous situation attributed to systematic faults, component failures, or driver mistakes.

Due to the limited time and resources allocated to performance testing, a design review could be used to verify how the vehicle handles different types of failure.

The objective is to verify that the design fulfils the specified requirements when the vehicle is operating in the occurrence of hazardous events. The important faults/failures that may influence the behaviour of the vehicle must be identified, and the vehicle and its ICT-based safety functions must be verified for different failure modes.

Failures in ICT-based safety functions are unlikely to occur during the limited time of performance testing. Thus, a design review is required to verify the vehicle behaviour at fault.

The design review shall after examination of the safety functions shows that:

- A situation analysis and hazard identification has been carried out.
- A classification of the hazards has been made
- A safety integrity level is assigned to each safety function.

The result of this design review is to present an opinion on the safety-related aspects of the ICT-based safety functions.

2.7 Next steps in Design Review

As stated before, the Design Review test procedures are in an advanced state. No major changes are expected but the work will continue in WP3 and WP4, with the objective of integrating them in an ‘eVALUE Test Programme and giving the assessment indications for the results of the tests. The option of adding new Design Reviews for aspects not considered will be open during the next work packages.

3 PHYSICAL TESTING

3.1 Introduction

The general approach of eVALUE is based on real accident scenarios. This approach is emphasized in physical testing, where there is a clear implementation of real traffic scenarios. It is approved among the partners that the approach for the physical tests is the scenario approach. The purpose of this type of test is to assess the complete vehicle's performance. In other words, the approach is not to test one particular ICT-based safety system, but to validate the whole vehicle's safety performance under different scenarios, i.e. specific real driving situations, which are relevant regarding the functionality of the considered ICT-based safety systems.

Physical testing serves mainly two purposes; to test that the vehicle meets a specific required behaviour in a certain scenario (verification) and to test and evaluate the safety effects of vehicle's behaviour in a certain scenario (validation). The test objectives with the two types of tests are both important and are closely linked. Tests performed for validation can be distinguished from verification tests in terms of the availability of reference documents; requirements to tests against and indicators to measure, but most importantly with respect to the necessity and feasibility of including drivers in the tests.

A test procedure shall fulfil the following requirements:

- Cover all safety categories
- High repeatability of the manoeuvre
- Driver independent
- Clear metric available for safety assessment
- Accurate results
- Reasonable test and evaluation effort
- Neutral for different vehicle categories
- As neutral as possible for different weather and track condition
- Motivate OEM for new system introduction and improvement
- Accident representative
- Promote the use of the available safety features

3.2 Definitions, measurements and safety indicators

The performance of active safety systems can be determined by safety indicators. These indicators are considered for all three clusters and all systems within the scope of eVALUE.

Potential safety indicators were introduced in deliverable D1.2 "CONCEPTS DEFINITION" of WP1. The indicators proposed are based on the variables collected from the common experience among the eVALUE partners and should be seen as potential indicators that can be applied to the eVALUE clusters. The next table shows the proposed safety indicators of deliverable D1.2 (eVALUE-081231-D12-V10-FINAL.pdf, see chapter 7).

SAFETY INDICATOR / cluster	CLUSTER1	CLUSTER2	CLUSTER3
Collision speed	X	X	X
Driver's acceptance and usability	X	X	X
Headway time	X		
Time Line Crossing		X	
Path deviation		X	X
Target detection, dimension and classification	X	X	
Function output type and relevance	X	X	X
Driver's intention	X	X	X
Braking distance			X
Vehicle's control			X

Based on the given proposal description of all potential safety indicators and measures are to be compiled. First a definition of the terminology is given. The detailed description and further explanation is provided below.

3.2.1 Definitions and measurements

This section shows all the measures which are necessary in order to calculate or derive the safety indicators for the active safety systems within the scenarios of eVALUE.

Distance between the subject and the target vehicle
This value is to be measured by a reference measurement unit, e.g. a motion pack unit in combination with a D-GPS installed in test vehicles.

Local position of the subject or target vehicle
This value is to be measured by a reference measurement unit, e.g. a motion pack unit in combination with a D-GPS installed in test vehicles.

Longitudinal acceleration of the subject or target vehicle
The longitudinal acceleration is to be measured by a reference measurement unit, e.g. using an accelerometer fixed to the body of the vehicle in the centre of gravity.

Velocity of the subject or target vehicle
This value is to be measured by a reference measurement unit, e.g. a motion pack unit in combination with a D-GPS installed in target vehicle.

Angular rates of the subject or target vehicles
These values to be measured by a reference measurement unit e.g. are provided by gyroscopes positioned at any rigid point of the body of the vehicle. Following SAE signs convention, roll rate corresponds to a rotation around X-axis, pitch rate corresponds to a rotation around Y-axis and yaw rate corresponds to a rotation around Z-axis.

Point of time of collision (if there is any)
The point of time of collision is the instant when the subject vehicle collides with the target. A collision takes place when any part of the subject vehicle touches the target. The value of the measured variable “Collision” is TRUE or FALSE. The value TRUE corresponds to a collision occurring.

One possible way to measure collision is to provide the target with a pressure-sensitive edge indicating contact with the subject vehicle. Another way is to accurately measure the position of both subject and target vehicles. Then, a collision has occurred when the position of the leading edge of the subject vehicle is equal to or exceeds the position of the trailing edge of the target vehicle.

Local time reference
Trigger signals for the video and audio need synchronisation. According to the data logging system capabilities, it may be necessary to create an external trigger signal to synchronise the recorded data, e.g. video, sound, speed etc. Some data loggers are able to record analogue data like video and sound and digital data simultaneously. In that case the trigger signal would not be necessary. The local time corresponds to the data logger time reference.

Warning signal to the driver
Audio and/or video recording of the dashboard and netter panel synchronised with vehicle data.

Brake fluid pressure
The brake fluid pressure allows knowing when the system is actuating on the brakes and to should identify which is the source: driver's action (brake pedal position or system action).

Braking lights signal
The brake lights signal is an important parameter to check, as it permits knowing when the vehicle is indicating to other drivers that it is braking. This is checked by capturing the power voltage of the third brake light.

Steering wheel angle
The steering wheel angle is the angle steered by the driver (or a steering robot). This can be measured with an absolute encoder.

Steering wheel torque
The steering wheel torque is the torque done by the driver (or a steering robot) in order to turn the steering wheel. This can be measured with a simple load cell and represents the effort needed to actuate on the steering wheel during a manoeuvre.

Brake pedal force
The pedal force is the force done by the driver (or a steering robot) in order to act on the brakes of the vehicle. This can be measured with a simple load cell and represents the effort to actuate on the pedal during a manoeuvre. This pedal force can be used as a trigger for the start of a braking manoeuvre.

Friction material temperature
The friction material temperature is the temperature of the braking pads of the braking system during the tests. For repetitive braking manoeuvres, it is necessary to monitor this temperature, in order to ensure that all the tests have been done under the same range and the braking system was on nominal working conditions.

3.2.2 Safety indicators

Within this section, all safety indicators which are necessary in order to assess the active safety performance of the vehicles within the scenarios of eVALUE are given.

3.2.2.1 Suitable for cluster 1

Mean/min. distance to target vehicle
The mean and minimal distance of the subject vehicle to the target vehicle during the whole test sequence.

Mean/min. time gap to target vehicle
The time gap is used to appreciate the distances from a human point of view. For example it is common for an ACC system to be set according to a time gap and not a distance. It represents the time separation between 2 vehicles cruising at constant speeds.

It is calculated by: *Time gap = relative longitudinal distance / Subject vehicle speed*

Mean/min. time to collision (TTC)
Time to collision is used in spite of time gap when during an impact scenario the relative speed between vehicles is bigger than 10 km/h. It gives clear information on how much time is available before having an impact. It makes sense to use this value to analyse evolution of this parameter during the test sequence each time an impact occurs between the target and the subject vehicle.

It is calculated by: *Time to collision = relative longitudinal distance / relative speed*

Timing of warning signal / intervention
The moment when the driver is warned shall be analysed according to the time gap or to the time to collision. Each types of warning shall be recorded (audio and visual) and used in the analysis.
The intervention action represents the point in time when the system acts the brakes (or not). It can be indicated by using a brake fluid pressure sensor. As for the warning signal, it may be analysed according to the time gap and to time to collision.

Max. initial speed
This is the maximum initial speed of the subject vehicle that does not result into a collision with a stationary or slower target vehicle.
The maximum initial speed of the subject vehicle is measured at a reference distance or initial distance from the target vehicle. The initial distance is specified in the testing protocol.

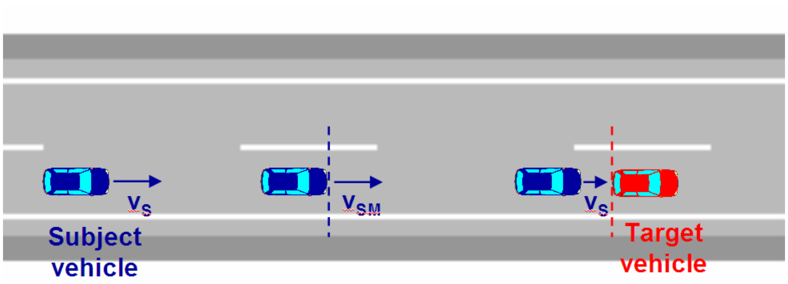

Figure 4: Maximum initial speed scheme

Generally, the subject vehicle is tested for its intervention capability to avoid collision with a stationary target vehicle. The safety indicator is the maximum initial speed that does not result into a collision with the target vehicle.

The safety criterion is: $V_{SM} \geq V_{min}$ where the minimum initial speed V_{min} is specified in the testing protocol.

Max deceleration of the target vehicle
The max deceleration of the target vehicle is the maximal deceleration of the target vehicle which does not result into a collision.

Max deceleration of the subject vehicle (% of max braking capabilities of the vehicle)
The max deceleration of the subject vehicle is the maximal deceleration of the subject vehicle during the whole testing procedure.

Collision speed
Collision speed is the speed, at which the subject vehicle collides into the target vehicle. It is measured at the moment of the collision. A possibility to measure the collision speed is by means of a rabbit vehicle or a balloon vehicle. Therefore the measurement is damage free and repeatable.

The collision speed has major impact on the kinetic energy in case of a collision:

$$E_{kin} = \frac{1}{2} m v_{collision}{}^{2}$$

Subject vehicle ax
Especially when the system is not able to avoid the crash, it is important to know whether the deceleration provided was up to the full capabilities of the vehicle or limited by the system. That indicates until which conditions (speed and distances) the vehicle will be able to avoid a crash.

Warning to other users
This value represents the moment and how the system warns the other drivers that a potential accident situation has been detected and the vehicle is braking (or not). As for the warning signal, it may be analysed according to the time gap to time to collision.

Brake pedal force
If required by the system, this is used to know the level of input required to operate a deceleration. It shall be expressed in % of the brake pedal maximal force applicable (usually 650 N).

3.2.2.2 Suitable for cluster 2

(Also, some of the safety indicators shown above could be suitable).

Collision speed
See previous chapter. In this case, the collision would be against a fixed object on the roadside or a vehicle driving in the next lanes.

Time to collision
See previous chapter. In this case, the collision would be against a fixed object on the roadside or a vehicle driving in the next lanes.

Timing of warning signal / intervention
See previous chapter.

Standard deviation lane position
During the manoeuvre, the middle of the lane is considered as optimum and deviations from the optimum are measured each time step. Then, the standard deviation of these measures is calculated. It is one of the most common performance metrics. Its popularity is probably due to its high face validity and computational simplicity.

Time to cross line (TTCL)
This value represents the time remaining before crossing the line. The objective is to know how much time before (or after) crossing the line the system warns or acts. Maximal or mean values can be used as indicators.

It is calculated by: *TTCL = lateral distance to lane / lateral speed (ground reference)*

Peak lane deviation
The peak lane deviation is the maximum magnitude of lateral position as measured from a point on the centreline of the vehicle projected downward to the pavement and subtracted from lane centreline or other fixed reference.

Time exposed TTC (TET)
The Time exposed TTC is the sum of the time being exposed to lower TTC during a manoeuvre. It describes the exposition to safety-critical time-to-collision values over specified time duration. A single TTC value gives no information about exposure to risk above a certain level, while TET does.

Time integrated TTC (TIT)
The Time integrated TTC gives information of the risk exposure in terms of time and severity to a TTC below than a certain defined threshold. TET has one major drawback: it does not consider enough really small TTC during a short time. TIT tries to overcome this by calculating the integral of time spent below a TTC threshold. .

3.2.2.3 Suitable for cluster 3

Related to mu-split braking scenarios

Stopping distance
It is the distance travelled by the vehicle during the braking manoeuvre. It is a performance parameter, directly correlated to the risk of collision.

Maximum initial speed (for a specific braking distance)
Maximum initial speed is the highest speed at which the vehicle can be stopped within a specific braking distance

Use of adherence
A parameter able to quantify the control done by the vehicle's systems of the available adherence of the different wheels in mu-split scenario.

Driver steering input
It will analyse the steering wheel angle, speed, torque done by the driver in order to quantify the amount of driver activity.

Lateral deviation
It is the maximum lateral deviation reached during the braking manoeuvre. For a closed-loop braking, it is a control parameter useful to check the quality of the closed-loop. For an open-loop braking it is an indicator of the vehicle stability.

Yaw response
Yaw response is the rotation around the z axis of the vehicle. Yaw rotation is related to the control of the vehicle hence it is important for safety.

Related to obstacle avoidance scenario
(Also, some of the safety indicators shown above could be suitable).

Lateral displacement
It is the value of the lateral displacement when the dwell manoeuvre starts (1.07 s). It is the responsiveness parameter suggested by FMVSS 126.

Maximum initial speed
Maximum initial speed is the highest speed at intervention at which the vehicle can manage the avoidance scenario.

Yaw rate ratios
They are the ratios between the yaw rate at certain times after the end of the steering wheel actuation and the yaw rate peak. They are the stability parameters suggested by FMVSS 126.

Driver intention following
This parameter represents the performance of a vehicle in terms of how closely it responds to the driver input. In an avoidance manoeuvre, the first half of the Dwell sine can be analysed and a prediction can be made about how the vehicle should respond in the second half. By comparing predicted response with actual response, effectiveness can be assessed in terms of response control and stability.

Vehicle speed variation
It is the difference in velocity between the start and the end of the manoeuvre. Together with sideslip angles peaks, it gives an idea about how much the ESC has to work in order to keep the vehicle stable.

Sideslip angle peaks
They are the minimum and maximum values of sideslip angles during a manoeuvre. They are stability parameters directly related to the oversteer tendency of the vehicle.

Related to fast driving into a curve scenario
(Also, some of the safety indicators shown above could be suitable).

Lateral deviation
Lateral position deviation respect to the closing curve reference.

Maximum initial speed (for a specific curve scenario)
Maximum initial speed is the highest speed at the entrance of the curve at which the vehicle can manage the curve scenario.

Related to rollover scenario
(Also, some of the safety indicators shown above could be suitable).

Two wheel lift
This is represents the rollover condition: if both inner wheels lifted more than 2 inches from the ground and for more than 20 ms.

Roll rotation
Roll rotation is the rotation around the x axis of the vehicle. Roll rotation is related to the stability of the vehicle and hence important for safety.

3.3 Instrumentation of the vehicles

This chapter describes the instrumentation to be used during the tests. It is described in a general sense, not differentiating among cluster 1, 2 or 3. Not all the instrumentation is required for all the tests developed within eVALUE. The devices are described according to the capabilities of the most commonly used ones. For this reason, all the instruments are represented by an example. The use of these instruments should not be understood as requirement, as other solutions with similar capabilities could be found. Some of the devices shown in this chapter may be used within eVALUE.

Positioning system
Example of equipment: *Oxford Technical Solutions - OXTS RT 3002*
The positioning system should include an inertial platform combined with a high accuracy GPS Navigation System. The objective of this combination is providing a high accuracy in the positioning of the vehicle, in order to calculate relative distances and closing speeds to other vehicles or objects. The use of the inertial platform should also provide highly accurate linear accelerations and angular velocities, which allow the calculation of parameters related to the dynamics of the vehicle. The system should be able to record the data of the test, with the suitable rate and filter it.

In a particular case, the OXTS RT 3002 is an advanced six-axis inertial navigation system that incorporates an L1/L2 RTK GPS receiver and delivers better than 0.02m RMS positioning under dynamic conditions using differential corrections. The outputs from the RT3002 Inertial and GPS Navigation System are derived from the measurements of the accelerometers and gyros. Using the inertial sensors for the main outputs gives the RT3002 system a fast update rate (100Hz) and a wide bandwidth. All the outputs are computed in real-time with a very low latency.

Figure 5: Installed positioning system – OXTS RT3002

Communications system
Example of equipment: *Oxford Technical Solutions - OXTS RT Range*
For tests where more than one vehicle takes part, it would be need to have a communications system able to exchange data between the positioning platform of all the vehicles, in real time, with the objective of synchronizing the registered data and the response actions.

In this particular case, the OXTS RT-Range is used for two functions: accurate (2 cm) measurement of the relative motion between two vehicles and synchronization. All measurements are online, in real-time and output on a CAN bus, including the Target vehicle measurements being relayed to the Subject vehicle's CAN bus.

Figure 6: communication system – OXTS RT Range

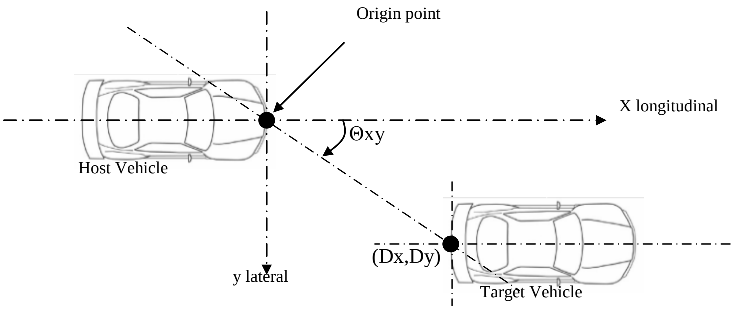

Figure 7: Coordinates system

Steering Robot System
Example of equipment: *Anthony Best Dynamics - ABD SR60*
The maneuvers implemented over the steering system of the vehicle need to be implemented in an accurate way, in order to provide consistent data. For this reason, the use of steering robots is recommended.

This will provide the repeatability required for implementing the tests and evaluating the results, but some issues related to the inclusion of a real driver (driver in the loop) might be limited. This problem is further discussed in the specification of the test procedures.

In a particular case, the ABD SR60 Steering Robot or the Programmable Steering Controller is designed to apply inputs to a vehicle's steering system through a closed loop control. The SR60 steering robot uses a direct drive brushed DC motor to produce over 60 Nm of torque. Torques of over 200 Nm might be needed for heavy vehicles. Typical maximum rates reach 2500 º/s.

Figure 8: Steering robot installed in vehicle

Braking Robot System
Example of equipment: *Anthony Best Dynamics – ABD BR1000*
The same comments done for the steering robot may apply for a braking pedal robot.

In a particular case, the ABD Brake Robot is designed to apply inputs to a vehicle's brake pedal for braking characterization and handling behavior measurement. It is typically used to apply step or ramped force or position inputs to the brake pedal. The ABD BR1000 can apply forces of 1400N to the brake pedal at a maximum velocity of 600mm/s.

Figure 9: Braking robot installed in vehicle

Accelerator Robot System
Example of equipment: *Anthony Best Dynamics – ABD AR series*
The same comments done for the braking robot may apply for an accelerator pedal robot.

The AR series Accelerator Pedal Robot is designed to apply inputs to a vehicle's throttle pedal for closed loop vehicle speed control.

Figure 10: Accelerator robot installed in vehicle

Driving robot capabilities
The driving robot is able to save and reproduce any manoeuvre made by a driver by saving the path. It is also possible to create specific path according to the test requirements as lane change, slalom, braking manoeuvre, accelerating manoeuvres. Using the driving robot with RT 3002 allows reaching a less than 2 cm path following precision.

Optical Speed / Slip Angle Sensor
The Optical sensor allows measuring the speed and the slip angle directly.

Figure 11: Optical Speed / Slip Angle Sensor

3.4 Specifications for Physical Tests of cluster 1

3.4.1 Introduction

In WP1, a total of three scenarios were selected in order to validate the vehicle from a longitudinal point of view. These scenarios represent a hazard in front of the vehicle when driving on a straight road, on a curve and when an object (vehicle, pedestrian…) crosses the road. For these 3 scenarios, different test procedures have been developed in D2.2.

Taking into account the safety functions suitable for the accident scenarios of cluster 1 and cluster 2, a general situation can be identified. A vehicle driving in a stabilized condition and having a sudden hazard (vehicle in front braking, object crossing, lane departure…). The systems fitted in this vehicle should be able to detect the situation, warn the driver and actuate to avoid the accident and minimize the consequences.

These situations can be represented with the following diagram:

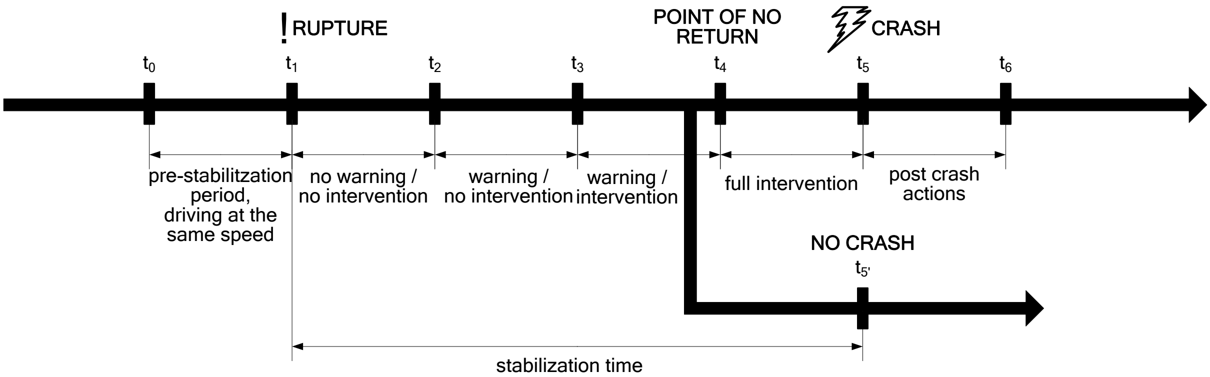

Figure 12: Timeline for cluster 1 and 2 analyses

3.4.2 Aims and goals with physical testing in cluster 1

The objective of the test procedures developed in cluster 1 should be able to represent the accident scenarios defined in WP1 and implement them in a way that it is possible to apply the timeline proposed in the previous chapter and identify the safety indicators proposed.

The safety functions studied in cluster 1 have two levels of operation, warning and intervention. These two levels should also be analysed within the test procedures proposed.

3.4.3 Test Procedures for Physical Tests of cluster 1

3.4.3.1 Test Procedure C1-1&2#1 Deceleration of target vehicle

3.4.3.1.1 Test Procedure description

Scenario:
C1-1 and C1-2: Straight road / curved road
It represents a rear end collision with decelerating target vehicle.

Environment:
The test is to be conducted on a flat dry surface with a horizontal visibility more than 1 km. The temperature shall be above 5°C. The environmental conditions shall not change during the course of the test.

Road parameters:
The friction coefficient of the road surface shall not differ from standard road types.

Road layout:
The test is to be performed on a straight track and on a curved track with a defined curve radius.

Subject vehicle:
The subject vehicle is to be equipped with measurement tools in order to record the necessary measures and to warranty the precision and repetitiveness requirements of the test.

Target vehicle:
The target vehicle is simulated by a dummy vehicle that is representative to an ordinary vehicle so that vehicle systems are able to detect them, but possible to crash into.
The target vehicle shall be varied between:

- passenger vehicle
- motorcycle
- truck

The target vehicles have to be in a clean condition. The vehicles shall not be changed during the course of the test.

The target vehicle is to be equipped with measurement tools in order to record the necessary measures.

Initial conditions:
The initial velocity of the subject vehicle and the target vehicle shall be varied between 30 and 90 km/h.

The time gap between the both vehicles should be between 0.5 and 3 s.

The deceleration of the target vehicle shall be between 0.1 and 0.7g.

3.4.3.1.2 Test Procedure implementation

The subject vehicle follows target vehicle in the same driving lane with same speed at a constant distance with the longitudinal safety functionality activated. The target vehicle performs a deceleration to reach its final speed after both vehicles have reached the initial condition for 5 s. The lateral distance between vehicles shall be 0m ±0.25 m during the entire test.

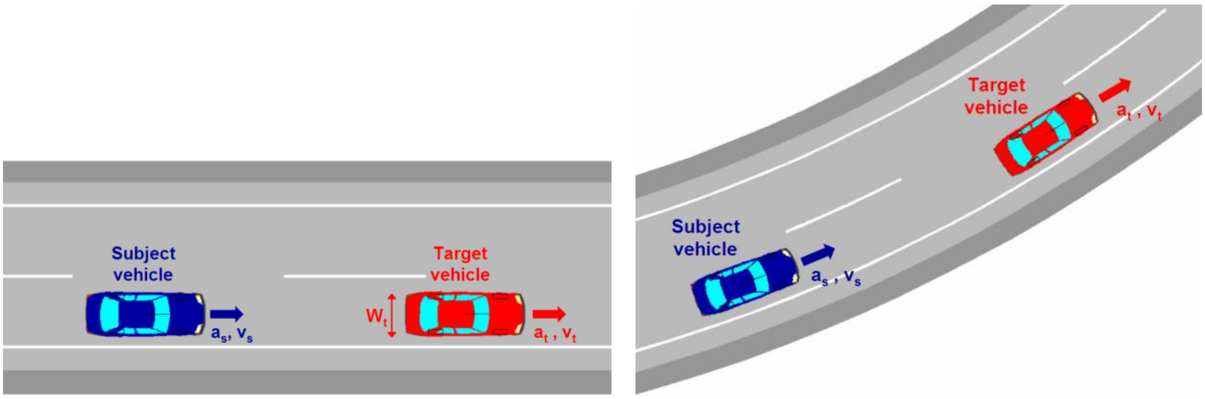

Figure 13: Scenario implementation

During the course of the test the following measures are to be recorded:

- distance between the both vehicles
- local Position of both vehicles
- velocity of the subject vehicle
- longitudinal acceleration of the subject vehicle
- velocity of the target vehicle
- longitudinal acceleration of the target vehicle
- point of time of collision (if there is any)
- local time reference
- warning signal to the driver
- brake fluid pressure
- brake lights signal
- brake pedal force (if needed by the systems to operate)

The measured data are to be logged from the beginning of the test until the full standstill of both vehicles.

3.4.3.1.3 Test Results analysis

Safety indicators to be evaluated:

- mean/min. distance to target vehicle
- mean/min. time gap to target vehicle
- mean/min. TTC
- timing of warning signal / intervention
- max. initial speed
- max deceleration of the target vehicle
- max deceleration of the subject vehicle (% of max braking capabilities of the vehicle)
- collision speed.

3.4.3.2 Test Procedure C1-1&2#2 Approaching a slower or stationary target vehicle

3.4.3.2.1 Test Procedure description

Scenario:
C1-1 and C1-2: Straight road / curved road
This represents a rear-end collision avoidance with a slower or stationary target vehicle

Environment:
The test is to be conducted on a flat dry surface with a horizontal visibility more than 1 km. The temperature shall be above 5°C. The environmental conditions shall not change during the course of the test.

Road parameters:
The friction coefficient of the road surface shall not differ from standard road types.

Road layout:
The test is to be performed on a straight track and on a curved track with a defined curve radius.

Subject vehicle:
The target vehicle is to be equipped with measurement tools in order to record the necessary measures.

Target vehicle:
The target vehicle is simulated by a dummy vehicle that is representative to an ordinary vehicle so that vehicle systems are able to detect them, but possible to crash into.
The target vehicle shall be varied between:

- passenger vehicle
- motorcycle
- truck

The target vehicles have to be in a clean condition. The vehicles shall not be changed during the course of the test.

The target vehicle is to be equipped with measurement tools in order to record the necessary measures.

Initial conditions:
The initial velocity of the subject vehicle shall be varied between 30, 50, 70, 90 km/h.
The initial distance to the target vehicle shall be more than 200m.
The initial velocity of the target vehicle shall be varied between 0 and 10 km/h.
The lateral distance between vehicles shall be 0m ±0.25 m during the entire test.

3.4.3.2.2 Test Procedure implementation

Subject vehicle approaches a slower or stationary target vehicle in the same lane. The target vehicle keeps a constant velocity or stationary.

The test speed of the subject vehicle shall be incremented until the subject vehicle is not able to avoid a severe impact with the target.

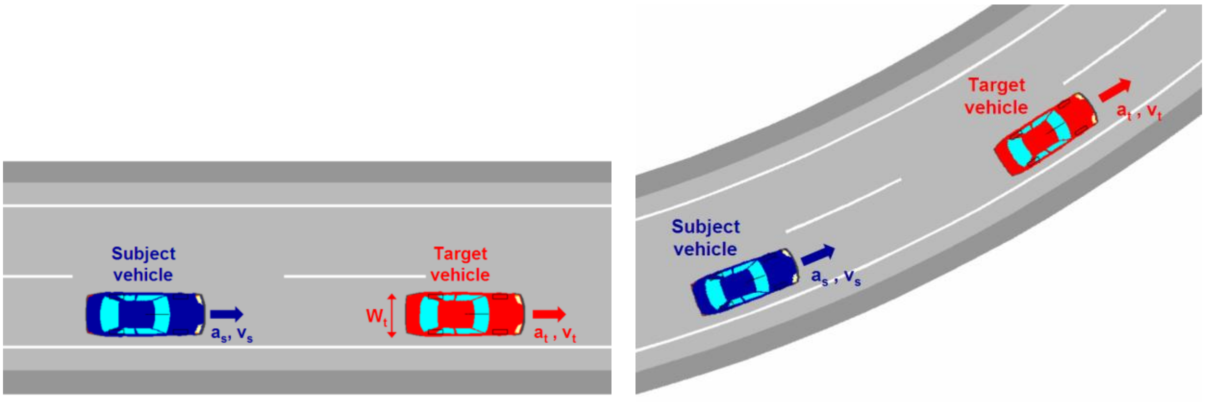

Figure 14: Scenario Implementation

During the course of the test the following measures are to be recorded:

- distance between both vehicles
- local Position of both vehicles
- velocity of the subject vehicle
- longitudinal acceleration of the subject vehicle
- velocity of the target vehicle
- longitudinal acceleration of the target vehicle
- point of time of collision (if there is any)
- local time reference
- warning signal to the driver
- brake fluid pressure
- brake lights signal
- brake pedal force (if needed by the systems to operate)

The measured data are logged from the beginning of the test until the full standstill of both vehicles and the accident situation has been avoided.

3.4.3.2.3 Test Results analysis

Safety Indicators to be evaluated:

- mean/min. distance to target vehicle
- mean/min. time gap to target vehicle
- mean/min. TTC
- timing of warning signal / intervention
- max. initial speed
- collision speed
- Max deceleration of subject vehicle (% of max braking capabilities of the vehicle).

3.4.3.3 Test Procedure C1-3#1 Transversally moving target

3.4.3.3.1 Test Procedure description

Scenario:
C1-3: Transversally moving target
This represents a frontal collision against a transversally moving target, which might represent another vehicle, a pedestrian, motorbike, bicycle or any other object.

Environment:
The test is to be conducted on a flat dry surface at an intersection with a horizontal visibility more than 1 km. The temperature shall be above 5°C. The environmental conditions shall not change during the course of the test.

Road parameters:
The friction coefficient of the road surface shall not differ from standard road types.
The straight section of the test track shall be more than 400 m.

Subject vehicle:
The subject vehicle is to be equipped with measurement tools in order to record the necessary measures.

Target objects:
The target object is simulated by a dummy vehicle or pedestrian that is representative so that vehicle systems are able to detect them, but possible to crash into.

The target object shall be varied between:

- passenger vehicle
- motorcycle
- pedestrian
- truck

The target objects have to be in a clean condition. The objects shall not be changed during the course of the test.

The target object is to be equipped with measurement tools in order to record the necessary measures.

The target object has to be detected the same way by the subject vehicle as a real reference target from the point of view of all the sensors (camera, radar or laser).

Initial conditions:
The initial velocity of the subject vehicle shall be varied between 30, 50 and 70 km/h.
The time gap to the target vehicle moving transversally should be varied between 1, 1.5 and 2 s.

The target movement shall be defined by:

- initial position of the target
- final position of the target
- acceleration and speed of the target
- time to collision between the target and subject vehicle when the moment the target finishes its manoeuvre.

3.4.3.3.2 Test Procedure implementation

The subject vehicle enters an intersection with constant speed. The target object enters the intersection on the left or right side suddenly in front of the subject vehicle to create a frontal collision scenario.

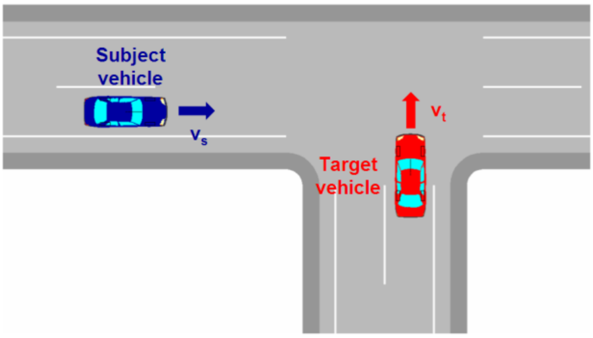

Figure 15: Scenario Implementation

During the course of the test the following measures are to be recorded:
- distance between both vehicles
- local position of both vehicles
- velocity of the subject vehicle
- longitudinal acceleration of the subject vehicle
- velocity of the target vehicle
- longitudinal acceleration of the target vehicle
- point of time of collision (if there is any)
- local time reference
- warning signal to the driver
- brake fluid pressure
- brake lights signal
- brake pedal force (if needed by the systems to operate)

The measures are to be logged from the beginning of the test until the full standstill of both vehicles.

3.4.3.3.3 Test Results analysis

Safety Indicators to be evaluated:
- mean/min. distance to target vehicle
- mean/min. time gap to target vehicle
- mean/min. TTC
- timing of warning signal / intervention
- max. initial speed
- collision speed
- max deceleration of subject vehicle (% of max braking capabilities of the vehicle).

3.5 Specifications for Physical Tests of cluster 2

3.5.1 Introduction

In this cluster focus is specifically on warning and supportive functions (BDS, LDW and LKA) and thus efforts will mainly be spent on how to include drivers in the loop in the tests but both verification tests and validation tests are included.

The same timeline proposed for cluster 1 (chapter 3.4.1) can be used for the specification and analysis of cluster 2.

3.5.2 Aims and goals with physical testing in cluster 2

The major purpose with the physical testing is to find methods for evaluating the safety effects of a vehicle (validation). However this presumes also that we use test setup where we can assure a correct functionality (verification) since the output of the vehicle is the basis for a potential response to that activation.

A number of general scenarios addressing the lateral control domain (cluster 2) have been defined in D1.2 based on available accident reports from EC and US. In order to derive test procedures and test protocols for this cluster the first step was to define the basis of the tests:

- The detailed scenario with respect to the specific course of events leading to activation from the system installed in the vehicle and a driver-vehicle response.
- The driver-vehicle-environment (DVE) parameters necessary for setting up the tests
- The test objectives
- What indicators or safety indicators to define and measure, depending on the test objective
- The necessary tools and environment for carrying out the test
- To define when to use representative test drivers (pilots) from the target group (e.g. based on age and gender of crash-involved drivers) in the tests and when to use a professional test driver.
- To investigate the usage of a braking/steering robot in this cluster is also of interest,

3.5.3 Test Procedures for Physical Tests of cluster 2

3.5.3.1 Proposed scenarios to be analysed

As it has been shown in the previous chapters and as it will be shown in the chapter for driving simulators, cluster 2 is complex because it is extremely influenced by the behaviour of the driver. Unlike cluster 3, where tests to be implemented with a steering robot might be sufficient for the assessment of the behaviour of the vehicle, cluster 2 needs a special focus on the reaction of the driver. cluster 1 is something in between, because the reaction of the driver is usually supported by an action of the vehicle and the systems are expected to act when a sudden hazard is taking part. On the other hand, the systems for cluster 2 mainly warn the driver during a period of inattention, which needs to be identified and taken into account.

For these reasons, the test procedures developed for cluster 2 should keep the requirements of robustness, receptivity and reproducibility (which, for vehicle dynamics testing are usually supported by driving robots) and also aspects of the driver and this needs a further development, which is not only involving physical testing, but also driving simulator tests.

Then, in this chapter, the proposed scenarios to be analysed as possible test procedures are described. The test procedures will be completed during WP3 and WP4.

3.5.3.2 Test Procedure C2-1to6#1 Lane and road departure

This chapter presents test procedures for lane and road departure on a straight and curved road respectively and thus summarizes the following test scenarios:

- Scen-C2-1 Lane departure on a straight road
- Scen-C2-2 Road departure on a straight road
- Scen-C2-3 Lane departure on a curve
- Scen-C2-4 Road departure on a curve

- ScenC2-5 Lane departure on a straight lane just before a curve
- ScenC2-6 Road departure on a straight lane just before a curve

3.5.3.2.1 Verification test procedure description

Test description: Lane or road departure on a straight lane or road or just before a curve.

Test objective: Verification tests performed at different speeds and departure angles with respect to e.g. the timing of warning and realization of warning with respect to HMI.

DVE-parameters:

- *Environment*
  According to ISO17361. The test shall be conducted on a flat dry asphalt or concrete surface with the nationally defined visible lane markings, in accordance with applicable standards for lane-marking design and material. The horizontal visibility greater than 1 km. The temperature shall be above 10 ± 30°C.
- *Subject vehicle:*
  The subject vehicle can be a truck or a passenger car travelling with speed 50-70 km/h (truck) or 50-90 km/h (passenger car). The subject vehicle will be equipped with measurement tools in order to record the necessary measures.
- *Target vehicle:*
  There are no target vehicles in this scenario.
- *Drivers:*
  Steering/braking robots or one professional test driver can be used for realizing the test.

3.5.3.2.1.1 Test Procedure implementation

Tools and equipment: Logging equipment. Steering/braking robot if needed. Positioning system.

Measures: During the test the following measures are to be recorded:

- Subject vehicle velocity
- Local position
  - Rate of departure
  - Subject vehicle deviation from the lane boundary
  - Point of departure across the lane boundary
- Local time reference
  - Warning signal to driver time point
  - Intervention time point

The measures are logged from the beginning of the test until the full standstill of the vehicle.

Figure 16 presents three examples on the scenarios for realizing the test. A more detailed description of the test implementation will be provided in test protocols within WP3 for test track and driving simulator respectively.

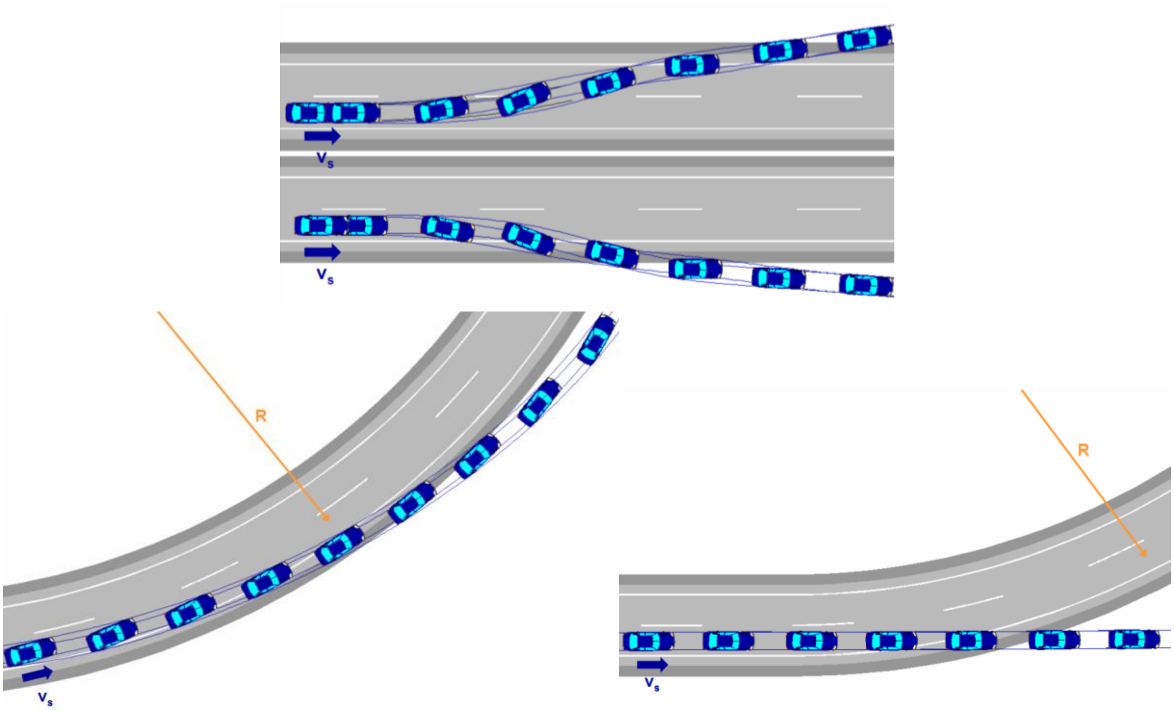

Figure 16: Scenario Implementation

3.5.3.2.1.2 *Test Results analysis*

The indicators to be evaluated are:

- Time to cross line (TTCL) at time for warning
- Correlation of visual and auditory HMI to available standards (see chapter 4).

3.5.3.2.2 *Validation test procedure descriptions*

The following tests may be realized also in a driving simulator with test drivers.

Test description: Lane or road departure on a straight lane or road or just before a curve. The scenario is tested with the safety system equipped and compared to a reference test without the safety system equipped. The driver gets visually distracted or occluded which induces a heading error, which in turn leads to a lane drift and an activation of a safety system.

Test objective: Validation test including driver response for evaluation of *intended safety effects* at a lane drift situation; that the driver, when driving with an active safety system and a lane drift occurs, responds to the system activation by re-allocating the attention to the road and makes a corrective steering manoeuvre to avoid a full lane departure.

DVE-parameters:

- *Environment*
  According to ISO17361. The test shall be conducted on a flat dry asphalt or concrete surface with the nationally defined visible lane markings, in accordance with applicable standards for lane-marking design and material. The horizontal visibility greater than 1 km. The temperature shall be above 10 ± 30°C.
- *Subject vehicle:*
  The subject vehicle can be a truck or a passenger car travelling with speed 50-70 km/h (truck) or 50-90 km/h (passenger car). The subject vehicle will be equipped with

an active safety system and measurement tools in order to record the necessary measures.

- *Target vehicle:*
  There are no target vehicles in this scenario.
- *Drivers:*
  Test drivers (pilot), distracted for creating a lane drift to the right or to the left are used for realizing the test.

3.5.3.2.2.1 Test Procedure implementation

Tools and equipment: Logging equipment.

Measures: During the test the following measures are to be recorded:

- Subject vehicle velocity
- Local position
  - Rate of departure
  - Subject vehicle deviation from the lane boundary
  - Point of departure across the lane boundary
- Local time reference
  - Warning signal to driver time point
  - Intervention time point
- Acceptance measures (see chapter 4.4)
- Usability measures (see chapter 4.4)
- Workload measures (see chapter 4.4)

The measures are logged from the beginning of the test until the full standstill of the vehicle.

Figure 17 presents three examples on scenarios for realizing the test. A more detailed description of the test implementation will be provided in test protocols within WP3 for test track and driving simulator respectively.

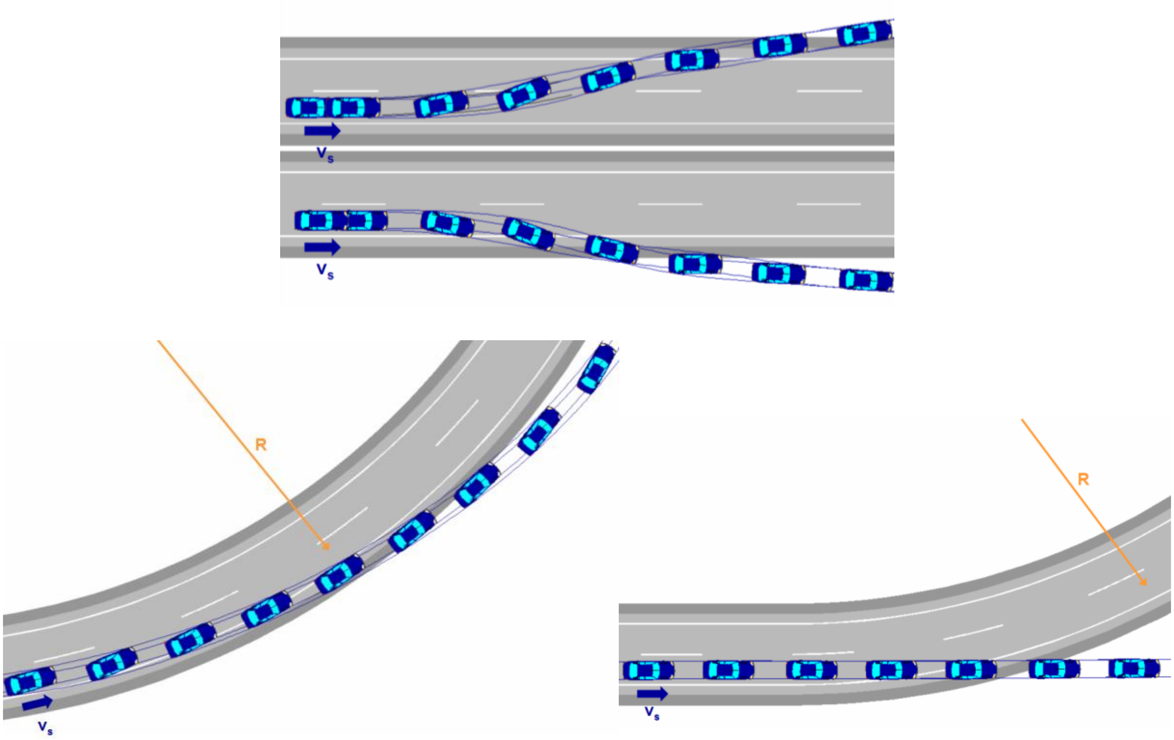

Figure 17: Scenario Implementation

3.5.3.2.2.2 Test results analysis

The safety indicators to be evaluated are:

- Mean/min time to cross line (TTCL)
- St. dev. lane position
- Peak lane deviation
- Mean/max time spent outside own lane
- Acceptance index (see chapter 4.4)
- Usability index (see chapter 4.4)
- Workload (see chapter 4.4)

3.5.3.3 Test Procedure C2-7#1 Lane change collision avoidance on a straight road

This chapter presents test procedures for lane change collision situations on straight roads.

3.5.3.3.1 Verification test procedure description

Test description: Lane change collision on a straight road. The subject vehicle changes lane to the right or to the left when there is another vehicle in the adjacent lane.

Test objective: Verification tests performed at different speeds for evaluating e.g. the timing of warning and realization of warning with respect to HMI.

DVE-parameters:

- *Environment*
  According to ISO17387. The test shall be conducted on a flat dry asphalt or concrete surface. The horizontal visibility greater than 1 km. The temperature shall be above 10 ± 30°C.
- *Subject vehicle:*
  The subject vehicle can be a truck or a passenger car travelling with speed 50-70 km/h (truck) or 50-90 km/h (passenger car). The subject vehicle will be equipped with an active safety system and measurement tools in order to record the necessary measures.
- *Target vehicle:*
  The subject vehicle can be a truck or a passenger car travelling with speed 50-70 km/h (truck) or 50-90 km/h (passenger car). The target vehicle will be positioned in the adjacent lane and can be a real vehicle representative dummy vehicle or a real vehicle, potentially protected with a cover with representative reflecting characteristics.
- *Drivers:*
  Steering/braking robots or one professional test driver can be used for realizing the test.

3.5.3.3.1.1 Test Procedure implementation

Tools and equipment: Logging equipment. Steering/braking robot if needed. Positioning system.

Measures: During the test the following measures are to be recorded:

- Subject vehicle velocity
- Target vehicle velocity
- Local position
  - Relative lateral and absolute distance between subject vehicle and target vehicle
- Local time reference
  - Warning signal to driver time point
  - Intervention time point

The measured are logged from the beginning of the test until the full standstill of the vehicle.

Figure 18 presents an example on the scenarios for realizing the test. A more detailed description of the test implementation with different realization of scenarios will be provided in test protocols within WP3 for test track and driving simulator respectively.

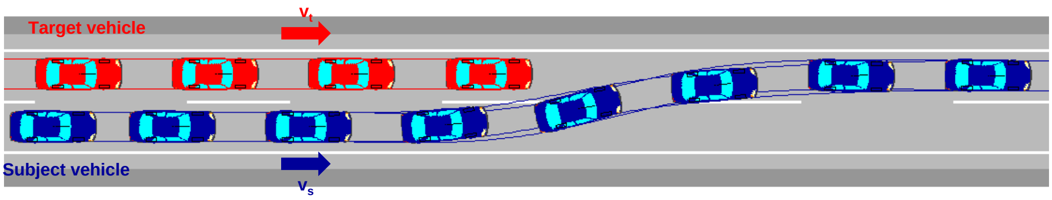

Figure 18: Scenario Implementation

3.5.3.3.1.2 *Test Results analysis*

The indicators to be evaluated are:

- Time to cross line (TTCL) at time for warning
- Time to collision (TTC) at time for warning
- Distance to target vehicle at time for warning
- Time gap to target vehicle at time for warning
- Correlation of visual and auditory HMI to available standards and guidelines (see chapter 4.4).

3.5.3.3.2 *Validation test procedure descriptions*

The following tests may be realized also in a driving simulator with drivers.

Test description: Lane change collision avoidance on a straight road. The scenario is tested with the safety system equipped and compared to a reference test without the safety system equipped. The driver is asked to make a lane change when another vehicle is travelling in the adjacent lane.

Test objective: Validation test including driver response for evaluation of *intended safety effects* at a lane change situation; that the driver, when driving with an active safety system and a lane change situation occurs with a vehicle close in the adjacent lane, makes the lane change in a less safety critical way.

DVE-parameters:

- *Environment*
  According to ISO17361. The test shall be conducted on a flat dry asphalt or concrete surface with the nationally defined visible lane markings, in accordance with applicable standards for lane-marking design and material. The horizontal visibility greater than 1 km. The temperature shall be above 10 ± 30°C.

- *Subject vehicle:*
  The subject vehicle can be a truck or a passenger car travelling with speed 50-70 km/h (truck) or 50-90 km/h (passenger car). The subject vehicle will be equipped with an active safety system and measurement tools in order to record the necessary measures.
- *Target vehicle:*
  The subject vehicle can be a truck or a passenger car travelling with speed 50-70 km/h (truck) or 50-90 km/h (passenger car). The target vehicle will be positioned in the adjacent lane. The target vehicle may be a real truck or passenger car travelling with speed 50-70 km/h (truck) or 50-90 km/h (passenger car) or a dummy target for safety reasons.
- *Drivers:*
  Test drivers (pilots).

3.5.3.3.2.1 Test Procedure implementation

Tools and equipment: Logging equipment. Steering/braking robot if needed. Positioning system.

Measures: During the test the following measures are to be recorded:
- Subject vehicle velocity
- Target vehicle velocity
- Local position
  - Relative lateral and absolute distance between subject vehicle and target vehicle
- Local time reference
  - Warning signal to driver time point
  - Intervention time point
- Acceptance measures (see chapter 4.4)
- Usability measures (see chapter 4.4)
- Workload measures (see chapter 4.4)

The measured are logged from the beginning of the test until the full standstill of the vehicle.

Figure 19 presents an example on the scenarios for realizing the test. A more detailed description of the test implementation with different realization of scenarios will be provided in test protocols within WP3 for test track and driving simulator respectively.

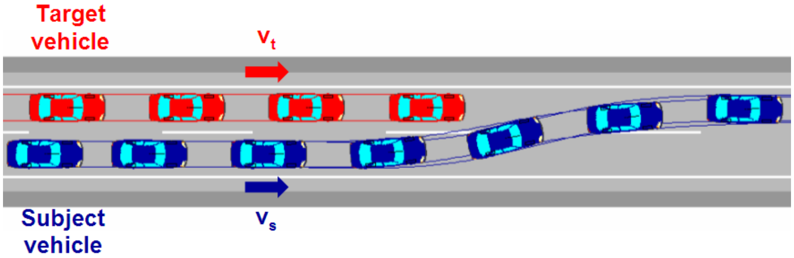

Figure 19: Scenario Implementation

3.5.3.3.2.2 Test Results analysis

The safety indicators to be evaluated are:
- Mean/min/max time to collision (TTC)
- Mean/min/max time exposed TTC (TET)
- Mean/min/max time integrated TTC (TIT)
- Mean/min distance to target vehicle
- Mean/min time gap to target vehicle

- Mean/min time to cross line
- Acceptance index (see chapter 4.4)
- Usability index (see chapter 4.4)
- Workload index (see chapter 4.4)

3.6 Specifications for Physical Tests of cluster 3

3.6.1 Introduction

Physical testing for cluster 3 is intended to reproduce the scenarios considered on a controlled environment in order to assess vehicle safety. The big difference in comparison with the tests proposed for cluster 1 and 2 is that the safety functions of cluster 3 are more common in the vehicles and have been fitted for a longer period of time. That means that time has allowed the development of methods which now are commonly used.

In addition to that, while safety functions for cluster 1 and 2 are usually related to new technologies and usually deal with the accuracy of sensors and the processing of the signals, cluster 3 is more related to the analysis of the physics affecting the vehicle. Traditionally, the dynamics of vehicles have been studied from a passive point of view, where the design of the chassis defined the response of the vehicle. With the new safety functions, such as the stability control, this response can be modified and this is what needs to be analysed. But, in any case, the techniques used for the analysis of the response from an active or passive point of view have the same basis. For this reason, the test procedures proposed here are based in the typical tests done in vehicle dynamics, but modified in order to take into account the effect of the new safety systems.

Generally, for cluster 3, the reaction of the driver (steer or brake action) is required before the intervention of the system and there is no warning given. In this case, the time line can be represented in a different way than in cluster 1 and 2 (chapters 3.4.1 and 3.5.1).

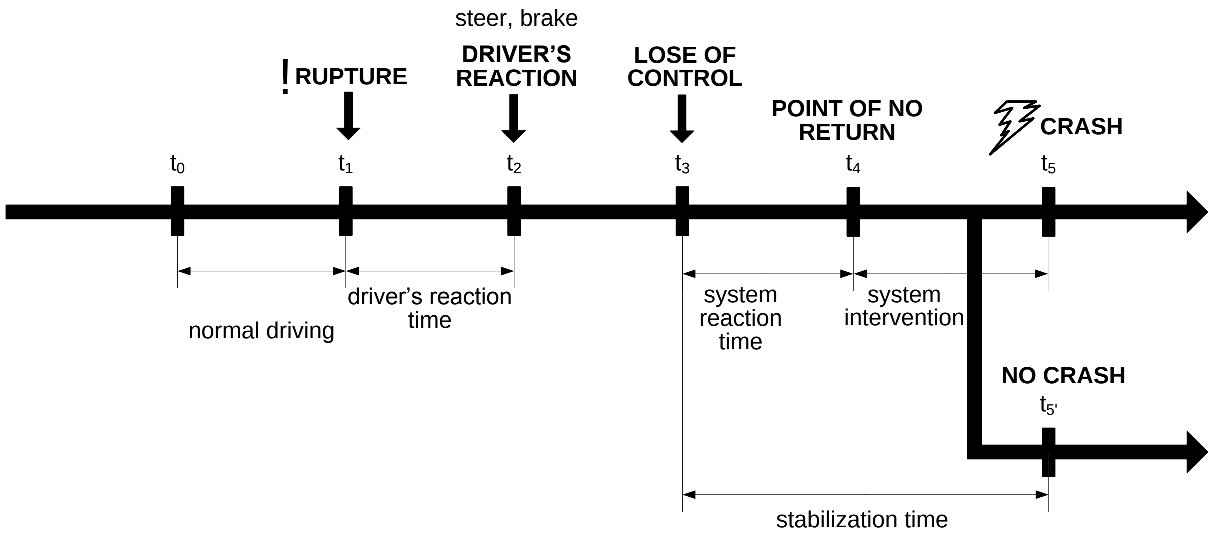

Figure 20: Timeline for cluster 3 analysis

3.6.2 Aims and goals for physical tests of cluster 3

The efforts in cluster 3 have been mainly dedicated to develop test procedures which:

- Neutral for different vehicle categories
  Vehicles are designed with the intention of transmitting certain values. For example, sports cars might be aggressive and exploit the entire grip available in the asphalt, while comfortable cars should be soft and filter any hard feeling. The test procedures should be able compare both types of vehicles and show the differences, but always in a relative context.

- Neutral for different weather and track condition
  Grip does affect in the response of the car. But the grip provided by the interaction between the grounds with the tyre is something which is not constant or proportional to the amount of mu available in the asphalt. For this reason, a test performed in different proving grounds might show different results and, then, the test procedures should be able to avoid this influence.

By now, concepts for cluster 3 are more oriented to passenger cars, rather than heavy goods vehicles. This has been established this way because grip management, which is what cluster 3 systems basically do, is more optimized in passenger cars. In any case, the test procedure C3-4#1, for rollover assessment, could be very interesting for HVG and, for this reason, it is still open to them.

3.6.3 Test Procedures for Physical Tests of cluster 3

3.6.3.1 Test Procedure C3-1#1 Mu-split braking

3.6.3.1.1 Test Procedure description

The following test procedure is intended to evaluate the safety performance of a vehicle in a mu split braking scenario. Open loop tests, with the aim of analysing the stability of the vehicle, and closed loop tests, with the aim of analysing the performance of the vehicle, are proposed.

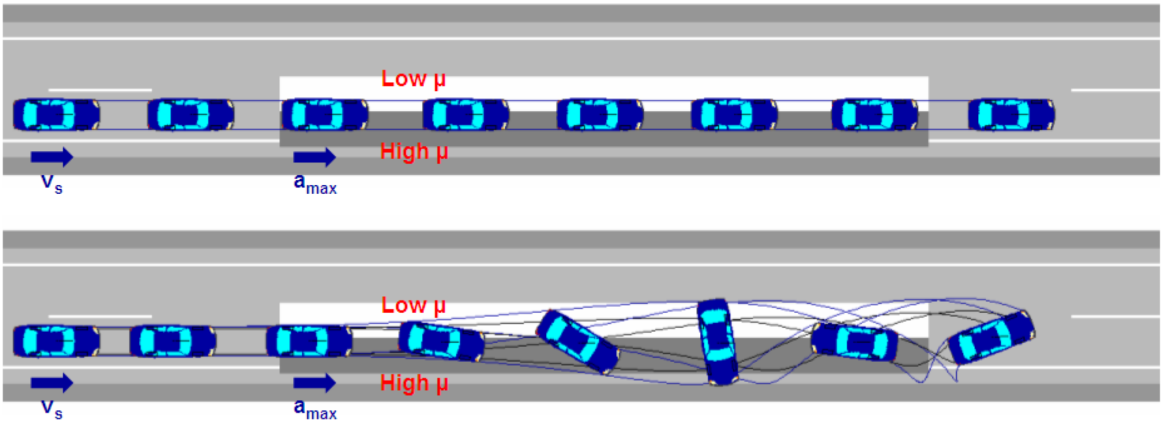

Figure 21: Scenario Implementation

- Track requirements
  Test track: minimum length of 200 m of mu split surface (low mu next to high mu). Friction coefficient shall be between 0.10-0.15 for low mu and between 0.8-1.0 for high mu. Example: wet ceramic (low mu) wet asphalt (high mu).

- Subject vehicle requirements
  Instrumentation List of parameters to be measured:
  - Local position
  - Velocity
  - Longitudinal acceleration
  - Steering wheel angle
  - Steering wheel torque
  - Yaw Rate
  - Brake pedal force (brake action trigger)
  - Friction material temperature (for repetitive brake condition)

3.6.3.1.2 Test execution

This test can be executed either in closed or open loop. Test conditions are described below:

- Initial conditions:
  - Speed: 100 km/h (closed loop) - 50 km/h (open loop)
  - Drive: gear in neutral position or clutch disengaged (panic brake situation)
  - Yaw rate: below ± 0.5 º/s
  - Vehicle position: vehicle longitudinal centreline projection must coincide with the longitudinal border line between surfaces.
- Braking manoeuvre:
  - Fast brake application
  - Closed loop: driver may act on the steering wheel in order to keep straight trajectory and stability
  - Open loop: steering wheel is kept at 0 º

3.6.3.1.3 Test Results analysis

The safety performance assessment is based on the evaluation of the safety indicators corresponding to the current scenario:

- Stopping distance
- Maximum initial speed
- Use of adherence
- Driver steering input
- Yaw response
- Lateral deviation

3.6.3.2 Test Procedure C3-2#1 Collision avoidance

3.6.3.2.1 Test Procedure description

The following test procedure is intended to evaluate the safety performance of a vehicle on an obstacle avoidance scenario. The execution of the test is based in the standard FMVSS 126 (Electronic Stability Control Systems, see chapter 7), proposed by NHTSA. What it is improved is the analysis of the results of the manoeuvre. Depending on the vehicle tested, this scenario can also be suitable for rollover testing.

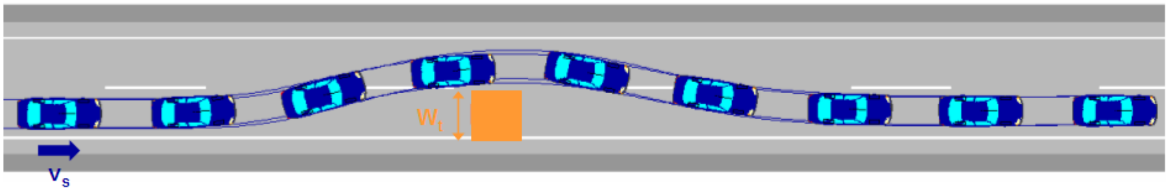

Figure 22: Scenario Implementation

- Track requirements
  Test track: high mu skid pad (dynamic platform) wide enough to perform the manoeuvre with safety

- Subject vehicle requirements
  Instrumentation List of parameters to be measured:
    - Local position
    - Velocity
    - Lateral acceleration
    - Steering wheel angle (with steering robot)
    - Steering wheel torque (with steering robot)
    - Yaw rate
    - Slip angle
    - Brake pedal force (no brake action during manoeuvre)
    - Friction material temperature (for repetitive brake condition)

3.6.3.2.2 Test execution

The test is an open loop test known as dwell sine and its execution is performed according to the FMVSS126 regulation by NHTSA. Main steps are summarised below:

- Initial conditioning: brake and tires
- Previous vehicle characterisation test for determination of $\delta_{0.3g}$: Slowly Increasing Steer (SIS)
    - Speed 80 km/h
    - Ramp steer 13.5 º/s

- Dwell sine test:
    - Speed: 80 km/h
    - Drive: highest gear engaged - throttle off
    - Steering wheel input amplitude: starts with 1.5*$\delta_{0.3g}$ until 6.5*$\delta_{0.3g}$ or 270º (whichever is greater) in 0.5*$\delta_{0.3g}$ steps
    - Dwell sine input: 500 ms dwell time – 0.7 Hz

3.6.3.2.3 Test Results analysis

The safety performance assessment is based on the evaluation of the safety indicators corresponding to the current scenario:
- Lateral displacement
- Vehicle speed variation
- Maximum initial speed
- Driver steering input
- Driver intention following

- Yaw rate ratios
- Sideslip angle peaks

3.6.3.3 Test Procedure C3-3#1 Fast driving into a curve scenario

3.6.3.3.1 Test Procedure description

The following test procedure is intended to evaluate the safety performance of a vehicle on a too fast driving into a curve scenario. The manoeuvre proposed reproduces a highway exit. Depending on the vehicle tested, this scenario can also be suitable for rollover testing.

Figure 23: examples of closing curves in highway exits

- Track requirements
  Test track: high mu skid pad (dynamic platform) wide enough to perform the manoeuvre with safety

- Subject vehicle requirements
  Instrumentation List of parameters to be measured:
  - Local position
  - Velocity
  - Lateral acceleration
  - Steering wheel angle (with steering robot)
  - Steering wheel torque (with steering robot)
  - Yaw Rate
  - Friction material temperature (for repetitive brake condition)

3.6.3.3.2 Test execution

This test can be executed either in closed or open loop. Test conditions are described below:

- Closed loop
  - The vehicle has to follow a clothoid (closing radius) trajectory starting from straight driving until the minimum radius R_{min}.
  - At minimum radius point, a lateral deviation condition must be passed in order to take the run as valid.
  - Drive: Throttle and gear conditions need to be defined.
  - Initial speed V_{in} is determined from a previous steady state test on a constant R_{min} radius test. Speed is incremented by 2% on successive runs as long as deviation check is passed. Test is finished when deviation check cannot be passed anymore.

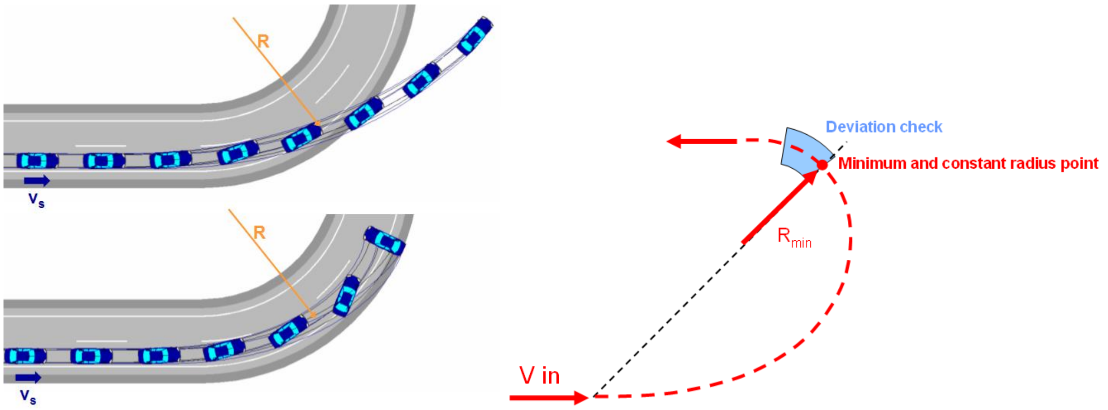

Figure 24: proposed closing radius manoeuvre

- Open loop:
    - Ramp steer test: 10 º/s (quasi steady state) until 180º
    - Speed: V_{in} (constant throttle, throttle release…)

3.6.3.3.3 Test Results analysis

The safety performance assessment is based on the evaluation of the safety indicators corresponding to the current scenario:

- Maximum initial speed
- Driver steering input
- Lateral deviation
- Yaw response

3.6.3.4 Test Procedure C3-4#1 Rollover scenarios

3.6.3.4.1 Test Procedure description

The following test procedure is intended to evaluate the safety performance of a vehicle on a rollover scenario. Depending on the vehicle tested, rollover testing can also be performed on C3-2 and C3-3 scenarios.

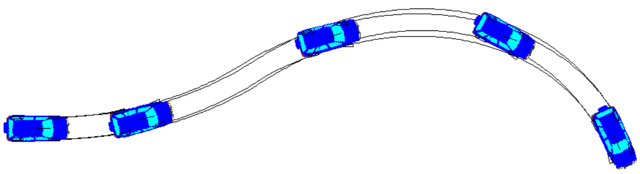

Figure 25: NHTSA fishhook manoeuvre

- Track requirements
  Test track: high mu skid pad (dynamic platform) wide enough to perform the manoeuvre with safety

- Subject vehicle requirements
  Instrumentation List of parameters to be measured:
    - Velocity
    - Lateral acceleration
    - Steering wheel angle (with steering robot)

- Steering wheel torque (with steering robot)
- Roll rate / roll angle
- 2 wheel lift / Tyre height

3.6.3.4.2 Test execution

The test is an open loop test known as Fishhook and its execution is performed according to the procedure defined by NHTSA in the Fishhook manoeuvre. Main steps are summarised below:

- Previous vehicle characterisation test for determination of $\delta_{0.3g}$: Slowly Increasing Steer (SIS)
  - Speed 80 km/h
  - Ramp steer 13.5 º/s

- Fishhook test:
  - Speed: 35 to 50 mph at 5 mph steps
  - Drive: highest gear engaged – throttle off
  - Steering wheel input amplitude constant: $6.5*\delta_{0.3g}$
  - Steering wheel rate: 270 º/s
  - Second part of the input is triggered by roll rate measurement 1.5 º/s
  - Dwell time of the second part of the input is 3 s
  - Weight condition: minimum and maximum

3.6.3.4.3 Test Results analysis

The safety performance assessment is based on the evaluation of the safety indicators corresponding to the current scenario:

- Maximum initial speed
- Driver steering input
- Tyre height / two wheel lift
- Roll rate / roll angle

3.7 Next steps in Physical Testing

The output of this Work Package is the specification of the test procedures to be integrated and evaluated in the next tasks within the project. Despite the test procedures have been specified for physical testing, not all of them are at the same level of development, because during the specification different problems have been found.

Cluster 1 has identified 3 main test procedures, which do not relate exactly to the accident scenarios found in WP1, but they cover all of them. One of the key aspects found in cluster 1 is the definition of the safety indicators and the definition of a time sequence for analysing the behaviour of the vehicle during the tests. The next steps should focus in the giving real values to this time sequence and finding which intervals should be achieved. Once this is concluded, the test procedures should be formalized in a testing protocol and an assessment protocol.

Cluster 2 has been dealing with the effect of the driver during the evaluation of the vehicle. This issue is not totally closed as, for this, an interaction with lab tests and driving simulators has been found and there are some aspects to analyse in supplementary studies. The scenarios for the test procedures have been identified and it has been defined what should be analysed within each scenario, including the effect of the driver. During the next tasks, these scenarios should be parameterized, by defining which are the desired values and how to introduce the behaviour of the driver in an appropriated way. Finally, the testing and assessment protocols should be defined.

Cluster 3 has proposed a different way of analysing the results of vehicle dynamics tests. This analysis has been oriented to avoid the influence of the ground in the vehicle's behaviour and to define an assessment which is able to compare vehicles with different characteristics. For this assessment, some parameters, such as test speeds, angles, trajectories, still need to be specified. After this precise specification, the testing and assessment protocols will be prepared.

4 LABORATORY TESTING

4.1 Introduction

The purpose of the laboratory test, as proposed and described in deliverable "*D1.2: Concepts definition*", is to verify the performance of a system or its components taking into account the conditions of the cluster(s) and scenario(s), by carrying out tests encouraging the verification of the capabilities of the system itself and of the driver by human factors in the proposed driving scenario, either into a simulator or in real traffic scenarios.

4.2 Aims and goals of the Laboratory Tests

Next table shows the types of component laboratory tests proposed for verification purposes within the eVALUE project. Refer to deliverable "*D1.2: Concepts definition*", Chapter 3 (Concepts for laboratory tests) for a description of each test.

Table 1: Laboratory tests: component tests originally proposed

Testing area	**Test type**
Sensor level	Detection area test. Discrimination test. Resolution test. Susceptibility test.
ECU level	System response time test. Fault insertion test
Actuator level	Function output relevance test. Function output type test. Function output location test.

Due to the wide diversity of electronic devices integrated in a vehicle and the manufacturing differences between them, as well as the use of different technologies between vehicles to achieve the same goals, it looks complex to obtain a performance comparison within the component level without affecting the main scope of the eVALUE project.

Based on an analysis of the state of the art on ICT-based safety systems and related technologies (refer to deliverable "*D1.1: State of the Art and eVALUE scope*"), and the decisions taken during the first project review, it has been approved by the eVALUE consortium to emphasize the scope of the project on the scenario approach. This way it will be avoided investing redundant efforts on component tests that have already been done by the car manufacturers.

This decision will allow the consortium to put in more efforts on physical tests, which will push to a better validation of the vehicle and the driver behaviour in each proposed scenario, matching eVALUE objectives. It will also emphasize the creation of more valuable tests according to real traffic situations, regardless the systems and the technologies the vehicles are based on. In other words, on this approach the vehicle will be considered as a "*black-box*".

In order to achieve this, the necessary information regarding the systems and components involved in the vehicle's safety rating will be obtained from the design review check, or by requesting the manufacturers to show evidences about the fulfilment of the necessary safety standards.

The considered approach does not take into account single systems and components. As a result, there will be no laboratory tests considered within eVALUE. Furthermore there is no common interface to the vehicle's components, i.e. sensors and actuators. Instead, the interface between the vehicle and the driver will be taken care by means of Driving Simulator studies, described in chapter 5 (page 52).

5 DRIVING SIMULATOR STUDIES

5.1 Introduction

The general approach of eVALUE is based on real accident scenarios, i.e. scenario approach. In consequence, reproducing some of these scenarios as physical tests can be dangerous.

The purposes of the Driving Simulator studies are two, first to evaluate the effectiveness of the ICT-based safety system taking into account the behaviour of the driver, and second to validate the systems under a safety environment. Therefore, this type of tests allows evaluating the effect of human factors, not only by means of subjective parameters but objective measures as well.

At the same time, in order to validate active safety systems which are designed to guide, interact with and assist drivers during their driving task, evaluations including the driver have to be performed. An easy method could be to evaluate the behaviour of the driver, under a virtual environment or under controlled real driving situations, which are starting points for a driving simulator study.

5.2 Aims and goals

As stated above, the simulated subject vehicle under a virtual environment will lead as support for these physical tests, unable to be driven on a test track due to economical, physical or human circumstances. In addition, the Driving Simulator studies will also consider driver reactions under the previously proposed physical tests, i.e. under real driving conditions with driver reactions being monitored for each test scenario.

The safe and repeatable environment in a driving simulator makes it possible to include both ordinary drivers and realistic traffic scenarios, with little cost and without physical risk involved when performing field experiments.

Driving Simulator studies defined under eVALUE project will be performed as a part of the research for understanding driver behaviour in predefined critical driving situations. The simulator tests should ideally be performed both with and without active safety systems, to assess driver's potential reactions in hazardous circumstances.

As a result, the quality of a vehicle's ADAS interface interacting with the driver will be assessed under eVALUE Driver Simulator studies.

5.3 Specifications for Driving Simulator studies

In order to test the efficiency of an active safety system, driving under virtual environment or on test track, well-defined test scenarios are required. The scenarios need to be repeatable, even for unexpected events in which loss of control in one way or other is imminent for most drivers. It is also important to consider if situations:

- Are perceived as critical for all drivers (Green, 2000; Lee et al., 2002).
- Mimics real dangerous traffic situations (from accident statistics and/or FOT data).

In one hand, simulator tests are appropriated to analyse the driver behaviour regarding scenarios of Cluster 1 and 2. Whereas, studies considering driver's behaviour in Cluster 3 scenarios are difficult to be carried out, as there are no existing standard simulation environments able to simulate high dynamic situations.

The Driving Simulator studies within eVALUE have two purposes:

- first, define a methodological approach for obtaining input patterns needed to perform the physical tests, and
- second, perform special tests intended to evaluate and validate the functionalities of the HMI.

5.3.1 Obtaining input parameters for physical tests

The Driving Simulator studies can be more complex or less complex studies in order to generate the necessary inputs for the physical tests.

The physical tests may require inputs intended for the driving robot, i.e. the steering angle for describing the standardised manoeuvres in order to define the tests. For their operation, the driving robots themselves need to be provided with driving parameter inputs that make the robot operate under open or closed loop modes:

- Under *open loop mode*, the robot follows the instructions previously given via software. These instructions - at a very low level - are basically profiles of steering angle or pedal positions, referred to a timeline. When the robot installed in a specific vehicle needs a previous calibration, open loop mode can provide this functionality. Therefore, the instructions might be given in a higher level, as profiles of curve radius and vehicle acceleration or deceleration.
  This mode is normally used for manoeuvres related to Cluster 3, where a vehicle is driven in a wide flat surface. The driver reaches the desired speed of the vehicle and starts the operation of the robot. At that point, the robot takes the control of the steer and pedals of the vehicle and implements the profiles. When the driving manoeuvre is finished, the driver retakes the control of the car.

- Under *closed loop mode*, the robot is not following a profile of a given magnitude, instead it is controlling certain parameters of the vehicle. Path following is a typical use where the input is the trajectory (XY points) of the vehicle and the speed desired at certain points. The controller of the robot supervises the state of the vehicle and adapts the steering angle and position of the pedals. Furthermore, other inputs can be considered, such as relative distance to vehicles.
  This mode is oriented to tests where the vehicle has to interact with other elements (vehicles, infrastructure, and objects). The robot is set to start following a specific path or keeping a distance to the target, next the test is implemented, maintaining that condition.

Therefore, the simulated driving tests - Driving Simulation studies - proposed under the eVALUE scope can be used for registering necessary patterns from the simulator, in order to provide parameters database. These patterns will command inputs for the steering robots, both in open loop mode (i.e. recorded steering angle and pedal positions from de simulator) or in closed loop mode (i.e. recorded path from the simulated test track).

5.3.2 Understanding the human - vehicle interaction

Another important part of Driving Simulator studies includes tests intended for HMI evaluation, since they are the core of human-vehicle interaction's understanding. Therefore, Testing Protocols will be defined for that purpose. The main objective is to have knowledge on how HMI works and how it can influence the behaviour of the driver in order to avoid dangerous situations. The driving simulator studies should ideally be performed both with and without active safety systems, to assess driver's potential reactions on hazardous settings. In those cases where it is not possible to repeat the scenario without active safety systems (in order to assure the safety aspects of the test), a possible solution is to use data from naturalistic driving studies together with information from crash data files, as baseline (Burgett et.al. 2008). In eVALUE is possible since the scenarios proposed are based on crash databases.

In this chapter, the capabilities of driving simulator studies for understanding vehicle-human interaction are discussed. This has a potential for assessing the HMI systems, which are very relevant in Cluster 1 and 2 scenarios. Cluster 1 and 2 may include systems which act fully automated or which provide a warning and driver reaction is needed. In this second case, the proper warning of a distracted driver about an oncoming danger is very important, because the most effective is this warning (in terms of timing and driver awareness), the better reaction of the driver can be obtained.

Concerning HMI, the studies that can be performed can be split into on-line and off-line testing. Next, the type of studies for the evaluation of HMI is presented:

Table 2: Driving Simulator studies: type of studies for HMI evaluation

<table>
<tr><td>On-line testing</td><td>Attention: Measurements of the time until recovering driver's attention after distractions or inattentions.</td><td rowspan="3">Usability: Measurement of the system performance and user-end acceptability.</td></tr>
<tr><td rowspan="2">Off-line testing</td><td>Mental Workload: Measurement of driver's mental workload in order to avoid an overload.</td></tr>
<tr><td>Acceptability: Subjective tests based on driver's opinion.</td></tr>
</table>

- **On-line testing: Attention and distraction**

Attention can be defined as human's gathered conscious mentally resources. If the human tries mentally to get a grip of more than his consciousness is able to at once, he generally loses control of the situation. The needs for his attention vary with the situations, but it is possible for him to control his attention with external factors such as colour, movement and placement, frequency of sounds, etc.

Other important factors are distraction and inattention concepts. The National Highway Traffic Safety Administration (NHTSA) differentiates between inattention and distraction in driving task. The following are considered causes for inattention:

- Driver performs a secondary task while driving so that his attention is drawn away from the driving task, e.g. talking on the mobile phone or looking at a road billboard.
- Manoeuvres related to the driving task but drawing away driver's attention from the road, e.g. looking to the rear mirror or attending navigator indications.
- Drowsiness of the driver.
- Any other reason that deviates the driver's attention from the main driving task.

When the inattention is performed voluntary by the driver during driving task and not related to the driving task itself it is called distraction. Therefore, distraction can be defined as drawing someone's attention away from something. Some examples of stimuli that can distract the driver and in consequence cause an accident are: a wasp in the vehicle, children quarrelling on the back seats, a mobile call or a dead dog on the ditch, etc.

Testing protocols for measuring parameters related to the driver attention will consist in the definition of distraction parameters in the selected scenarios, and the measurement of the safety indicators (mainly Driver Reaction Time (DRT)) related to driving situation safety levels.

Figure 26 shows the sequence of time measurements for HMI evaluation.

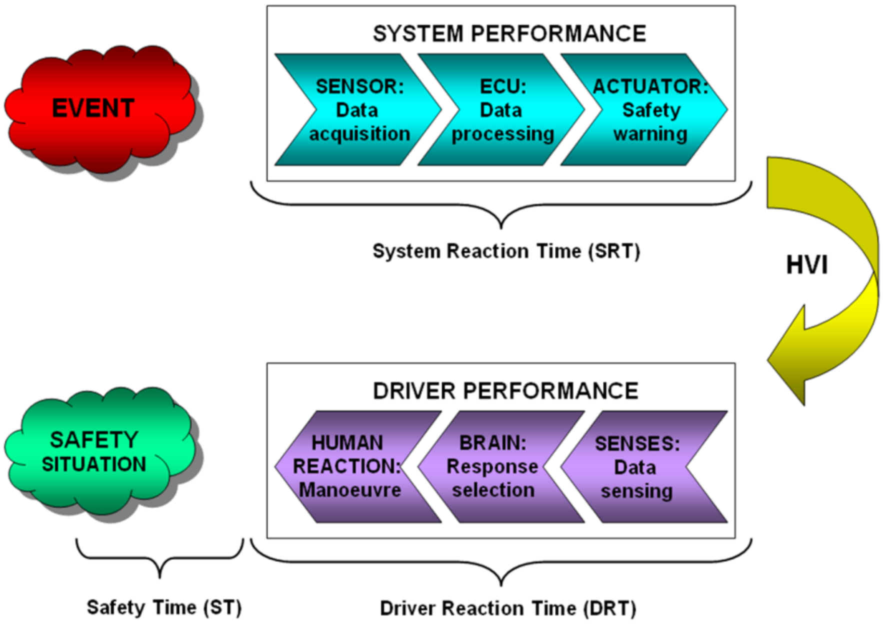

Figure 26: Time measurements for HMI evaluation.

- **Off-line testing: Mental Workload**

A model of the main task of the driver is useful in driving studies involving mental workload research. The primary task of the driver can be defined as "safe control of the vehicle within the traffic environment". Car driving is a dynamic control activity in a continuously changing environment. The driving task is not only influenced by the drivers themselves, but also by the behaviour of other traffic participants. In consequence, sources of driver workload may be found both inside and outside the vehicle.

The factors that affect driver's workload are the following:

- driver state affecting factors such as fatigue,
- driver tail factors such as driving experience and
- factors related to the vehicle and environment such as traffic or vehicle automation level.

Workload measures can be grouped on: subjective (i.e., self-report) measures, performance measures and physiological measures. According to this association, these groups of measurement for mental workload testing are defined:

- **Self-report measures.** There are several methodologies. One of these methodologies is the RSME (Rating Scale Mental Effort), a one-dimensional scale. Other methodologies of this type are the NASA Task Load Index or the Subjective Workload Assessment Technique (SWAT). Since workload rating can seem a bit abstract and hard to estimate for drivers, another approach is to ask the driver to rate his/her driving performance at regular interval during the test drive (Merat, N., and Karsten, O., HASTE D3, 2005). The HASTE test regime uses a vertical scale from 1 (extremely poor) to 10 (extremely well) and the response is verbal. In the HASTE project this method was used with good results and it proved to be a good dependent measure for assessment of in vehicle information systems.

- **Performance measures.** In tasks under virtual environment, motor or tracking performance, the number of errors made, speed of performance or reaction time measures are used as primary-task performance measures. Primary-task performance is a measure of the overall effectiveness of man-machine interaction.
  In order to evaluate ADAS influence it is necessary to compare primary-task performance and driving-task under virtual environment with a reference, in order to know how this system influences on drivers' performances. Reference tasks are standardized tasks that are performed before and after the task under evaluation and they mainly serve as a checking instrument for trend effects. In this case, the reference-task consists in measuring the same parameters without active safety systems.

- **Off-line testing: Driver acceptability**

In order to test user-end acceptability, a common solution is to apply off-line methods. Most of the methodologies are based on questionnaires for measuring the driver/user-end opinion regarding acceptance of the system or vehicle.

It is advisable to test whether the system or vehicle creates exaggerated and/or false user expectations, leading to incorrect system use and driving behaviour. In general, one can say that the higher the level of automation, the higher the driver expectation regarding system reliability, situation coverage, system accuracy and system performance.

The driver expectative tends to be converted into frustration or acceptance in terms of HMI design, but in order to completely accept new unknown systems, i.e. a new HMI into the vehicle, the driver needs and wants to be sure that they are safe. This means safe vehicle operation as well as occupant safety in real accident scenarios. Therefore, the HMI may be perceived by the driver as related to an active or passive safety system. To a great extent costumer expectation is subject to the marketing statement of the manufacturer.

Depending on the vehicle, drivers have varying expectations concerning system reliability. User expectations result from a multitude of influencing factors, like presentation or marketing of the product, advertisement statements or media presentations. The user's view is however not limited to the evaluation of relevant information on new technologies, but also the knowledge about products used in the past.

In order to assess drivers' acceptability under eVALUE, a simple procedure has been selected. The technique is known as Van der Laan scale (Van der Laan, J.D., Heino, A., and De Waard, D., 1997). It consists of nine 5-point rating-scale items. These items load on two scales, a scale denoting the usefulness of the system, and a scale designating satisfaction.

The technique has been applied in many different studies in different test environments and analyses performed over these studies show that it is a reliable instrument for the assessment of acceptance of new technology. Different systems were judged after subjects had been exposed to them.

The evaluation is based on the questionnaire, showed on Figure 27. This survey itself consists of nine items. The instruction given to subjects is: “Could you please indicate below what was your opinion about the equipment that (...)?”. Next, individual item scores run from -2 to + 2. Item numbers 3, 6 and 8 are mirrored compared to the other items.

1	Useful	|__|__|__|__|__|	Useless
2	Pleasant	|__|__|__|__|__|	Unpleasant
3	Bad	|__|__|__|__|__|	Good
4	Nice	|__|__|__|__|__|	Annoying
5	Effective	|__|__|__|__|__|	Superfluous
6	Irritating	|__|__|__|__|__|	Likeable
7	Assisting	|__|__|__|__|__|	Worthless
8	Undesirable	|__|__|__|__|__|	Desirable
9	Raising Alertness	|__|__|__|__|__|	Sleep-inducing

Figure 27: The nine items in the questionnaire.

5.4 Scenarios to be analysed with Driving Simulator

Since the scenarios to be analyzed using a driving simulator - under the eVALUE scope - are based on driver actions/reactions referred to the situation and the system, there is a challenge making the planned scenario happen, even in a simulated environment.

For instance, in a driving simulator it is possible to programme the target vehicle to brake hard and subsequently to create a dangerous situation; however, it will be not possible to control the driver’s active choices and reactions in the specific driving situation.

In order to achieve the desired results Driving Simulator Studies will have to face up to three main tasks:

- Create realistic environment.
- Deal with expectancy effects.
- Design scenarios in order to reduce the risk of driver actions that could inhibit the scenario.

As stated earlier, studying the behaviour of the driver can set the basis for defining different braking reactions or steering patterns that could then be implemented in a braking or steering robot. For this purpose, when carrying out the Driving Simulator studies the following interactive elements will be installed on the available simulator:

- Programmable touch screens for simulating different vehicle HMI systems
- Haptic throttle pedal and/or other haptic devices, programmed to be activated on (simulated) dangerous situations.
- Devices for interacting with different steering wheel torques.
- Other signalization devices such as acoustic and visual devices.
- Measuring tools for driver’s reaction times.

A set of scenarios corresponding to the ones used for physical tests in Cluster 1 and 2 will be defined and elaborated in Testing Protocols in WP3. Only Cluster 1 and 2 related functions are proposed to be tested with driving simulators because the objective is to analyse the driver interaction with warning signals and/or braking actions. Cluster 3 functions, where the dynamic limits of the vehicles are met, are out of the scope of theses studies.The selected scenarios for Driving Simulator studies under eVALUE are summarized in the following sections, according to the needs of the project.

5.4.1 Cluster 1: Scenarios for Driving Simulator

5.4.1.1 Scenarios C1-1&C1-2: Straight road and curved road

C1-1&2-DrivSim#1A&1B:
Subject vehicle approaches target vehicle stationary or moving with lower speed.

Description:
Research for understanding different braking reactions from drivers to be implemented in a braking robot. Performed with active safety systems to assess driver’s potential reactions (A scenarios).

And, research on safety indicators used at the same scenario as above, driven with and without a safety system equipped (B scenarios).

Test objective:
Create a near rear end collision scenario where the subject vehicle approaches the target vehicle which is stationary or moving with a lower speed for instance in a queue, or after a right-hand or left-hand curve.

Test environment and equipment:
Driving simulator, real drivers, and a distraction task for distracting the driver so that he/she is not aware about the stationary/slowly moving vehicles ahead.

Safety Indicators:
Driver Reaction Time (DRT) relative to when a warning is issued (reactions in terms of e.g. pressing the brake pedal and/or turning the steering wheel). Mean/min TTC, Mean/ Min/ Max Time Exposed TTC (not applicable if the vehicle is stationary), Mean/ Min/ Max Time Integrated TTC (not applicable if the vehicle is stationary).

C1-1&2-DrivSim#2A&2B:
Variation 1, Subject vehicle approaches target vehicle stationary or moving with lower speed.

Description:
A similar scenario as 1A and 1B but target vehicle is hidden behind the top of a hill.

C1-1-&2DrivSim#3A&3B:
Variation 2, Subject vehicle approaches target vehicle stationary or moving with lower speed.

Description:
In these scenarios, the variation to scenarios 1A and 1B is that the subject vehicle follows another vehicle, for example a truck and the visibility ahead are limited. The truck suddenly changes lane and another vehicle (the target vehicle) which now appears, stationary or moving with much lower speed creating a near rear end collision.

5.4.1.2 Scenario C1-3: Transversally moving target

C1-3-DrivSim#1A:
Transversally moving target

Description:
Research for understanding different braking reactions from drivers to be implemented in a braking robot.

Test objective:
Create a near frontal collision scenario in an intersection where the subject vehicle enters an intersection and another vehicle enters the intersection in opposite direction, suddenly turning to the left in the intersection.

Test environment and equipment: Driving simulator, real drivers, a distraction task for distracting the driver prior to the intersection.

Safety Indicators: Driver Reaction time (for instance on pressing brake pedal). Mean/min TTC, Mean/ Min/ Max Time Exposed TTC (not applicable if the vehicle is stationary), Mean/ Min/ Max Time Integrated TTC (not applicable if the vehicle is stationary). Reaction time (for instance on pressing brake pedal)

5.4.2 Cluster 2: Scenarios for Driving Simulator

5.4.2.1 Scenarios C2-1, C2-2, C2-3, C2-4, C2-5 & C2-6: Lane/Road departure on a straight road/curve

Next scenarios, shown in the table, have as **test environment and equipment** the same components: Driving simulator and real drivers, distracted for creating the dangerous manoeuvre. Their **safety indicators** are mean/ min TLC, St.dev. lane position, Peak lane deviation, Mean/ Max Time spent outside own lane.

Table 3: Driving Simulator Cluster 2 scenarios C2-1, C2-2, C2-3, C2-4, C2-5 & C2-6

Scenario	Description
C2-1-DrivSim#1	Lane departure to the right OR to the left on a straight road.
C2-2-DrivSim#1	Road departure on a straight road performed with driving simulator.
C2-3-DrivSim#1	Lane departure to the right OR to the left in a RIGHT-hand curve. (will be difficult to control at what side the lane departure will occur)
C2-4-DrivSim#1	Road departure on a curve.
C2-5-DrivSim#1	Lane departure on a straight road just before entering an upcoming curve.
C2-6-DrivSim#1	Road departure on a straight road just before entering an upcoming curve.

5.4.2.2 Scenarios C2-7: Lane change collision avoidance in a straight road

In these scenarios **test environment and equipment** are driving simulator with real drivers, and the **safety indicators** are: Driver Reaction Time (DRT). Mean/ Min/ Max Time to Collision (TTC), Mean/ Min/ Max Time Exposed TTC (TET), Mean/ Min/ Max Time Integrated TTC (TIT), mean/ min Distance to target vehicle, mean/ min time gap to target vehicle, mean/ min TLC.

Next table shows the scenarios and the definition for each one:

Table 4: Driving Simulator Cluster 2 scenarios C2-7

Scenario	Description
C2-7-DrivSim#1A&1B	Subject vehicle (truck/car) travelling in the left lane or in the right lane, changes lane to the right or to the left when there is another target car in the adjacent lane.
C2-7-DrivSim#2A-2B	Subject vehicle (truck/car) is switching lane from left or right to middle lane, and merge of car from the right or left to the middle lane (perhaps when coming on an entrance).
C2-7-DrivSim#3	Subject vehicle (truck/car) is travelling in right lane, car comes on an entrance and a collision to the right of the truck (but the car is causing the accident).
C2-7-DrivSim#4A&4B	Target vehicle is travelling in right or left lane while the subject vehicle comes on an entrance in main way from a secondary road.

5.5 Next steps in Driving Simulator studies

The actions to be done regarding driving simulator studies will be done in parallel with the development of physical tests, mainly for Cluster 2. These actions will consist in the definition of procedures which are representative of real driving condition and will take into account the driver reaction. In order to achieve this, the driving simulators will be used with 2 objectives:

- The definition of manoeuvres for physical tests.
- The definition of test scenarios to be implemented into a driving simulator.

The scenarios defined in chapter 3 (page 18) will be used for this purpose.

6 CONCLUSIONS

6.1 Conclusions related to Design Reviews

Four testing protocols for design reviews have been developed. Some of the design reviews have been fairly straight-forward to specify and to use by the project partners. While some of the design reviews require the application on real vehicles in cooperation and discussion with vehicle OEMs. Many questions can only be answered by the OEM. The different design reviews serve different purposes. A design review has the purpose of defining the subject vehicle while another checks for which environmental conditions the vehicle has been tested by the OEM. There are also design reviews dealing with HMI design as well as functional safety.

6.2 Conclusions related to Physical Tests

The safety indicators are the key parameters which allow the evaluation of a safety function in an objective way. They are the values which will enable the comparison of different vehicles and show which are the strengths and weaknesses of each one, by establishing a ranking among them. These safety indicators should be consistent for different situations and it should be possible to measure or calculate them with the equipment used during the test.

Testing procedures have been specified for cluster 1 and 3. Cluster 2 has also provided a specification of the aspects to be evaluated with the testing procedures. It has been found that for this particular cluster, it is needed to have special emphasis in the driver behaviour.

All the test procedures are representative of the accident scenarios defined in Work Package 1 and allow the evaluation of the Safety Indicators defined in Work Package 2. In Work Packages 3 and 4 the Testing and Assessment Protocols will be elaborated.

6.3 Conclusions related to Laboratory Tests

It has been found that Laboratory Tests understood as component tests do not follow the scope of eVALUE. A component test should be oriented to check whether a subsystem is making what it has been designed for or not. This is a previous check, before integrating it into a complete system which is providing a safety function. But the information obtained from this check is not about the performance of the safety function, but just a verification of the response from the components. It is considered that this check is something to be done by the provider of the system or the OEM, and not inside the eVALUE assessment program for safety systems of a vehicle.

Laboratory tests understood as driving simulator tests are expected to provide useful information on the interface driver- vehicle. The work to be done on the interaction between vehicle and driver will be carried out under Driving Simulator studies, defining accurate test procedures where the driver response is essential. From now on, all tests referred to as laboratory testing will be considered as Driving Simulator studies.

6.4 Conclusions related to Driving Simulator studies

Driving Simulator studies are supplementary studies that can be understood as tests on a driving simulator for the evaluation of the interaction of the driver with a safety function and/or as tests for the analysis of the general behaviour of the driver in real traffic scenarios.

They are expected to provide useful information about the interaction between the driver and the vehicle. For this reason, several test scenarios, representing different accident scenarios of Cluster 1 and 2 have been defined. It has been justified that Cluster 3 related functions are not reproducible in driving simulators.

The tests from the studies may be used for:

a) analyzing human response towards HMI communicating capabilities and to understand driver behaviour in hazardous situations. These tests are intended for validating the interaction of real drivers with the vehicle.
b) as well as for supporting physical tests, e.g. by creating realistic input patterns for steering robots. These tests are intended for the development of new test procedures in proving grounds, taking into account more accurate standardised driver reactions.

The results of driving simulator tests will help to define more accurate test procedures for real traffic scenarios (physical tests), including the driver reaction.

7 GLOSSARY

Scenarios	Scenarios represent specific driving situations (related to real driving situations) which are relevant regarding the functionality of considered systems in the different clusters.
Test Procedure	A description of how to perform a test. It can contain specific driving manoeuvres, including different test cases (tests with different speeds, different weather conditions, etc.), laboratory tests or design reviews to evaluate the system. (A test procedure should be described in such detail so the test results will be repeatable. A test procedure will specify the test resources needed to perform the test.)
Testing Protocol	A Testing Protocol is the formal document containing test procedures necessary to evaluate the functionality of a vehicle or a system.
Assessment protocol	An Assessment protocol is the formal document which describes how to evaluate the test results.
Test Case	A Test Case is a particular implementation of a test procedure which differentiates from other test cases by the variation of one or more of specified parameters.
Test Suite	A Test Suite is a collection of the tests procedures of a cluster which are representative for the evaluation of a safety function, a safety system or the behaviour of a vehicle under a specific scenario.
Test Program	A Test Program is the collection of all the test procedures for all clusters. The eVALUE Test Program will be integration of all the test procedures developed within the project.
Test Resource	A resource used to perform a test.
Test	The execution of a Test Procedure
Design Review	A Design Review is a systematic, comprehensive and documented analysis of a design to determine its capability and adequacy to meet its requirements. A design review also serves to identify present and potential problems.
Physical Testing	The Physical Vehicle Testing shall be based on preliminary scenarios that simulate the sequence of events that potentially can lead to specific hazards. The objective of this test procedure is to gather quantitative information regarding safety requirements, response of the system and result of the activation of the system.
Laboratory Testing	Laboratory Tests verify the performance of a system or its components taking into account the conditions of the cluster(s) and scenario(s), by carrying out tests encouraging the verification of the capabilities of the system itself and of the driver by human factors in the proposed driving scenario, either into a simulator or in real traffic scenarios. Laboratory Tests understood as component tests do not follow the scope of eVALUE.
Driving Simulator studies	Driving Simulator studies are supplementary studies that can be understood as tests on a driving simulator, or analysis on the behaviour of the driver in real traffic scenarios. They are expected to provide useful information of the interaction between the driver and the vehicle.
Validation	Validation describes the process of evaluating the system impact e. g. on safety. That is, validation checks and tests whether the system "does what it was designed for", e. g. increase traffic safety by increasing headway, by avoiding impacts and so on. For this purpose the driver needs to be in the loop. Driver in the loop testing is required.
Verification	Verification describes the test of a system/ function against its requirements, that is, whether it fulfils its requirements.
Measurement	A measurement is the result obtained during the process of assigning a number or level to a physical magnitude according to a rule or set of rules.
Safety Indicator	A Safety Indicator is a parameter based on measurements during a test which gives information about the overall behaviour of the vehicle during that test. It should be possible to associate Safety Indicators obtained to a certain level of safety offered by the vehicle.

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9 ANNEX I – Testing Protocols for Design Reviews

In this annex the four testing protocols for the eVALUE design reviews are presented. The four design reviews are:

1. Definition of the subject vehicle
2. Environmental requirements
3. HMI requirements
4. Functional safety

Each design review is organised in the same way. The first three sections are Scope, References, and Definitions. The content of these chapters are rather self-explanatory: Scope deals with the applicability of the Testing Protocol, References lists useful references, and Definitions defines term which are used throughout the Testing Protocol.

Testing Protocol

for

Design Review

to

Define the Subject Vehicle

1 SCOPE

It is important to clearly identify the vehicle under test (i.e. the subject vehicle), especially if the vehicle is a prototype vehicle. All major characteristics of the vehicle influencing the performance testing must be noted. The challenge of identifying the vehicle under test is greater at performance testing than at testing of passive safety. Even small design modifications in the active safety systems may severely influence the performance.

A certain model of a road vehicle is normally produced in several different types. There will be differences in engine, chassis, brakes etc. Many of these differences will not be important for the performance testing. It will in many cases be possible to choose one type of vehicle for the performance testing, and to assume that the test results are valid also for other types of the same vehicle.

Evaluation of longitudinal, lateral, and stability safety functionalities require information about their characteristics and limits, e.g. the kind of sensor used and limits of its operation range. If the manufacturer has already done tests it is helpful to receive information about these tests to ensure that they are adapted to the system tested and the related standards.
The safety performance dependence on reliable external communication will also be reviewed. External communication includes positioning, vehicle-to-vehicle, and vehicle-to-roadside communication. Transmission anomalies, such as distortion and interference, can have a negative effect on the overall performance and it is consequently addressed in the review.

This testing protocol describes how to perform a design review to identify the type of vehicle, its safety functionalities, and possible dependence on external communication. The design review is necessary to specify the vehicle under test and all other types of the vehicle model intended to be covered by the performance test. It is also a necessary step for the test engineers familiarizing with the subject vehicle and its safety functionalities.
The design review will be applicable for cars, trucks and buses. It shall be performed before any physical testing or laboratory testing is performed. The results of the design review cannot be a pass or fail judgement, but simply a definition of the subject vehicle and its safety functionalities.

.

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[J2400] SAE standard J2400
Human Factors in Forward Collision Warning Systems: Operating Characteristics and User Interface Requirements
Society of Automotive Engineers, 2003-08

Lateral devices (BSD, LDW, and LKA):

[17361] International standard ISO 17361:2007
Intelligent transport systems – Lane departure warning systems – Performance requirements and test procedures
International Standardisation Organisation, 2007

[17387] International standard ISO 17387:2008
Intelligent transport systems – Lane change decision aid systems (LCDAS)– Performance requirements and test procedures
International Standardisation Organisation, 2007

[FMC05a] Houser, A., Pierowicz, J., and Fuglewicz, D.
Concept of Operations and Voluntary Operational Requirements for Lane Departure
Warning Systems (LDWS) On-Board Commercial Motor Vehicles.
FMCSA-MCRR-05-005, Federal Motor Carrier Safety Administration, 2005

[810757] Development of Crash Imminent Test Scenarios for Integrated Vehicle-Based Safety Systems (IVBSS)

Publication DOT 810 757
U.S. Department of Transportation, National Highway Traffic Safety Administration
April 2007
Download at
http://www.itsa.org/itsa/files/pdf/IVBSS%20Crash%20Imminent%20Test%20Scenario%20Report%20-%20DOT%20HS%20810%20757.pdf

[J2808] SAE standard J2808
Road/Lane Departure Warning Systems: Information for the Human Interface
Society of Automotive Engineers, 2007-08

Stability devices (ABS and ESC):

[21994] International standard ISO 21994:2007
Passenger cars – Stopping distance at straight-line braking with ABS – Open-loop test method
International Standardisation Organisation, 2007

[FMVSS126] FMVSS No. 126
Laboratory Test Procedure for Electronic Stability Control Systems
U.S. Department of Transportation
National Highway Traffic Safety Administration
April, 2007
Download at
http://www.nhtsa.dot.gov/staticfiles/DOT/NHTSA/Vehicle%20Safety/Test%20Procedures/Associated%20Files/TP126-00.pdf

3 DEFINITIONS

Model – the model of a vehicle is the basic model used as a trade name by the OEM (e.g. Citroen C5 Tourer 2.0 16V)

Type – the type of a vehicle is one specific configuration of the vehicle model characterized by chassis, engine, ICT based safety systems, brakes etc

Subject vehicle: Vehicle equipped with ADAS system and related to the topic of discussion

Target vehicle: The target vehicle reproduces the characteristics of the required vehicle according to sensor's technology ant the test protocol requirements.

Relative speed: The relative speed rv is the difference between the target vehicle's speed vt and the subject vehicle's speed vs.; rv = vs. - vt

Clearance: Distance from target vehicle's trailing surface to the subject vehicle's leading surface

Time gap: Time interval for travelling the clearance between consecutive vehicles. The time gap is related to vehicle speed v and clearance c by t = c/v

Time to collision: Time interval before an impact between subject vehicle and target vehicle. The time to collision is related to relative speed rv and clearance c by: tc = c/rv

Normal environmental conditions: Conditions normally applied at performance testing on the test track:

- Test location shall be on a flat, dry asphalt or concrete surface.
- Temperature 20 ˚C ±20˚C.
- Horizontal visibility shall be greater than 1 km.

[Standard ISO 15622, clause 7.1]

Botts' dots: Round nonreflective raised pavement markers

Rumble strips: Also known as audio tactile profiled markings are a road safety feature that alerts drivers to potential danger by causing a tactile vibration and audible rumbling, transmitted through the wheels into the car body.

4 DESIGN REVIEW

4.1 Principle

The vehicle OEM will supply information of the model of the vehicle, the type of the vehicle and all other information on factors influencing the performance testing.

The vehicle OEM or safety system supplier will supply information about their ICT-based safety functionality. The information sent must contain results of previous tests and simulations with an analysis on how their systems will decrease accidents and how they will influence the drivers. They will also supply information concerning the development testing of the safety systems during different driving conditions.

The vehicle OEM or safety system supplier will provide their analysis with regard to the communication influence on the operation of the ICT-based safety functionality installed in the vehicle. They will also supply information concerning the development testing of the safety systems under poor transmission conditions

The design review will include a study of the documentation provided, and an interview with representatives of the manufacturer. The design review is supported by checklists. The result will be summarized in a written report.

The design review only addresses the type of vehicle and its safety functionality. Aspects on the preparation of the vehicle (load, fuelling, driving robots etc) are specified in the testing protocols describing physical testing and laboratory testing.

4.2 Equipment

Special equipment will not be required at this design review.

4.3 Testing environment

A specific testing environment will not be required at this design review.

4.4 Information required from the manufacturer

Following information will be necessary for the design review:

- name, prototype status, chassis, engine, brakes, tyres
- ICT-based safety functionality
    - description of the system, its characteristics, limitations and expected capabilities and to which standards it complies
    - description of test set-ups (targets, lane markings etc)
    - description of which external communication channels that are used

4.5 Vehicle preparation

Vehicle preparation will not be required for this design review

4.6 Review procedure

Following aspects shall be reviewed:

- name/designation (e.g. Volvo FH16)
- prototype vehicle
- chassis (e.g. sedan, coupé, cabriolet, station wagon, bus, truck)
- engine (e.g. diesel D16G: 540, 600, 700 hp)
- brakes
- tyres (e.g. winter tyres Michelin X-ice 205/60R15)
- ICT-based safety functionality (e.g. ABS, ESC)
    - Test documentation of the OEM
    - test conditions
    - system characteristics
    - related standards
    - accuracy and repetitiveness o the test

    - accuracy of sensors used during the test
- external communication requirements

The design review will study the documentation provided by the manufacturer. At least one meeting with representatives of the manufacturer should be held. Working notes shall be taken by reviewers.

The review is supported by checklists (see Annex 1-5) listing specific aspects. For each ICT-based safety function checklist in Annex 5 shall be considered. The design review will end when the type of vehicle and safety functionality has been identified and a report has been written.

4.7 Uncertainty

Not applicable.

4.8 Report

The result of the design review will be:

- a clear identification of the subject vehicle. The identification shall include a list of all active safety functions included.
- a list of all other types of the vehicle model for which the performance testing results will be regarded valid.
- if the characteristics of the system complies with the related standard
- if the testing protocol used matches with the requirements of the standard
- if the testing protocol used by the OEM provides repeatable test results
- influence of the availability of communication systems on the performance of the subject vehicle
- definition of safe-state in the occurrence of communication failures/faults
- performed test cases for communication shortcomings by the manufacturer

The result will be documented in a report based on the questions in the checklists in Appendix 1 to 5.

APPENDIX 1. CHECKLIST Type of Vehicle

n.a. = Not applicable question (Some questions may not be applicable for all vehicles.)

Design Review of Type of Vehicle

No	Question	Answer
	Name/designation	
A	What trade name is used for the subject vehicle?	
B	Are there other trade names for the same vehicle?	
C	What is the date of production (model year) of the vehicle?	
	Prototype	
D	Is the vehicle a prototype vehicle? If so, please identify all active safety functions including electronic hardware and software versions extra carefully. (See question O.)	
	Chassis	
E	Which chassis is used for the subject vehicle?	
F	Are there other chassis types for which the test results should be considered valid?	
G	If the vehicle is a truck; what trailer is used at the performance testing?	
	Engine	
H	Which engine is used in the subject vehicle?	
I	Are there other engines for which the test results should be considered valid?	
	Brakes	
J	Which brakes are used in the subject vehicle?	
K	Are there other brakes for which the test results should be considered valid?	
	Suspension	

No	Question	Answer
L	Which brakes are used in the subject vehicle?	
M	Are there other brakes for which the test results should be considered valid?	
	Tyres	
N	Which tyres (type and dimension) are used in the subject vehicle?	
O	Are there other tyres (types and dimensions) for which the test results should be considered valid?	
	ICT-based safety systems	
P	Which ICT-based safety functions are used in the subject vehicle?	
Q	Have all ICT-based safety systems been adequately identified (including electronic hardware and software versions)?	
	Supplemental equipment	
R	Is there other supplemental equipment at the subject vehicle which is standard when the vehicle is marketed?	
	Identification numbers	
S	Is there already a type approval number for the vehicle type?	
T	Is there a chassis number of the vehicle?	

APPENDIX 2. CHECKLIST Longitudinal Functionality

n.a. = Not applicable question (Some questions may not be applicable for all vehicles.)

Design Review of Longitudinal functionality

No	Question	n.a.	Yes	No	Comment
A	**Capabilities of the subject vehicle**				
	1) Does the subject vehicle warn the driver when a target is detected?				
	2) Does the subject vehicle warn the driver when a dangerous situation is detected?				
	3) Does the safety function act on any component of the vehicle (brakes, brakes light, steering…)?				
	4) Does the safety function advise the driver before actuating any component?				
	5) Is the longitudinal safety function active in a specified speed range? (Or at all speeds?)				
B	**Was the subject vehicle tested with different Target Vehicles?**				
	1) Real target				
	a. Car				
	b. Truck				
	c. Motorbike				
	d. Bus				
	2) Dummy target				
	a. Car				
	b. Truck				
	c. Motorbike				

No	Question	n.a.	Yes	No	Comment
	d. Bus				
	e. Pedestrian				
C	**Does the subject vehicle detect different targets?**				
	1) Real vehicle				
	a. Car				
	b. Truck				
	c. Motorbike				
	d. Bus				
	2) Dummy Vehicle				
	3) Car				
	4) Truck				
	5) Motorbike				
	6) Bus				
	7) Pedestrian				
D	**Which data was obtained from the tests?**				
	1) Speed				
	2) Relative speeds (longitudinal and lateral)				
	3) Acceleration lateral and longitudinal				
	4) Positions X,Y,Z of target and subject vehicle				
	5) Time				
	6) Brake light actuation				
	7) Brake fluid pressure				

No	Question	n.a.	Yes	No	Comment
	8) Clearances (longitudinal and lateral)				
	9) Time gap				
	10) Time to collision				
	11) Off board video				
	12) On board video				
E	**Was the subject vehicle tested with different road characteristics?**				
	1) Straight road				
	2) Curve road				
	3) Longitudinal slopes – ramps (hills)				
	4) Transversal slopes (in bends)				
	5) Guard rails				
	6) Signs				
	7) Lamp posts				
	8) Tunnel				
	9) Town				
F	**Was the subject vehicle tested with different scenarios?**				
	1) Following the target				
	2) Overtaking the target				
	3) Overtaken by the target				
	4) Target braking				
	5) Target accelerating				
	6) Lane change of the target				
	7) Lane change of the subject vehicle				

No	Question	n.a.	Yes	No	Comment
	8) Without target				
G	**Test driver information**				
	1) Driving robot				
	2) Professional driver				
	3) Normal driver				
H	**Test equipment information**				
	1) Is position information provided by a GPS or differential GPS equipment with suitable accuracy?				
	2) Is speed information provided by a speed sensor with suitable accuracy?				
	3) Is information provided at suitable data acquisition frequency?				

APPENDIX 3. CHECKLIST Lateral Functionality

n.a. = Not applicable question (Some questions may not be applicable for all vehicles.)

Design Review of Lateral functionality

No	Question	n.a.	Yes	No	Comment
A	**Capabilities of the subject vehicle**				
	1) Does the subject vehicle warn the driver when a lane departure is detected?				
	2) Does the subject vehicle support the driver when a road departure is detected?				
	3) Does the safety function act on the steering of the vehicle?				
	4) Does the safety function act on the braking of the vehicle?				
	5) Does the safety function advise the driver before actuating any component?				
	6) Is the lateral safety function active in a specified speed range? (Or at all speeds?)				
B	**Was the subject vehicle tested with different Target Vehicles?**				
	1) Real vehicle				
	a. Car				
	b. Truck				
	c. Motorbike				
	d. Bus				
	2) Dummy Vehicle				
	a. Car				

No	Question	n.a.	Yes	No	Comment
	b. Truck				
	c. Motorbike				
	d. Bus				
C	**Does the subject vehicle detect different targets?**				
	1) Real vehicle				
	a. Car				
	b. Truck				
	c. Motorbike				
	d. Bus				
	2) Dummy Vehicle				
	a. Car				
	b. Truck				
	c. Motorbike				
	d. Bus				
D	**Which data was obtained from the tests?**				
	1) Speed				
	2) Lateral relative speeds				
	3) Lateral acceleration				
	4) Positions X,Y,Z of target and subject vehicle				
	5) Time				
	6) Turn signal light actuation				
	7) Steering force				

No	Question	n.a.	Yes	No	Comment
	8) Lateral clearances				
	9) Time gap				
	10) Time to collision				
	11) Off board video				
	12) On board video				
E	**Was the subject vehicle tested with different types of lane marking?**				
	1) Circular reflectors?				
	2) Rumble strips?				
	3) Botts' dots?				
	4) Solid lines?				
	5) Dashed lines?				
	6) Dots?				
	7) Yellow lane marks?				
	8) White lane marks?				
	9) Wide lane marks?				
	10) Narrow lane marks?				
F	**Was the subject vehicle tested with different road characteristics?**				
	1) Straight road				
	2) Curve road				
	3) Hills				
	4) Guard rails				
	5) Signs				
	6) Lamp posts				

No	Question	n.a.	Yes	No	Comment
	7) Tunnel				
	8) Town				
G	**Was the subject vehicle tested with different scenarios?**				
	1) Lane departure?				
	2) Road departure?				
	3) Lane change with target vehicle overtaking?				
H	**Test driver information**				
	1) Driving robot				
	2) Professional driver				
	3) Normal driver				
I	**Test equipment information**				
	1) Is position information provided by a GPS or differential GPS equipment with suitable accuracy?				
	2) Is speed information provided by a speed sensor with suitable accuracy?				
	3) Is lane mark information provided by a camera with suitable accuracy				
	4) Is lane mark information provided by a laser scanner with suitable accuracy?				
	5) Is lane mark information provided by infrared sensor with suitable accuracy?				
	6) Is lateral object information provided by a camera with suitable accuracy?				
	7) Is information provided at suitable data acquisition frequency?				

APPENDIX 4. CHECKLIST Stability Functionality

n.a. = Not applicable question (Some questions may not be applicable for all vehicles.)

Design Review of Stability functionality

No	Question	n.a.	Yes	No	Comment
A	**Capabilities of the subject vehicle**				
	1) Does the subject vehicle warn the driver when it intervenes?				
	2) Has the safety function showed overall good performance during the tests?				
	3) Has the safety function showed undesired interventions during tests?				
B	**Have the interactions of the safety function with other control systems been tested?**				
	1) Driver steering recommendation				
	2) Active front steering				
	3) Active rear steering				
	4) Active differential				
	5) Roll stability control				
	6) Trailer stability assist				
	7) Others (specify)				
C	**Was the subject vehicle tested for different trucks configurations? (only for trucks)**				
	1) Tractor only				
	2) Tractor with semitrailer				
	3) Tractor with trailer				
D	**Was the subject vehicle tested for different vehicle load conditions?**				
	1) Driver only				
	2) Full load condition				

No	Question	n.a.	Yes	No	Comment
	3) Other load conditions (specify)				
E	**Was the subject vehicle tested on different road surface?**				
	1) Dry asphalt				
	2) Wet asphalt				
	3) Snow / ice				
	4) µ-split				
F	**Was the subject vehicle tested for different dynamic manoeuvres?**				
	1) Emergency braking in straight line				
	2) Emergency braking in curve				
	3) Slow ramp steer				
	4) Step steer				
	5) Swept-sine steer				
	6) Single / double lane change				
	7) Sine with Dwell				
	8) ATI reversed steer				
	9) Other (specify)				
G	**Which data was obtained from the tests?**				
	1) Speed				
	2) Lateral acceleration				
	3) Longitudinal acceleration				
	4) Vehicle X,Y positions				
	5) Yaw rate				
	6) Sideslip angle				
	7) Corner pressures				

No	Question	n.a.	Yes	No	Comment
	8) Vehicle speeds				
	9) Steering wheel angle				
H	**Driver information**				
	1) Driving robot				
	2) Professional driver				
	3) Normal driver				
I	**Test equipment information**				
	1) Is system sensors information available (acquisition via CAN bus)?				
	2) Is information provided at suitable data acquisition frequency?				

APPENDIX 5. CHECKLIST External Communication

n.a. = Not applicable question (Some questions may not be applicable for all vehicles.)

Design Review of External Communication

No	Question	n.a.	Yes	No	Comment
	Requirements for external communication				
A	Is the safety performance of the subject vehicle dependent of external communication?				
B	Are requirements to availability and integrity of information/data specified?				
	Type of Information/data				
	Positioning system				
C	Is the subject vehicle safety dependent on positioning information?				
D	Have the effect of different communication errors been analysed by the manufacturer/developer? 1) corruption 2) unintended repetition 3) incorrect sequence 4) loss 5) unacceptable delay 6) insertion 7) masquerade 8) addressing				

No	Question	n.a.	Yes	No	Comment
E	Has a safe-state in the occurrence of communication failures been defined?				
	Vehicle-to-roadside communication				
F	Is the subject vehicle safety dependent of vehicle-to-roadside information?				
G	Have the effect of different communication errors been analysed by the manufacturer/developer? 1) corruption 2) unintended repetition 3) incorrect sequence 4) loss 5) unacceptable delay 6) insertion 7) masquerade 8) addressing				
H	Has a safe-state in the occurrence of communication failures been defined?				
	Vehicle-to-vehicle communication				
I	Is the subject vehicle safety dependent of vehicle-to-vehicle information?				
J	Have the effect of different communication errors been analysed by the				

No	Question	n.a.	Yes	No	Comment
	manufacturer/developer? 1) corruption 2) unintended repetition 3) incorrect sequence 4) loss 5) unacceptable delay 6) insertion 7) masquerade 8) addressing				
K	Has a safe-state in the occurrence of communication failures been defined?				

Testing Protocol

for

Design Review

of

Environmental Requirements

1 SCOPE

Development of ICT based safety systems requires extensive testing to understand how the vehicle is influenced by its environment. Temperature, light conditions, pollution, precipitation or road characteristics may influence the performance. Sensors, controllers, and actuators might be negatively affected by adverse environmental conditions. Development testing by the manufacturer will address all identified hazards.

Performance testing on the test track is often performed at normal environmental conditions. Due to the limited time and resources during performance testing, a design review could be used to validate which environmental conditions the vehicle can handle.

The objective is to verify that the design fulfils the requirements on operation during different environmental conditions. The important environmental influence factors must be identified, and the vehicle and its ICT-based safety systems must be verified during different environmental conditions.

The design review will be applicable for cars, trucks and buses. The results of the design review will be input to physical testing and lab testing in all clusters. If not already tested by the OEM, the laboratory tests will be used to identify how environmental conditions affect vehicle performance and in which way. These laboratory tests will establish the range (or limits) of the subsequent physical tests.

2 REFERENCES

[15622] International standard ISO 15622:2002 Transport information and control systems – Adaptive Cruise Control Systems – Performance requirements and test procedures

[15623] International standard ISO 15623:2002 Transport information and control systems – Forward vehicle collision warning systems – Performance requirements and test procedures

[17361] International standard ISO 17361:2007 Intelligent transport systems – Lane departure warning systems – Performance requirements and test procedures

3 DEFINITIONS

normal environmental conditions : the conditions normally applied at performance testing on the test track:

- test location shall be on a flat, dry asphalt or concrete surface.
- temperature 20 ˚C ±20˚C.
- horizontal visibility shall be greater than 1 km.

[standard ISO 15623, clause 6.2]

4 DESIGN REVIEW

4.1 Principle

The vehicle OEM or safety system supplier will supply their analysis how different environmental conditions are expected to influence the safety function. They will also supply information concerning the development testing of the safety systems during different environmental conditions.
The design review will include a study of the documentation provided, and an interview with representatives of the manufacturer. The design review is supported by a checklist. The parameters to be analysed depend on the design validated. E.g. lane markings affect the performance of lateral functionality systems but not of stability.

4.2 Equipment

Special equipment will not be required at this design review.

4.3 Testing environment

A specific testing environment will not be required at this design review.

4.4 Information required from the manufacturer

Following information will be necessary for the design review:

- information on which environmental parameters were identified to influence the performance
- information on how environmental influence was tested by the manufacturer.

Following information is optional for the design review:

- test protocols for environmental stress tests
- references to standards

4.5 Vehicle preparation

Vehicle preparation will not be required for this design review

4.6 Review procedure

Following environmental parameters shall be reviewed:

- temperature
- light conditions
- pollution
- precipitation
- road characteristics
- miscellaneous parameters

The design review will study the documentation provided by the manufacturer. At least one meeting with representatives of the manufacturer should be held. Working notes shall be taken by reviewers. It may also be helpful to drive the vehicle, if possible at different environmental conditions.

The review is supported by a checklist (see annex) listing specific aspects associated to environmental parameters. The design review will end when conclusions have been drawn and a report has been written.

4.7 Uncertainty

Not applicable.

4.8 Report

The result of the design review will be four conclusions:

- If environmental conditions are expected to influence the performance of the design to be tested.
- If the developer has specified requirements for environmental influence.
- if the developer has performed adequate tests of the environmental influence.
- if normal environmental conditions can be applied at performance testing on the test track.

The result will be documented in a report based on the checklist in Appendix 1.

APPENDIX 6. CHECKLIST ENVIRONMENTAL CONDITIONS

n.a. = Not applicable question (Some questions may not be applicable for all vehicles.)

Design Review of Environmental Conditions

No	Question	n.a.	Yes	No	Comment
	Environmental requirements specification				
A	Will the performance of the vehicle be affected by environmental conditions?				
B	Are environmental condition parameters addressed in the requirements specification of the design?				
	Temperature				
C	Is the performance dependent on temperature conditions?				
D	Has the manufacturer tested the performance in the appropriate temperature range? 1) 10 ± 30 ºC [17361] 2) 20 ºC ± 20 ºC [15623] [15622]				
	Light conditions				
E	Is the performance dependent on lighting conditions?				
F	Has the manufacturer tested the performance under lighting performance such as:				
	1) Daylight?				
	2) Night?				
	3) Dusk or dawn?				
G	Has the manufacturer tested the performance under				

No	Question	n.a.	Yes	No	Comment
	different sun orientation?				
	1) Sun in the front?				
	2) Sun in the back?				
	3) Sun at left				
	4) Sun at right				
	Pollution				
H	Is the performance affected by pollution?				
I	Has the manufacturer tested the performance in traffic conditions affected by pollution such as:				
	1) Mud?				
	2) Salt?				
	3) Water spray?				
	4) Smoke?				
	Precipitation				
J	Will the performance of the vehicle be affected by precipitation?				
K	Has the manufacturer tested the performance in different precipitation conditions such as:				
	1) Rain?				
	2) Snow?				

No	Question	n.a.	Yes	No	Comment
	3) Hail?				
	4) Fog?				
L	Has the manufacturer tested the performance on road/track with different friction such as:				
	1) Ice?				
	2) Wet road?				
	3) Water puddle?				
	Wind conditions				
M	Will the performance of the vehicle be affected by wind conditions?				
N	Has the manufacturer tested the performance at different wind conditions?				
	Road characteristics				
O	Will the performance of the vehicle be affected by the road characteristics?				
P	Has the manufacturer tested the performance in the presence of parts of the road infrastructure such as:				
	1) Signs?				
	2) Guard rails?				
	3) Lamp posts?				
	4) Tunnel?				
Q	Has the manufacturer tested the performance on different road surface materials such as:				

No	Question	n.a.	Yes	No	Comment
	1) Concrete?				
	2) Asphalt?				
	3) Gravel?				
	4) Sand?				
R	Has the manufacturer tested the performance at different road inclinations?				
S	Has the manufacturer tested the performance at different road curvatures?				
T	Has the manufacturer tested the performance at different types of lane marking?				
U	Has manufacturer tested the performance at different types of crossing, such as:				
	1) Y-crossing				
	2) normal-crossing				
	3) T-crossing				
	4) roundabouts				
	Miscellaneous				
V	Has the manufacturer identified other environmental conditions affecting the performance?				

Testing Protocol

for

Design Review

of

HMI Requirements

1 SCOPE

Development of ICT-based safety systems requires extensive testing to understand how the vehicle and driver are influenced by the HMI design. Depending on level, the driver will be warned, supported, and/or intervened by the vehicle. Hence the interaction between the vehicle and the driver is paramount.

Performance testing on the test track is often performed using robots or professional drivers. Due to the limited time and resources during performance testing, a design review could be used to validate the appropriateness of the HMI design of the vehicle.

The design review will be applicable for cars, trucks and buses. The results of the design review will be input to physical testing and lab testing, simulation, in all clusters. If not already tested by the OEM, simulations will be used to identify how HMI affect vehicle performance and in which way. These simulations will serve as input to the subsequent physical tests.

2 REFERENCES

ISO 2575: Road Vehicles – Symbols for Controls, Indicators and Telltales

ISO 4040: Road Vehicles – Location of Hand Controls, Indicators and telltales in Motor Vehicles

ISO 16352: Road Vehicles – Ergonomic Aspects of In-Vehicle Presentation for Transport Information and Control Systems: Warning Systems

SAE J2402: Road Vehicles – Symbols for Controls, Indicators and Telltales

ISO 7000: Graphical symbols for use on equipment

ISO 17287: Road vehicles – Ergonomic aspects of transport information and control systems – Procedure for assessing suitability for use while driving

ISO 9355: Ergonomic requirements for the design of displays and control actuators

ISO 11428: Ergonomics – Visual danger signals - General requirements, design and testing

ISO 15005: Dialogue principles

ISO 15622: Transport information and control systems -- Adaptive Cruise Control Systems -- Performance requirements and test procedures

ISO 15623: Transport information and control systems -- Forward vehicle collision warning systems -- Performance requirements and test procedures

ISO 17361: Intelligent transport systems -- Lane departure warning systems -- Performance requirements and test procedures

ISO 17387: Intelligent transport systems -- Lane change decision aid systems (LCDAS) -- Performance requirements and test procedures

3 DEFINITIONS

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4 DESIGN REVIEW

4.1 Principle

The vehicle OEM or safety system supplier will supply their analysis how HMI design is expected to influence the safety function. They will also supply information concerning the development testing of the HMI of the safety systems.
The design review will include a study of the documentation provided, and an interview with representatives of the manufacturer. The design review is supported by a checklist. The parameters to be analysed depend on the design validated.

4.2 Equipment

Special equipment will not be required at this design review.

4.3 Testing environment

A specific testing environment will not be required at this design review.

4.4 Information required from the manufacturer

Following information will be necessary for the design review:

- information on which HMI parameters were identified to influence the performance
- information on how HMI design was tested by the manufacturer.

Following information is optional for the design review:

- test protocols for HMI design
- references to standards

4.5 Vehicle preparation

Vehicle preparation will not be required for this design review

4.6 Review procedure

For each functionality (longitudinal, lateral, and stability), the following HMI design aspects shall be reviewed:

- warnings
  - visual
  - auditory
  - haptic
- support
- intervene
  - system/driver override
  - competition between systems
- workload
- system status indication

The design review will study the documentation provided by the manufacturer. At least one meeting with representatives of the manufacturer should be held. Working notes shall be taken by reviewers. It may also be helpful to examine and drive the vehicle.

The review is supported by a checklist (see annex) listing specific aspects associated to HMI design. The design review will end when conclusions have been drawn and a report has been written.

4.7 Uncertainty

Not applicable.

4.8 Report

The result of the design review will be four conclusions:

- If HMI design are expected to influence the performance of the design to be tested.
- If the developer has specified requirements for HMI design.
- if the developer has performed adequate tests of the HMI design.
- if simulation experiments of the HMI design is necessary to complement performance testing on the test track.

The result will be documented in a report based on the checklist in Appendix 1.

APPENDIX 7. CHECKLIST HMI DESIGN

n.a. = Not applicable question (Some questions may not be applicable for all vehicles.)

Design Review of HMI Design

No	Question	n.a.	Yes	No	Comment
	HMI requirements specification				
A	Will the performance of the subject vehicle be affected by the HMI design?				
B	Is HMI design addressed in the requirements specification of the subject vehicle?				
	Manual				
C	Is the HMI well-explained in the manual of the subject vehicle?				
	Longitudinal Functionality				
	General				
D	Is the subject vehicle equipped with longitudinal safety functionality?				
	Status Indication				
E1	Are the modes of operation of the longitudinal safety functionality presented to the driver? (E.g. activated - deactivated)				
E2	Is there a possibility to turn off longitudinal safety functionality?				
E3	Is there a risk to turn the longitudinal safety functionality off by mistake?				

No	Question	n.a.	Yes	No	Comment
E4	Are the conditions of the longitudinal safety functionality presented to the driver? (E.g. faulty – fault-free, capable/incapable)				
	Visual warnings				
F1	Are there visual warnings related to longitudinal safety functionality?				
F2	Are standardized symbols used for visual warnings? (E.g. ISO 2575, SAE J2402)				
F3	Is the size of the symbols adequate? (in relation to other warning symbols)				
F4	Is the colour of the symbols adequate? (has a appropriate warning colour been selected)				
F5	Is the luminance of the symbols adequate? (in relation to other warning symbols)				
F6	Is the contrast of the symbols adequate? (in relation to other warning symbols)				
F7	Is the viewing angle of the symbols adequate?				
F8	Is the timing of symbol presentation adequate? (not too late or too early)				
F9	Is the interval at which symbols are presented adequate?				
F10	Is the location of the symbols adequate? (is head movement necessary)				
F11	Is there an intensification of the warnings? (E.g. caution -> warning)				
F12	Is the intensification performed adequately?				

Visual information						
G1	Is there visual information related to longitudinal safety functionality? (e.g. menus)					
G2	Is the choice of graphics/representational features suitable for what they represent?					
G3	Are graphics/representational features grouped where possible?					
G4	Is the information presented legible? (i.e. size, contrast, brightness, illumination, image stability, resolution, colour, etc.)					
Auditory warnings						
H1	Are there auditory warnings related to longitudinal safety functionality?					
H2	Is the auditory output (warning info) appropriate for the information to be conveyed?					
H3	Is the volume of auditory warnings adequate? (possible to hear during normal driving conditions)					
H4	Is the volume adjustable by the driver?					
H5	Is the tone of auditory warnings adequate? (in relation to other warning sounds)					
H6	Is the timing of auditory warnings adequate? (not too late or too early)					
H7	Is the interval at which auditory warnings are presented adequate?					
H8	Is the location of auditory warnings adequate? (threat from one side gives warning from the same side)					
H9	Is there an intensification of the warnings? (E.g. caution -> warning)					
H10	Is the intensification performed adequately?					

Haptic warnings						
I1	Are there haptic warnings related to longitudinal safety functionality?					
I2	Is the intensity used for haptic warnings adequate? (possible to feel during normal driving conditions)					
I3	Is the timing of haptic warnings adequate? (not too late or too early)					
I4	Is the interval at which haptic warnings are presented adequately?					
I5	Is the location of haptic warnings adequate? (threat from one side gives warning from the same side)					
I6	Is there an intensification of the warnings? (E.g. caution -> warning)					
I7	Is the intensification performed adequately?					
Interventions						
J1	Are there interventions related to lateral safety functionality?					
J2	Can the driver override the safety functionality if needed?					
J3	Can the safety functionality override the driver?					
Lateral Functionality						
General						
K	Is the subject vehicle equipped with lateral safety functionality?					
Status Indication						
L1	Are the modes of operation of the lateral safety functionality presented to the driver? (E.g. activated - deactivated)					
L2	Is there a possibility to turn off lateral safety functionality?					

L3	Is there a risk to turn the lateral safety functionality off by mistake?					
L4	Are the conditions of the lateral safety functionality presented to the driver? (E.g. faulty – fault-free, capable/incapable)					
	Visual warnings					
M1	Are there visual warnings related to lateral safety functionality?					
M2	Are standardized symbols used for visual warnings? (E.g. ISO 2575, SAE J2402)					
M3	Is the size of the symbols adequate? (in relation to other warning symbols)					
M4	Is the colour of the symbols adequate? (has a appropriate warning colour been selected)					
M5	Is the luminance of the symbols adequate? (in relation to other warning symbols)					
M6	Is the contrast of the symbols adequate? (in relation to other warning symbols)					
M7	Is the viewing angle of the symbols adequate?					
M8	Is the timing of symbol presentation adequate? (not too late or too early)					
M9	Is the interval at which symbols are presented adequate?					
M10	Is the location of the symbols adequate? (is head movement necessary)					
M11	Is there an intensification of the warnings? (E.g. caution -> warning)					
M12	Is the intensification performed adequately?					
	Visual information					
N1	Is there visual information related to lateral safety functionality? (e.g. menus)					
N2	Is the choice of graphics/representational features suitable for what they					

	represent?					
N3	Are graphics/representational features grouped where possible?					
N4	Is the information presented legible? (i.e. size, contrast, brightness, illumination, image stability, resolution, colour, etc.)					
	Auditory warnings					
O1	Are there auditory warnings related to lateral safety functionality?					
O2	Is the auditory output (warning info) appropriate for the information to be conveyed?					
O3	Is the volume of auditory warnings adequate? (possible to hear during normal driving conditions)					
O4	Is the volume adjustable by the driver?					
O5	Is the tone of auditory warnings adequate? (in relation to other warning sounds)					
O6	Is the timing of auditory warnings adequate? (not too late or too early)					
O7	Is the interval at which auditory warnings are presented adequate?					
O8	Is the location of auditory warnings adequate? (threat from one side gives warning from the same side)					
O9	Is there an intensification of the warnings? (E.g. caution -> warning)					
O10	Is the intensification performed adequately?					
	Haptic warnings					
P1	Are there haptic warnings related to lateral safety functionality?					
P2	Is the intensity used for haptic warnings adequate? (possible to feel during normal driving conditions)					
P3	Is the timing of haptic warnings adequate? (not too late or too early)					

P4	Is the interval at which haptic warnings are presented adequately?					
P5	Is the location of haptic warnings adequate? (threat from one side gives warning from the same side)					
P6	Is there an intensification of the warnings? (E.g. caution -> warning)					
P7	Is the intensification performed adequately?					
	Interventions					
Q1	Are there interventions related to lateral safety functionality?					
Q2	Can the driver override the safety functionality if needed?					
Q3	Can the safety functionality override the driver?					
	Stability Functionality					
	General					
R	Is the subject vehicle equipped with stability safety functionality?					
	Status Indication					
S1	Are the modes of operation of the stability safety functionality presented to the driver? (E.g. activated - deactivated)					
S2	Is there a possibility to turn off stability safety functionality?					
S3	Is there a risk to turn the stability safety functionality off by mistake?					
S4	Are the conditions of the stability safety functionality presented to the driver? (E.g. faulty – fault-free, capable/incapable)					
	Visual warnings					
T1	Are there visual warnings related to stability safety functionality?					

T2	Are standardized symbols used for visual warnings? (E.g. ISO 2575, SAE J2402)				
T3	Is the size of the symbols adequate? (in relation to other warning symbols)				
T4	Is the colour of the symbols adequate? (has a appropriate warning colour been selected)				
T5	Is the luminance of the symbols adequate? (in relation to other warning symbols)				
T6	Is the contrast of the symbols adequate? (in relation to other warning symbols)				
T7	Is the viewing angle of the symbols adequate?				
T8	Is the timing of symbol presentation adequate? (not too late or too early)				
T9	Is the interval at which symbols are presented adequate?				
T10	Is the location of the symbols adequate? (is head movement necessary)				
	Visual information				
U1	Is there visual information related to stability safety functionality? (e.g. menus)				
U2	Is the choice of graphics/representational features suitable for what they represent?				
U3	Are graphics/representational features grouped where possible?				
U4	Is the information presented legible? (i.e. size, contrast, brightness, illumination, image stability, resolution, colour, etc.)				
	Auditory warnings				
V1	Are there auditory warnings related to stability safety functionality?				
V2	Is the auditory output (warning info) appropriate for the information to be conveyed?				

V3	Is the volume of auditory warnings adequate? (possible to hear during normal driving conditions)				
V4	Is the volume adjustable by the driver?				
V5	Is the tone of auditory warnings adequate? (in relation to other warning sounds)				
V6	Is the timing of auditory warnings adequate? (not too late or too early)				
V7	Is the interval at which auditory warnings are presented adequate?				
V8	Is there an intensification of the warnings? (E.g. caution -> warning)				
V9	Is the intensification performed adequately?				
	Haptic warnings				
W1	Are there haptic warnings related to stability safety functionality?				
W2	Is the intensity used for haptic warnings adequate? (possible to feel during normal driving conditions)				
W3	Is the timing of haptic warnings adequate? (not too late or too early)				
W4	Is the interval at which haptic warnings are presented adequately?				
W5	Is the location of haptic warnings adequate? (threat from one side gives warning from the same side)				
W6	Is there an intensification of the warnings? (E.g. caution -> warning)				
W7	Is the intensification performed adequately?				
	Intervention				
X1	Are there interventions related to stability safety functionality?				
X2	Can the driver override the safety functionality if needed?				

X3	Can the safety functionality override the driver?					
	Combinations					
	Warnings					
Y1	Could there be combination of warnings? (from two or more safety functionalities)					
Y2	Are priorities of warnings handled adequately? (i.e. priority is given to the warning related to the function of highest safety relevance)					
Y3	Can warnings be discriminated from each other?					
Y4	Is there a risk that the workload of the driver becomes too high? (i.e. safety function(s) present(s) excessively distracting information)					
	Interventions					
Z1	Could there be combination of interventions? (from two or more safety functionalities)					
Z2	Are priorities of interventions handled adequately?					

Testing Protocol

for

Design Review

of

Functional Safety

1 SCOPE

The components within vehicles are becoming more and more replaced by electronic devices which are taking over additional (safety) functionalities. The consequence is an increased complexity of safety requirements, preventive actions to avoid faulty states and failures of those components. Safety turns out to be one of the key issues as new functionalities as ADAS (Advanced Driver Assistance System), dynamics control and additional safety systems emerge.

Failure in ICT-based safety functions may cause risks. Meanwhile when designing such a system, the goal is to develop a system that provides the safety functions it is designed for under any probable situation. The design review of the functional safety shall address the safety principles applied and the safety measures implemented to avoid hazardous system states or operation modes. The development of ICT-based functions must be based on a requirement specification set-up adapted to the hazardous situation attributed to systematic faults, component failures, or driver mistakes.

Due to the limited time and resources allocated to performance testing, a design review could be used to verify how the vehicle handles different types of failure.
The objective is to verify that the design fulfils the specified requirements when the vehicle is operating in the occurrence of hazardous events. The important faults/failures that may influence the behaviour of the vehicle must be identified, and the vehicle and its ICT-based safety functions must be verified for different failure modes.

The design review will be applicable for cars, trucks and buses.

Failures in ICT-based safety functions are unlikely to occur during performance testing. Thus, a design review is required to verify the vehicle behaviour at fault.

2 REFERENCES

[26262] ISO/CD 26262 Road vehicles – Functional Safety, Rev.1 – Part 1 to Part 9, 2008-02-29

[26262-1] ISO/CD 26262-1 Road vehicles – Functional Safety – Part 1: Glossary

[26262-2] ISO/CD 26262-2 Road vehicles – Functional Safety – Part 2: Management of functional safety.

[26262-3] ISO/CD 26262-3 Road vehicles – Functional Safety – Part 3: Concept phase

[26262-4] ISO/CD 26262-4 Road vehicles – Functional Safety – Part 4: Product development system level

[61508] IEC 61508-1:1998, Functional safety of electrical/electronic/programmable electronics safety-related systems Part 1: General requirements

[60812] IEC 60812 Analysis techniques for system reliability – Procedure for failure mode and effects analysis (FMEA)

[61078] IEC 61078 Analysis techniques for dependability – Reliability block diagram method

[61025] IEC 61025 Fault Tree Analysis (FTA)

3 DEFINITIONS

ASIL: the Automotive Safety Integrity Levels are determined by a systematic evaluation of potentially hazardous operational situations. The ASIL-Level shall be determined for each hazardous event using the estimation parameters severity (S), probability of exposure (E) and controllability (C) in accordance with Table 4. [26262-3]

Controllability (C): The controllability shall be assigned to one of the controllability classes C0, C1, C2 and C3 in accordance with Table 3. If a situation is regarded as simply distracting or disturbing but as controllable in general, the class C0 may be assigned. If a hazard is assigned to controllability class C0, no ASIL assignment is required. [26262-3]

Element: sub-units of items including system, subsystem, component. [26262-3]
E/E system: system that consists of electrical and/or electronic elements, including programmable electronic elements, power supplies, sensors and other input devices, data highways and other communication paths, and actuators and output devices. [26262-3]

Failure Mode and Effect Analysis (FMEA): Method used for the identification of potential failure/error types in order to define its effect on the examined object (System, Segment, SW/HW Unit) and to classify the failure/error types with regard to criticality or persistency.

Fault Tree Analysis (FTA): Method to identify potential design weaknesses using a highly detailed logic diagram depicting basic faults and events that can lead to system failure and/or safety hazard.

Functional safety: absence of unacceptable risk due to hazards caused by mal-function behaviour of E/E systems. [26262-3]

Functional safety concept: specification of the functional safety requirements, their allocation to architectural elements and their interaction necessary to achieve the safety goals, and information associated with these requirements.

Functional safety requirements: specification of implementation-independent safety-related behaviour or a safety measure including its safety-related attributes.
NOTE 1 Safety requirement implemented by a safety-related E/E system or by a safety-related system of other technologies in order to achieve or maintain a safe state for the item taking into account a determined hazardous event.
NOTE 2 The functional safety requirements are specified independent of the used technology in the concept phase of product development. They are detailed into technical safety requirements after concept phase.
[26262-3]

Hazard classification: the hazard classification scheme comprises the determination of the severity (S), the probability of exposure (E) and the controllability (C) associated with the considered hazard of the item. For a given hazard, this classification will result in one or more combinations of S, E and C classes. Each such combination represents an estimate of a potential harm in a particular driving situation, with the severity determined by the potential harm and the exposure determined by the situation. The controllability rates how easy or difficult it is for the driver or other road traffic participant to avoid the considered accident type in the considered situation. [26262-3]

Probability of exposure (E): The probability of exposure of the operational situations shall be estimated. The probability of exposure shall be assigned to one of the probability classes E1, E2, E3 and E4 in accordance with Table 2. [26262-3]

Quality management (QM): A certified quality management system complying with a quality standard, such as ISO TS 16949, ISO 9001 or equal, shall operate effectively.

NOTE This Clause applies to every organisation involved in the development of the safety related items.

The overall quality management system shall ensure the application of the requirements in ISO 26262.

Reliability Block Diagrams (RBDs): Method which establishes system reliability on a modular or block oriented basis.

Risk: Combination of the probability of a harm/damage occurring and the severity of evolving harm or damage.

Safety: Freedom from unacceptable risk of physical injury or of damage to the health of people, either directly or indirectly as a result of damage to property or to the environment.

Severity (S): The severity of potential harm shall be estimated. The severity shall be assigned to one of the severity classes S0, S1, S2 or S3 in accordance with Table 1. [26262-3]

Situation analysis and hazard identification: The operational situations and operating modes in which the item is able to trigger hazards shall be described for cases when correctly used, when incorrectly used in a foreseeable way, or in case of item failure. [26262-3]

Table 5 Classes of severity

Class	**S0**	**S1**	**S2**	**S3**
Description	No injuries	Light and moderate injuries	Severe and life-threatening injuries (survival probable)	Life-threatening injuries (survival uncertain), fatal injuries

Table 6 Classes of probability of exposure regarding operational situations

Class	**E1**	**E2**	**E3**	**E4**
Description	Very low probability	Low probability	Medium probability	High probability

Table 7 Classes of controllability

Class	**C0**	**C1**	**C2**	**C3**
Description	Controllable in general	Simply controllable	Normally controllable	Difficult to control or uncontrollable

Table 8 ASIL determination

		C1	C2	C3
S1	E1	QM	QM	QM
	E2	QM	QM	QM
	E3	QM	QM	A
	E4	QM	A	B
S2	E1	QM	QM	QM
	E2	QM	QM	A
	E3	QM	A	B
	E4	A	B	C
S3	E1	QM	QM	A
	E2	QM	A	B
	E3	A	B	C
	E4	B	C	D

4 DESIGN REVIEW

4.1 Principle

The vehicle OEM or safety system supplier will provide their risk analysis with regard to the impact of subsystem/component mal-functional on the operation of the ICT-based safety system. They will also supply information concerning the development testing of the safety systems and safety functions with regard to the identified risks and hazards.
The design review will include a study of the documentation provided, and an interview with representatives of the manufacturer. The design review is supported by a checklist.

4.2 Equipment

Equipment will not be required for this design review.

4.3 Testing environment

A specific testing environment will not be required at this design review.

4.4 Information required from the manufacturer

For each ICT-based safety function following information is required for the design review.
A description of the safety goals
A specification of the basic safety mechanisms and safety measures in the form of functional safety requirements shall be provided. These requirements shall describe what has to be provided by each element in the system architecture.
A description of feasible safety mechanisms such as:

- Fault detection and failure mitigation by switching to a safe state;
- Fault tolerance mechanisms, where a fault does not lead directly to the violation of the safety goals and which maintains the system in a safe state (with or without back-up);
- Fault detection and driver warning in order to reduce the risk exposure time to an acceptable span (repair request, stop request).

The technical safety concept shall include details concerning how the functional safety requirements are technically implemented by each of the elements of the architecture. The system architecture includes hardware as well as software.
Following information is optional for the design review:

- Management of functional safety
- references to standards

4.5 Vehicle preparation

Vehicle preparation will not be required at this design review.

4.6 Review procedure

General aspects related to basic concepts of ICT-based system development are treated in the first part of the review. See questions A to D in the checklist.
For each ICT-based safety function the following issues are reviewed:
- the implementation of the situation analysis and hazard identification, see questions E to O in the checklist:
- the realisation of the hazard classification and ASIL determination, see questions P to U in the checklist .
Safety principles, hardware design and software design are not parts of this design review.

4.7 Uncertainty

Not applicable.

4.8 Report

The design review shall after examination of the safety functions shows that:

- A situation analysis and hazard identification has been carried out.
- A classification of the hazards has been made
- A safety integrity level is assigned to each safety function.

The result of this design review is to present an opinion on the safety-related aspects of the ICT-based safety functions.

APPENDIX 8. CHECKLIST FUNCTIONAL SAFETY

n.a. = Not applicable question (Some questions may not be applicable for all vehicles.)

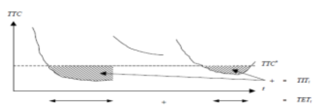
Design Review of Functional safety

No	Question	n.a.	Yes	No	Comment
A	Are ICT-based safety functions implemented in the vehicle?				
B	Is each ICT-based safety function developed according to any specific international or European standard?				
C	Are all ICT-based safety functions identified and documented?				
D	Are the test results of the ICT-based function integration at system and vehicle level documented?				
For each ICT-based safety function					
Situation analysis and hazard identification					
E	Is the Hazard analysis and Risk assessment fully documented with regard to situation analysis and hazard identification?				
F	Have the potential unintended functional states that could lead to a hazard event been identified?				
G	Has foreseeable driver use and misuse been considered in the situation analysis and hazard identification?				
H	Has the impact of high speed driving been considered in the situation analysis and hazard identification?				
I	Has urban driving been considered in the situation analysis and hazard identification?				
J	Has parking been included as a vehicle usage scenario in the situation analysis and				

	hazard identification?				
K	Has off-road driving been included as a vehicle usage scenario in the situation analysis and hazard identification?				
L	Has road surface friction been considered in the situation analysis and hazard identification?				
M	Has foreseeable driver use and hazard identification misuse been considered in the situation analysis?				
N	Has the impact of side winds been considered in the situation analysis and hazard identification?				
O	Has the interaction between operational systems been considered in the situation analysis and hazard identification?				
Hazard classification					
P	Is the Hazard analysis and Risk assessment fully documented with regard to Hazard classification?				
Q	Has the severity (S) associated with the considered hazard been determined?				
R	Has the probability of exposure (E) associated with the considered hazard been determined?				
S	Has the controllability (C) associated with the considered hazard been determined?				
ASIL determination					
T	Is the Hazard analysis and Risk assessment fully documented with regard to ASIL determination?				
U	Has the ICT-based safety function been				

	assigned a safety integrity level (ASIL)?				
Fault detection capabilities					
V	Can faults in the ICT-based safety systems be detected?				
W	Has the manufacturer identified the failure modes of the system? [60812]				
X	Has the manufacturer identified the causes and effects of such failures?				
False alarms					
Y	Has the manufacturer tested and analysed the identified situations where a false alarm occurs?				

9 ANNEX II – Review of possible safety indicators for cluster 1 and 2

Test scenario	Safety Indicator	Description of Safety Indicator	Reason for Safety Indicator	How to measure the Safety Indicator (tools)	How to assess Safety Indicator (impact on safety)	Publication on safety impact of Safety Indicator
Longitudinal and Lateral Cluster	Mean/ Min/ Max Impuls	The impulse, time derivative of impact force, during an impact describes both, collision speed and mass of the vehicle hitting a target. It is well suited to take different vehicle classes (passenger vehicle, HGV) into account.	Safety functions are supposed to avoid accidents or mitigate accident consequences. Changes in impulse reflect directly the impact of the safety system.	Measurement of collision speed Measurement of speed at end of collision (commonly zero after accident) Mass of vehicle I=F*t=m*v1-m*v0 Tools: high precision positioning system, CAN-reader, CORREVIT or similar.	same as collision speed	
Longitudinal and Lateral Cluster	Mean/ Min/ Max Time to Collision (TTC)	A TTC value at an instant t is defined as the time that remains until a collision between two vehicles would have occurred if the collision course and speed difference are maintained.	Commonly and successfully used as safety indicator in many studies, describes time distance to potential collision if both vehicles keep up current velocity.	Numerator describes distance to leading vehicle, can be measure with e. g. radar sensor. Denominator describes speed distance, usually also measured by radar (tracking). Tools: high precision positioning system, CAN-reader, CORREVIT or similar. $TTC_i = \frac{X_{i-1}(t) - X_i(t) - l_i}{\dot{X}_i(t) - \dot{X}_{i-1}(t)} \forall \dot{X}_i(t) > \dot{X}_{i-1}(t)$ X Position $\dot{X}$ Speed l length of vehicle	the higher the TTC, the safer the situation (qualitative relationship)	Hayward, J. C. Near Miss Determination Through Use of a Scale of Danger The Pennsylvania Transportation Institute, 1971 Minderhoud, M. M. & Bovy, P. H. L. Extended time-to-collision measures for road traffic safety assessment Accident Analysis & Prevention, 2001, 33, 89 - 97
Longitudinal and Lateral Cluster	Mean/ Min/ Max Time Exposed TTC	TET describes the exposition to safety-critical time-to-collision values over specified time duration H. 	A single TTC value gives no information about exposure to risk above a certain level, while TET does.	TTC* is the threshold of TTC tau is the time step, H the considered time period, T=H/tau are the number of time instants t taken into account. Tools: high precision positioning system, CAN-reader, CORREVIT or similar $TET_i^* = \sum_{t=0}^{T} \delta_i(t) \cdot \tau_{sc}$ $\delta_i(t) = \begin{cases} 0 \\ 1 \forall 0 \le TTC_i(t) \le TTC^* \end{cases}$	The smaller TET, the more safe is a specific situation of duration H.	Minderhoud, M. M. & Bovy, P. H. L. Extended time-to-collision measures for road traffic safety assessment Accident Analysis & Prevention, 2001, 33, 89 - 97
Longitudinal and Lateral Cluster	Mean/ Min/ Max Time Integrated TTC	TIT gives information about exposure in terms of time and severity to a TTC below a defined threshold.	TET has one major drawback: it does not consider enought really small TTC during a short time: TTC lower than TTC* does not affect the PI. TIT tries to overcome this by calculating the integral of time spent below TTC*.	Tools: high precision positioning system, CAN-reader, CORREVIT or similar $TIT^* = \sum_{i=1}^{N} \int_0^T \left(TTC^* - TTC_i(t)\right) dt$ $\forall 0 \le TTC_i(t) \le TTC^*$	The smaller TIT, the more safe is a specific situation of duration H.	Minderhoud, M. M. & Bovy, P. H. L. Extended time-to-collision measures for road traffic safety assessment Accident Analysis & Prevention, 2001, 33, 89 - 97
Longitudinal and Lateral Cluster	mean/ min Distance to target vehicle	Minimum or mean distance to a target vehicle in a specific scenario. Describes how close ego and target vehicle got. Drawback: independent from absolute and relative speed and mass	TTC might be undefined (division by zero), but very short distance to leading vehicle still not safe	Tools: high precision positioning system, CAN-reader, CORREVIT or similar, radar or lidar sensor	the smaller the less safe.	
Longitudinal and Lateral Cluster	mean/ min time gap to target vehicle	Minimum or mean time gap to a target vehicle in a specific scenario. Describes how close ego and target vehicle got. Drawback: independent from absolute and relative speed and mass	TTC might be indefined (division by zero), but very short distance to leading vehicle still not safe	Tools: high precision positioning system, CAN-reader, CORREVIT or similar, radar or lidar sensor	the smaller the less safe.	

Test scenario	Safety Indicator	Description of Safety Indicator	Reason for Safety Indicator	How to measure the Safety Indicator (tools)	How to assess Safety Indicator (impact on safety)	Publication on safety impact of Safety Indicator
Lateral Cluster	Stdev lane position	Standard deviation of lane position. Middel of the lane is considered as optimum and deviations from the optimum are measured each time step, then calculation of StDev This is one of the most common performance metrics. Its popularity is probably due to its high face validity and computational simplicity. The metric has been shown to be relatively independent of speed (Godthelp, Milgram and Blaauw, 1984).	Together with steering wheel movement, lane keeping metrics are the most commonly used lateral control performance metrics. The rationale is that increased lane weaving and/or lane exceedences indicate degraded control and, hence, increased accident probability. underlying reasoning: drivers try to optimise the lane keeping task and to stay to the centre of the lane	center line vehicle in relation to centre line of lane Tools: lane tracker	Given the assumption that it is safer to drive as close to the centre of lane, safety is increasing the smaller STDEV LP is.	AIDE
Lateral Cluster	mean/ min TLC	The time remaining before the driver's vehicle will reach a lane boundary assuming the current steering wheel angle remains constant and the driver fails to intercede (Godthelp et al., 1984) The lateral counterpart to the time-to-collision (TTC) metric is the time-to-line crossing (TLC), first developed by Godthelp and Konings (1981).	In driving, TLC could be regarded as reflecting the driving strategy, or more precisely, the time-based lateral safety margins adopted by the driver. This interpretation is supported by results in Godthelp, Milgram and Blaauw (1984), demonstrating that the TLC correlates strongly to driver's self-chosen occlusion time. Too small TLC values are thus strong indicators of reduced lateral control (where "too small" is determined relative the subjectively chosen safety margins).	In the real world lane position is normally measured by means of video-based lane-tracking systems, many of which are commercially available. AIDE recommends a minimum accuracy of about +/- 5 cm.	The smaller TLC, the less safe is a situation. However, the definition of a threshold is neccessary.	Godthelp et al. (1984). The development of a time-related measure to describe driving strategy. Human Factors, 26, 257. Paul, A., Boyle, L.N., Tippin, J., Rizzo, M. (2005). Variability of driving performance during microsleeps. Third International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design. Van Winsum, W; Brookhuis, K.A.; De Waard, D. (2000). A comparison of different ways to approximate Time-to-Line? Crossing (TLC) during car driving. Accident Analysis and Prevention, 32, 47-56 Johansson et al. (2004) Review of existing techniques and metrics for IVIS and ADAS assessment. Del 2.2.1 of the AIDE project. Östlund et al. (2004), Driving performance assessment methods and metrics. Del 2.2.5 of the AIDE project.
Lateral Cluster	Peak lane deviation	The maximum magnitude of lateral position as measured from a point on the centreline of the vehicle projected downward to the pavement and subtracted from lane centreline or other fixed reference.	Together with steering wheel movement, lane keeping metrics are the most commonly used lateral control performance metrics. The rationale is that increased lane weaving and/or lane exceedences indicate degraded control and, hence, increased accident probability.	Tools: lane tracker	The more a vehicle deviates from its own lane, the higher is the probability that an accident occurs (given traffic and road etc. conditions)	Wierwille, W., Tijerina, L., Kiger, S., Rockwell, T., Lauber, E. And Bittner, A Jr. (1996). Heavy Vehicle Driver Workload Assessment. Task 4: Review of Workload and Related Research. US Department of Transportation, NHTSA. DOT HS 808 467 (4).
Lateral Cluster	Mean/ Max Time spent outside own lane	Time, a part of the vehicle is outside its own lane, measured between outside contour of vehicle and lane marking	reflects the time the driver needs to bring the vehicle back to its own lane and therefore inherits information about both, system performance and HMI (usbility, etc.)	Tools: lane tracker	The shorter the time outside own lane, the safer..	Wierwille, W., Tijerina, L., Kiger, S., Rockwell, T., Lauber, E. And Bittner, A Jr. (1996). Heavy Vehicle Driver Workload Assessment. Task 4: Review of Workload and Related Research. US Department of Transportation, NHTSA. DOT HS 808 467 (4).
Lateral Cluster	frequency of lane exceedance	number of lane exceedences in given time or on given length of road.	Lane exceedances are potentially risky, so if a system decreases those (unintended!) exceedancec, it decreases porbability of frontal collisions (given road and traffic conditions)	Tools: lane tracker	the fewer exceedances, the safer	Wierwille, W., Tijerina, L., Kiger, S., Rockwell, T., Lauber, E. And Bittner, A Jr. (1996). Heavy Vehicle Driver Workload Assessment. Task 4: Review of Workload and Related Research. US Department of Transportation, NHTSA. DOT HS 808 467 (4).

10 ANNEX III – Review of possible safety indicators for cluster 3

Test scenario	Safety Indicator	Description of Safety Indicator	Reason for Safety Indicator	How to measure the Safety Indicator (tools)
C3-1	Stopping distance	It is the distance traveled by the car during the braking manoeuvre until the vehicle becomes standstill.	It is a performance parameter, directly correlated to the risk of collision, safety	Speed/distance sensor: optical or GPS
	Maximum initial speed	Maximum intitial speed is the highest speed at which the vehicle can be stopped within a specific braking distance	The ability to stop in a specific distance from a high speed is important for safety	Speed/distance sensor: optical or GPS
	Use of adherence	Use of available adherence: high/low	Performance	X axis accelerometer (inertial platform)
	Driver steering input	Steering wheel angle, speed, torque (sign, peak value, averaged, integrated…)	Level of driver input required for driving through the scenario	Steering wheel sensor: torque and angle
	Yaw response	Yaw change respect straight driving. Yaw angle and yaw rate.	Stability	Z axis gyro (inertial platform)
	Lateral deviation	It is the maximum lateral deviation reached during the braking manoeuvre.	For a closed-loop braking it is a control parameter useful to check the quality of the closed-loop, for an open-loop braking it is a an indicator of the car stability and safety.	Position measurement: DGPS. Also can be calculated from inertial platform and optical sensor data.
C3-2	Lateral displacement	Lateral displacement at 1.07s after the steering wheel input	It is the avoidance responsiveness parameter suggested by FMVSS 126.	Calculated from Y axis gyro (inertial platform). Also can be measured with DGPS
	Vehicle speed variation	It is the difference of velocity between the start and the end of the manoeuvre.	Together with sideslip angles peaks it gives an idea about how much the ESC has to work in order to keep the car stable VT=0-VT0+1.75	Speed sensor: optical or GPS
	Maximum initial speed	Maximum intitial speed is the highest speed at intervention at which the vehicle can manage the avoidance scenario	The ability to perform an avoidance manoeuvre is important for safety	Speed sensor: optical or GPS
	Driver steering input	Steering wheel angle, speed, torque (sign, peak value, averaged, integrated…)	Level of driver input required for driving through the scenario	Steering wheel sensor: torque and angle
	Driver intention following	Comparison between expected vs actual vehile response	Driver intention following is safety related	Steering wheel sensor and inertial platform
	Yaw rate ratios	They are the ratios between the yaw rate at certain times after the end of the SW actuation and the yaw rate peak.	They are the stability parameters suggested by FMVSS 126.	Z axis gyro (inertial platform)
	Sideslip angle peaks	They are the minimum and maximum values of sideslip angles during the manoeuvre.	They are stability parameters directly related to the oversteer tendency of the vehicle.	Slip sensor: optical or GPS
C3-3	Maximum initial speed	Maximum intitial speed is the highest speed at which the vehicle can manage the curve scenario	The ability to negotiate a curve at a high speed is important for safety	Speed sensor: optical or GPS
	Driver steering input	Steering wheel angle, speed, torque (sign, peak value, averaged, integrated…)	Level of driver input required for driving through the scenario	Steering wheel sensor: torque and angle
	Lateral deviation	Lateral position deviation (respect closing curve reference)	The ability to keep the trajectory is important for safety	Position measurement: DGPS
	Yaw response	Yaw change respect straight driving. Yaw angle and yaw rate.	Yaw stability is important for safety	Z axis gyro (inertial platform)
C3-4	Maximum initial speed	Maximum intitial speed is the highest speed at which the vehicle can manage the roll stability scenario	The ability to negotiate a curve at a high speed is important for safety	Speed sensor: optical or GPS
	Driver steering input	Steering wheel angle, speed, torque (sign, peak value, averaged, integrated…)	Level of driver input required for driving through the scenario	Steering wheel sensor: torque and angle
	Two wheel lift	This is represents the rollover condition: if both inner wheels lifted more than 2 inches from the ground and for more than 20 ms.	Tyre height is related to roll stability of the vehicle and hence important for safety	Height sensors: laser
	Roll rotation	Roll rotation is the rotation around the x axis of the vehicle	Roll rotation is related to the stability of the vehicle and hence important for safety	X axis gyro (inertial platform)