ECSS

Study on a new performance test for electronic safety components at roadworthiness tests

Final Report

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ECSS

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Executive summary

In the interest of road safety and the environment it is important to ensure that vehicles on European roads are maintained to a high degree of technical roadworthiness, taking into account the increasingly complex and dynamic functionality of vehicle systems, particularly Electronically Controlled Safety Systems (ECSS).

To help address this issue, the European Commission contracted a consortium led by CITA and including EGEA to undertake a project to develop and evaluate roadworthiness inspection methods and associated equipment for the inspection of the functionality and performance of Electronically Controlled Safety Systems (ECSS) and perform a cost benefit analysis for their potential introduction into European legislation.

Starting from an expansive review of vehicle test equipment, vehicle safety system design, functionality, communication and control requirements, test methods were developed to inspect the following ECSS:

- Braking system: ABS, ESC, EBS, EBA (otherwise called BAS)
- Electronic Steering system: EPS
- Tyre Pressure Monitoring System (TPMS)
- Supplementary Restraint System (SRS): Airbags, pre-tensioners, occupancy / belt sensors,
- Headlamps: automatic levelling and dynamic aiming functions

Wherever possible these test methods incorporated the highest level of testing as defined below to ensure a 'robust as possible' inspection of the ECSS.

Definition of test level:
- Baseline – Observation of ECSS MIL.
- Test level 1 – ECSS Fitment test:
  Check through the OBD port that ECSSs, originally included in the vehicle at end-of-line or first registration, are still fitted and potentially operational.
- Test level 2a – ECSS PTI relevant information:
  Evaluation of the status of the electronic system accessed through the OBD port and using the vehicle's on-board electronic test routines designed for roadworthiness inspection and to read the relevant data, e.g. sensor data/threshold values or the safety system pre-defined fault codes.
- Test level 2b – ECSS triggering with the PTI test tool
  Checking the potential functionality of the components pertinent to roadworthiness inspection that are part of the complete electromechanical (ECSS) system by actuating those electromechanical components (actuators) via the OBD port of the vehicle.
- Test level 3 – Physical evaluation of system performance
  Checking of the correct physical functioning of the overall electromechanical (ECSS) system by actuating via the OBD port directly, or indirectly the system components, and measuring their physical performance using external test equipment.

  Notes:
  - Baseline and level 1 are always included in all other levels

- Level 2a is not included in level 2b or level 3
- Level 2b is sometimes, or partially included in level 3

Laboratory testing was used to prove that the test methods worked as designed. This was achieved by testing vehicles where the ability to monitor as well as actuate and control ECSS components was possible, or where vehicles were pre-configured with known failures and the vehicles tested to show that the methods could detect them.

The methods were optimized to combine common steps into three modules for use in a PTI environment.

1. Braking/steering/TPMS
2. SRS
3. Lights

Using these modules, field tests were performed at PTI centres in Germany, Sweden, and Belgium. The results of these tests showed the methods were suitable for introduction into a PTI regulatory regime provided that:

- Tools are available that are specifically designed for use in a PTI regime using these methods and that the test routines are automated.
- Required vehicle technical data is readily available.

A detailed list of the technical information/data required from vehicle manufacturers was made.

A cost benefit analysis (CBA) was performed for the introduction of the methods into European legislation. The analysis used a socio-economic model which evaluated both safety and non-safety critical impact channels. A number of calculations were performed because of uncertainties in the input data, specifically equipment costs and labour costs (i.e. the additional inspection time needed for the inspection of ECSS compared to today’s PTI). The benefit to cost ratio (BCR) was calculated for the years 2015 to 2030. For all calculations, for all years the BCR was estimated to be greater than 1, i.e. the benefits are greater than the costs. For each calculation the BCR was at a minimum in 2019 and a maximum in 2030. The 2019 minimum BCR calculated ranged from 1.26 to 5.97 corresponding to the pessimistic and optimistic assumptions of high and low equipment and labour costs, respectively. Similarly, the 2030 maximum BCR calculated ranged from 2.18 to 11.11.

Recommendations for the way forward are given, in particular for implementation of the methods developed into legislation and for how other and future ECSS which are not included in this study should be inspected.

1 Introduction

In the interest of road safety and the environment it is important to ensure that vehicles on European roads are maintained to a high degree of technical roadworthiness, taking into account the increasingly complex and dynamic functionality of vehicle systems, particularly for Electronically Controlled Safety Systems (ECSS).

To help address this issue, the European Commission contracted a consortium led by CITA and including EGEA to undertake a project to develop and evaluate roadworthiness inspection methods and associated equipment for the inspection of the functionality and performance of Electronically Controlled Safety Systems (ECSS) and perform a cost benefit analysis for their potential introduction into European legislation.

This report describes the work completed during the ECSS project which was active from August 2013 to July 2014. This first chapter provides an overview of the project, including the objectives, the funding, the administrative arrangements and the work programme. The subsequent chapters present the background to the project, the work conducted, the findings, and the recommendations. A glossary of terms used in the report is provided in the Glossary section 12.

1.1 Objectives and requirements of project

The overall aim of the ECSS project is to develop new inspection methods, requirements for associated tools, and the basis for future tools for inspection of Electronically Controlled Safety Systems (ECSS) suitable for use in a regulatory regime. These methods should assess the ECSS function to an appropriate level to ensure it is functioning correctly, be practical for implementation in the current PTI regime and be cost beneficial. The existing and future tools should be commercially available from a number of suppliers using their own product design solutions to ensure that PTI organisations can resource them easily at a competitive price.

The initial aim was that inspection methods/requirements for tools should be developed for the Electronically Controlled Safety Systems (ECSS) tabulated below (Table 1). These include the ECSS to be inspected in the EU legislation (Directive 2014/45/EU) for inspection of vehicles within Europe and three others identified by the project consortium, namely Emergency Brake Assist (EBA), sometimes referred to as Brake Assist System (BAS), headlamps (Active /dynamic headlight direction control system) and Tyre Pressure Monitoring System (TPMS).

Table 1: Electronically Controlled safety Systems (ECSS) for which methods/requirements for tools will be developed to inspect.

No.	ECSS	Included in 2014/45/EU Y/N	Proposed inspection method in 2014/45/EU (if applicable)
1	Anti-lock Braking System (ABS)	**Y**	Visual inspection and inspection of warning device and/or using electronic vehicle interface.
2	Electronic Stability Control (ESC)	**Y**	Visual inspection, and /or using electronic vehicle interface.
3	Electronic Braking System (EBS)	**Y**	Visual inspection and inspection of warning device and/or using electronic vehicle interface.
4	Electronic Power Steering (EPS)	**Y**	Visual inspection and consistency check between the angle of the steering wheel and the angle of the wheels when switching the engine on/off and/or using the electronic vehicle interface.
5	Emergency Brake Assist (EBA)	**N**	N/A
6	Supplemental Restraint Systems (SRS)	**Y**	Visual inspection of MIL and/or using electronic interface.
7	Safety Belt Load Limiter	**Y**	Visual inspection and/or using electronic interface.
8	Safety Belt Pretensioner	**Y**	Visual inspection and/or using electronic interface.
9	Airbag	**Y**	Visual inspection and/or using electronic interface.

In addition, a review of the status of development of methods/requirements for tools for future ECSS, in particular those that are planned to be mandated (listed in Table 2), will be performed and recommendations for the further development made.

Table 2: Exemplary future ECSS.

No.	Future ECSS	Mandatory fitment date	
		New type	New registration
1	Automatic Emergency Braking System (AEBS)	M2, M3, N2, N3 only 01/11/2013	M2, M3, N2, N3 only 01/11/2015
2	Lane Departure Warning System (LDWS)	M2, M3, N2, N3 only 01/11/2013	M2, M3, N2, N3 only 01/11/2015
3	Tyre Pressure Monitoring System (TPMS)	M1: 01/11/2012	M1: 01/11/2014
4	Ecall	Fully functioning system circa 2015	
5	Dynamic brake light intensity control/hazard flasher activation		
6	Automatic headlight levelling system		
7	Automatic headlight dip system		
8	Active/dynamic headlight direction control system		
9	Active cruise control		
10	Active low speed braking		
11	Active aerodynamics		
12	Electronic suspension/ Adaptive damping system		
13	Pedestrian airbag systems/bonnet raising devices		
14	Automatic door closing systems (door closing pressure sensor)		
15	Driver drowsiness/sleep detection system		

1.2 Funding

The ECSS project was funded primarily by the European Commission Directorate-General for Mobility and Transport (DG-MOVE[1]) under a service contract No. MOVE/C4/SER/2012-323/SI2.656968. Some additional resource was provided by the International Motor Vehicle Inspection Committee (CITA), the European Garage Equipment Association (EGEA) and other project consortium members to cover supplementary work and ensure a successful outcome to the project.

[1] PTI is one of the responsibilities of DG-MOVE.

1.3 Consortium

The project consortium which is led by the International Motor Vehicle Inspection Committee (CITA aisbl) CITA, consists of the following partners:

- CITA
- EGEA
- IERC GmbH
- BASt
- GOCA
- DEKRA

In addition CITA have the following subcontractors to supply additional expertise and capability where necessary.

CITA subcontractors:

- TRL - project management
- ADIS - Technology – independent review to ensure impartiality of project results.
- TÜV Rheinland – PTI field testing
- Bilprovningen – PTI field testing
- Robert Bosch GmbH – tool expertise and supply of tools for testing
- FSD – inspection method/tool expertise and supply of vehicles for testing

1.4 Project administration

The members and roles of the various groups involved in the administration of the project are described below.

- The *CITA Bureau Permanent,* which had overall responsibility for the project and its deliverables.
- The *Project Steering Group (PSG)* consisted of members of the CITA Bureau Permanent, Regional Advisory Group for Europe and the EGEA board of directors. The PSG provided strategic guidance and ensured impartiality and independence of project results.
- The *Project Management Team* (PMT) comprised the project manager, the project director and work package leaders. The PMT was responsible for:
  - Directing and managing the project
  - Detailed planning of work package content
  - Writing interim and final reports.
  - Communication with the customer (EC) and relevant stakeholders.

1.5 Work programme

To deliver the objectives and requirements described above, the project was divided into six workpackages which are described in Table 3**.**

Table 3: Project Workpackage (WP) descriptions.

WP no.	WP Title	Brief description of content
1	Review of ECSS, previous work and requirements for tools	Review and evaluation of electronically controlled safety systems that should be tested as part of a PTI test and definition of requirements for tools, equipment, software, communication and information requirements needed to achieve these tests.
2	Preliminary laboratory tests	Development of a cost benefit based approach to select concept inspection methods/requirements for tools. Laboratory tests with these methods and tools to demonstrate proof of concept and provide information for further selection of methods/requirements for tools to take forward for elaboration for field testing.
3	Elaborate PTI methods and recommendations for tools and information	A number of concept inspection methods/requirements for tools tested in WP2 will be selected and elaborated further for field tests.
4	Field tests with selected methods/tools	Field tests at PTI centres to assess the ability of the elaborated methods/tools and associated equipment to detect faults accurately and correctly .
5	Cost benefit analysis	Cost benefit analysis to help select inspection methods/requirements for tools for preliminary laboratory and field tests and cost benefit analysis for implementation of elaborated selected inspection methods and requirements for tools into European legislation.
6	Project management	Day to day project management including workpackage development and administration; project meetings including face-to-face meetings in Brussels; reporting (interim and final) and financial administration.

It should be noted that a cost benefit type of approach was used to select methods and requirements for tools to take forward in the project for laboratory and field testing to ensure that the selection was made in an independent and impartial manner. Also, to further ensure the impartiality of this process various measures were taken, such as review of selections by an independent consultant and the Project Steering Group (PSG) and the use of independent organisations such as TRL for project management and BASt for laboratory testing.

A Gantt chart with a list of internal deliverables is shown below to illustrate the timeline of the project and the interaction between workpackages.

Table 4: Gantt chart with list of internal deliverables.

				2013				Month			2014		
No.	Workpackage /Task	August	Sept	Oct	Nov	Dec	Jan	Feb	March	April	May	June	July
1	Review of previous work and available tools												
1.1	Overview of functionality of ECS and previous work				D1.1								
1.2	Study of available tools				D1.2								
1.3	Optimisation through standardisation of communication between vehicle and PI mode scan tool						D1.3						
2	Preliminary laboratory tests												
2.1	Develop approach/criteria to select methods/tools for lab testing and select					D2.1							
2.2	Perform laboratory tests to assess candidate methods/tools						D2.2						
3	Select inspection methods/tools and elaborate												
3.1	Develop approach/criteria to select methods/tools for field testing and select								D3.1				
3.2	Elaborate selected PTI methods/tools									D3.2			
4	Field tests with selected methods/tools												
4.1	Perform field tests										D4.1		
4.2	Analyse results of field tests											D4.2	
5	Cost benefit analysis												
5.1	CBA to help select methods/tools for laboratory and field tests					D5.1							
5.2	CBA for potential introduction of selected methods/tools ino European legislation											D5.2	
6	Project management												
6.1	Day to day management												
6.2	Reporting					Interim					Draft final		
6.3	Meetings		Kickoff				Interim						Final
6.4	Financial administration												

Internal Deliverables

D1.1: A prioritized list of items /faults for each ECSS that should be inspected. This should include the level of inspection and concepts for methods/requirements for tools needed to detect them. Prioritization should be on a cost benefit basis in terms of cost against potential to prevent / mitigate road traffic accident casualties.

D1.2: List of available and potential tools and their requirements, together with inspection items / faults and a clear understanding of what solutions exist or could be created.

D1.3: Report which summarises the options and preferred solution to optimise communication between vehicle and PTI scan tool through standardisation. This will include:

- A list with available options for communication between vehicle and tool
- A recommendation of potential requirements for standardisation of communication between vehicle and tool

D2.1: Approach/criteria to select methods/tools for laboratory testing and selection (to be reviewed by project steering group).

D2.2: Results of laboratory tests showing proof of concept and issues arising.
D3.1: Elaborated inspection methods and requirements for tools for field testing with associated equipment, instruction manuals, etc. (to be reviewed by project steering group).
D3.2: Approach/plan for field tests and analysis (to be reviewed by project steering group).
D4.1: Results of field tests.
D4.2: Analysis of results of field tests and inspection methods/recommendations for tools and other equipment for use in a regulatory regime.
D5.1: Short report detailing CBA analysis and results for helping to select methods/requirements for tools for lab and field testing.
D5.2: Report detailing CBA analysis for finally selected methods/tools and results.

1.6 Meetings

In order to maintain regular contact and ensure cost effectiveness most project meetings, about 35 to 40, were held using a telephone conference call facility. In addition face-to-face meetings were held as detailed in Table 5 below.

Table 5: Project face-to-face meetings.

Date	Location	Description
23/08/2013	Brussels	Project kick-off meeting with European Commission
17/09/2013	Brussels	Meeting between WP1 participants
01/10/2013	Brussels	Meeting between WP1 participants
09/12/2013	Brussels	Meeting between WP1 participants
10/12/2013	Cologne	Meeting between WP1 leader and BASt
28/01/2014	Brussels	Interim project meeting with European Commission
04/07/2014	Brussels	Final project meeting with European Commission

2 Background

Sustainability of transport and the safety and reliability of the different transport modes are key concepts in the EU transport policy, as reiterated by the European Commission in its White Paper on Transport published on the 28th March 2011[2]. In this document a key target for the longer term is to move towards a 'zero-vision' for deaths for road transport. For the shorter term the European Commission has a target to halve the number of deaths in the European Union by 2020 starting from 2010[3]. A key initiative to help meet these targets is to harmonise and deploy road safety technology, many of which are electronically controlled, as well as improved roadworthiness tests.

Obviously, to deliver the envisaged reduction in road accident casualties electronically controlled safety systems (ECSS) must function as designed throughout the life of the vehicle. Previous studies (AUTOFORE, IDELSY) [4] [5] have shown that the defect rate of electronically controlled safety system components is similar to that of pure mechanical systems.

Both the electronic (even when monitored by On-Board Diagnostic (OBD) systems) and mechanical components of the safety related systems are subject to deterioration over time. Therefore, a functionality and performance test of ECSS as part of Periodic Technical Inspection (PTI) for motor vehicles is necessary to ensure that they continue to operate as designed to help avoid or mitigate road accidents.

Previous work by CITA and EGEA has identified three fundamental levels for the inspection of Electronically Controlled Safety Systems (ECSS) at PTI. This work was reported in the AUTOFORE and IDELSY projects as well as the EGEA 2011 Position Paper on the Future of the EU Roadworthiness Legislation.

The three levels defined by IDELSY/AUTOFORE are as follows:

Level 1: system identification

Level 2: read-out of system data

Level 3: Physical evaluation of system electromechanical performance

The level that is most suitable for evaluating the condition of the system will be dependent on the characteristics of that system, for example it is clear that level 3 cannot be used for restraint

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[2] White paper on transport: 'Roadmap to a single European Transport Area – towards a competitive and resource-efficient transport system', EC DG for Mobility and Transport, http://ec.europa.eu/transport/strategies/doc/2011_white_paper/white-paper-illustrated-brochure_en.pdf

[3] COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS: 'Towards a European road safety area: policy orientations on road safety 2011-2020', COM(2010) 389 final, Brussels, 20.7.2010.

[4] AUTOFORE:'Study on the Future Options for Roadworthiness Enforcement in the European Union', http://ec.europa.eu/transport/roadsafety_library/publications/autofore_final_report.pdf

[5] IDELSY. 'Initiative for Diagnosis of Electronic Systems in Motor Vehicles for PTI', http://ec.europa.eu/transport/road_safety/pdf/projects/idelsy.pdf

safety systems which can only be activated once. However, for interactive systems such as Electronic Stability Control (ESC) systems, the interaction between multiple vehicle safety and control systems can be controlled and evaluated.

The approach recommended by the IDELSY/AUTOFORE studies and EGEA in their 2011 position paper[6] is to achieve the highest possible level of inspection for each ECSS.

[6] EGEA (2011) 'EGEA Position Paper: Future of the EU Roadworthiness Legislations',

3 Review of ECSS, previous work and requirements for tools

This work was divided into the following three tasks:
Task 1.1 'Overview of functionality of ECSS and previous work'
Task 1.2 'Study of available tools'.
Task 1.3 'Optimisation through standardisation of the communication between vehicle and PTI mode scan tool'.

The approach taken to perform the work was to have face-to-face meetings for work to be defined (e.g. definition of templates) and reviewed. In the periods between these meetings the Work Package (WP) leader co-ordinated input from participants and fed it into the appropriate document templates. Participants from WP2 and WP3 were also involved in the WP1 meetings to ensure a better integration of the outputs from WP1 into WP2 and WP3 and to help minimise the overall project time requirements. It should also be noted that an independent consultant, ADIS-Tech, was present at all face-to-face meetings and reviewed outputs to ensure the process was conducted in an independent and impartial manner.

The results of the work performed for each task are reported in the sections below. However, before these sections, for reference, a definition of inspection level is detailed because this is referenced many times within the work reported.

3.1 Definition of inspection level

The inspection levels referred to in this report are defined as follows:

- **Baseline:** Observation of the ECSS Malfunction Indicator Light (MIL)

- **Level 1:** ECSS Fitment test

Check through the OBD port that ECSSs, originally included in the vehicle at end-of-line or first registration, are still fitted and potentially operational.

- **Level 2a**: ECSS PTI relevant information

Evaluation of the status of the **electronic system** accessed through the OBD port and using the vehicle's on-board electronic test routines designed for roadworthiness inspection and to read the relevant data, e.g. sensor data/threshold values or the safety system pre-defined fault codes.

- **Level 2b**: ECSS triggering with the PTI test tool

Checking the potential functionality of the components pertinent to roadworthiness inspection that are part of the complete **electromechanical** (ECSS) system by actuating those electromechanical components (actuators) via the OBD port of the vehicle.

- **Level 3**: Physical evaluation of system performance.

Checking of the correct physical functioning of the overall electromechanical (ECSS) system by actuating via the OBD port directly, or indirectly the system components, and measuring their physical performance using external test equipment.

Note:

- Baseline and level 1 are always included in all other levels
- Level 2a is not included in level 2b or level 3
- Level 2b is sometimes, or partially included in level 3.

3.2 Review of functionality of ECSS and previous work and proposal of possible methods to inspect systems

During the first WP1 meeting, the design and functionality of the various ECSS were discussed to establish the key elements of not only how the systems operate, but also how they can be inspected to establish that they continue to function to their design criteria as the vehicles age. These discussions were based on the expert knowledge of the WP1 meeting participants and the test methods used as part of diagnostic test routines, including the ECSS OBD functions as well as the use of external tools to control and assess a system's functionality.

This detail was then applied to the PTI test environment, where speed and accuracy of testing are the main requirements and where key elements of several ECSS could be tested in parallel to optimise the inspection methods.

It was considered that the OBD functionality is designed to detect the behaviour or values of components which exceed pre-determined threshold values within a dedicated system. However, OBD may not be able to identify mechanical or electro-mechanical related problems that are an integral part of the system functionality. As PTI exists to check the roadworthiness of vehicles, it cannot rely on OBD only, so functional tests are necessary to check the good behaviour of the system in addition to the available OBD information.

The ECSS shown below were reviewed and possible methods to inspect them proposed:

- Anti-lock Braking System (ABS)
- Electronic Stability Control (ESC)
- Electronic Braking System (EBS)
- Emergency Brake Assist (EBA) sometimes referred to as Brake Assist System (BAS)
- Electronic Power steering (EPS)
- Supplemental Restraint System (SRS) including safety belt load limiter and pretensioner and airbag.
- Automatic Emergency Braking System (AEBS)
    - Note: This method was not taken forward into laboratory testing because:
        - At present, the mandatory fitment of AEBS for M1 vehicles is **not** planned – it is only planned for M2, M3, N2, N3.
        - There are many practical difficulties to implement a level 3 test, which are likely to make the cost benefit case unviable at present.
- Tyre Pressure Monitoring System (TPMS)
- Headlamps including automatic levelling system, dip system and direction control system

For each of these ECSS, the following information was gathered:

- Description of ECSS, including its function, architecture and components
- A list of possible failures at a sub-system level

This information was analysed in the following manner:

- For each failure a rating of its potential effect on safety and the potential ability of each level of inspection to detect it was made on a scale of 1 to 10 using expert judgment.
- An outline concept methodology for each level of inspection was developed.
- An estimate of the cost of tools for each level of inspection – generally Vehicle Communication Interface (VCI) and associated software (SW) was made.
- An estimate of time for test for each level of inspection was made.

The information gathered and results of the analysis performed were entered into individual documents for each ECSS. A template was constructed for these documents so that it was presented in a consistent manner for use in the next stage of the project (WP2), where it was used to help select the methods and tools to be taken forward into laboratory testing. The completed documents for each ECSS are contained in Annex 1.

In addition, a list of vehicle failures, which in general, do not light the MIL, was also compiled. This is shown in Annex 2. This list was needed for laboratory testing, so that it could be investigated whether or not the concept level 2 or 3 inspection methods proposed could detect these failures. The idea was that this would then help demonstrate the additional value of these level 3 inspection methods compared to lower levels of inspection, in particular the baseline level, which is fundamentally a check whether or not the MIL is operational and / or lit, or level 1, which only establishes if a system is potentially fitted and connected. It was thought that this information could be used to support the cost benefit analysis to be performed later in the project.

Tampering

One of the key aims of the work was to develop functional (level 3) test methods whenever possible. Reasons for this included that functional (level 3) testing has the potential to identify failures which may not be possible to detect through the vehicle's on-board diagnostic system (OBD) and also to identify where an ECSS has been tampered with.

Tampering may take many forms, from the simple disconnection of the vehicle battery to force a system re-set which may not be complete by the time a PTI test was conducted, to by-passing of the ECSS MIL by using a timer control, to the replacement of components with appropriate values/functions that deceive the OBD monitoring into considering that the system is able to function correctly.

Limitations of OBD self-diagnostics

OBD is designed to find system failures to facilitate repairs and in case of "imminent, immediate danger" to inform the driver of the malfunction via tell-tales (MIL) or indicators. As there is no general definition of "imminent, immediate danger", the MIL behaviour differs from model to model and from system to system.

In general, the OBD system relies on the capability of the ECSS to monitor the input values received from the major sensors that provide input to the system. The ECSS Control Module will interrogate input signals and recognise whenever the signal deviates outside of a permitted operating range. By doing this the OBD system can detect, for example, an open or short circuit. However, signals that are within the permitted range, but do not alter with a changing condition will often not be detected and therefore not light the MIL.

Another problem with OBD systems is with actuator signals. The ECSS Control Module will drive or control various system actuators. Actuators are mostly solenoid type devices and receive signals from, or are controlled directly by the ECSS Control Module. Therefore unless a feedback sensor has been added there's very little chance of a faulty actuator being identified by the system's OBD. For example, the ECSS control module will send a signal to an actuator, but it has no way of knowing if the actuator has responded unless a feed-back system has been put in place and these are rarely used.

3.3 Study of available tools

A list of tools available for laboratory testing was developed based on a survey of garage equipment suppliers and manufacturers. All EGEA members and any suppliers / manufacturers known to project members were included in the survey. To ensure the list was comprehensive and un-biased, it was reviewed by ADIS-TECH and the Project Steering Group (PSG). The list developed is shown in Annex 3.

3.4 Optimisation through standardisation of the communication between vehicle and PTI mode test tool

The work performed focused on detailing recommendations of requirements for a standardised PTI vehicle communication interface (VCI) in a face-to-face meeting of PTI and garage equipment experts.

It was agreed that existing vehicle communication Interface (VCI) designs were suitable from the hardware perspective, so no further hardware design changes are anticipated.
However, some firmware changes may be necessary to support the PTI test requirements, depending on the details of the technical implementation (e.g. ISO 22900-2 or ISO 22900-3).
It was agreed that it was not necessary to propose a new VCI dedicated to PTI testing, but that there should be some further recommendations to better support PTI testing requirements.

For the communication with the vehicle:

- Wired communication:
    - usage of ISO 15031-3/SAE J1962/ISO 13400-4 connector
    - Standardization of pin assignment for ECSS communication. The proposal is to reuse for ECSS communication the same pin assignment as the ones used for emission-related communication.
- For the communication protocols, it is proposed to use UDS (ISO 14229) based protocols derived from ISO 27145 on both CAN (ISO 15765) and DoIP (ISO 13400), using a new ISO standard for data (such as ISO 27145-2 for emission) but dedicated to ECSS testing.
  By using ISO 27145, it would also support better definitions of the diagnostic trouble codes (DTCs) which could be used for the 'notion of severity' (over three levels) for the DTCs as part of the PTI testing.

Some further recommendations included:

- The standardisation of the VCI interface (API) to the PTI test application to provide the widest choice of platforms

- Power supply requirements (internal and external) and vehicle voltage evaluation
- VM PTI technical information requirements (generic overview)
- Standardisation of ECSS data would be beneficial
- Status of vehicle controller´s hardware/software to ensure correct test method and result

3.5 Summary

Key points from Work Package 1:

1. The identification of the various vehicle ECSS component or system failures beyond those which can be identified by the system's OBD functionality.
2. The mathematical comparison across different levels of PTI testing to illustrate the optimised test methods.
3. A standardised (template) format was utilised to ensure that all ECSS followed the same evaluations process, criteria and assessment.
4. Diagnostic expertise was used to create the most effective functionality test methods for autonomous or interrelated systems.
5. The communication with the vehicle was assessed using existing and anticipated connection and communication methods to minimise the cost of providing the VCI (vehicle communication interface) whilst providing flexible choices for the foreseeable future.
6. A general overview of the requirements for tools to allow the test equipment to be designed, manufactured and supported in PTI test centres to provide optimised PTI testing of a vehicle's ECSS was created – see Section 8.2.
7. An example of automated and interactive ECSS testing concept was included as part of the study activities. This concept would support both faster and more accurate ECSS functionality testing, whilst minimising the costs involved to provide an optimised PTI testing solution.

4 Initial selection of inspection methods and tools

The work to select inspection methods and tools for laboratory testing was divided into two parts, namely the development of a methodology and associated criteria to make the selection and then to make the actual selection. Each part of the work is described in the sections below.

4.1 Selection of inspection methods and tools

The methodology developed for selection of concept inspection methods and tools for laboratory testing consisted of two parts, the first to select the concept inspection method and the second to select the tools.

4.1.1 Methodology for selection of concept inspection methods

The methodology developed essentially used the information supplied by WP1 ‘Review of ECSS, previous work and requirements for tools’ described in Section 3 above to select the appropriate concept level of inspection method on a cost benefit basis for each ECSS. This was achieved by estimating a rating value for the potential benefit for each concept inspection method level and comparing this with a rating value for the cost. The concept inspection method with the highest benefit to cost rating should therefore be selected. It should be noted that it was not possible to obtain estimates for the failure (defect) rate in the time available, although this information is necessary to perform a rigorous benefit analysis. Hence, the selection of concept methods was performed without this information. However, it was highlighted that it was absolutely necessary to obtain this information for the full cost benefit analysis to be performed later in the project.

The benefit rating for each level of inspection was calculated using the ’safety potential’ and ‘potential to identify fault’ ratings for each possible failure supplied by WP1. Specifically, these ratings were multiplied, summed and normalised as can be seen in Annex 4 for each ECSS. Ideally, defect rate data should have been used as well at this stage of the study, but this was not possible as explained above.

The cost rating for each level of inspection was calculated in a similar manner using the ‘tool costs’ and the ‘inspection time’ estimates supplied by WP1. Specifically, equipment costs and inspection times were normalised to give a rating on a scale of 1 to 10. These were then combined and averaged with a weighting for equipment cost to inspection time of 1:3 to give a rating for the overall cost on a scale of 1 to 10. The 1:3 rating was used because of the lower contribution of equipment cost when compared to inspection time as part of the overall cost.

The calculations for the benefit to cost ratings for each ECSS are shown in Annex 4.

4.1.2 Methodology for selection of tools

The aim was to select tools which were far enough advanced, in particular in terms of vehicle communication, diagnostic and component actuation capability, to enable the development of the concept methods in the laboratory testing. The aim was also that the tools selected should have a reasonable chance of being developed further, e.g. automated, for field testing, and were representative of the full range of tools available.

Criteria for the selection of the tool were:
- Ability to investigate and trial the proposed concept test method and associated failures implemented on test vehicles.
- Speed and ease of use.
- Degree of automation of the test.
- Interfaces to other test equipment.
- Adaptability / further development potential for use in the field test.

It was not possible to make this selection using only information provided by manufacturers. Therefore it was decided to use an iterative approach in which tools would be selected throughout the laboratory testing. However, some initial decisions for proceeding were made. These were:
- All specialist tools should be selected on the basis that they would probably be better developed for the detection of faults in the particular ECSS that they were specialised for and hence provide more information in the laboratory testing.
- A number of universal tools should be selected on a practical basis. This was based on the need to be able to communicate with the various cars and ECSS selected for the laboratory testing because if they could not communicate with the cars, no field test work would be possible!

4.1.3 Selected methods and tools for laboratory tests

The following sections detail:
- The concept methods selected for laboratory testing
- The tools selected for laboratory testing
- Failures and vehicles on which they should be implemented selected for testing of concept methods

4.1.4 Selected methods

Following the methodology above, a cost benefit assessment was performed to select the assessment level and associated concept inspection method to take forward into laboratory testing.

The assessment level selected for each ECSS described above using cost benefit analysis (CBA) are summarised in Table 6 below. The details of the CBA are given in Annex 4.

Table 6: Concept method assessment level selected for each ECCS using CBA.

Electronically Controlled Safety System	Assessment Level			
	Level 1	Level 2a	Level 2b	Level 3
ABS - Antilock braking system				X
ESC - Electronic Stability Control				X
EBS- Electronic Braking System				X
EPS - Electronic Power Steering				X
SRS - Supplementary Restraint Systems		X	X	
AEBS - Automatic Emergency Braking Systems				X
Headlight control systems				X
TPMS - Tyre Pressure Monitoring System				X

The ECSS shown in the table above are detailed below to describe the basis of the test method and failures that can be identified for each ECSS.

4.1.4.1 Antilock Braking System (ABS) – level 3

Diagnostic communication and ABS system functionality test

Via the OBD port, communicate with the ABS ECU:

Send control signals for each wheel/axle.

Use brake tester to verify system functionality through a check of the change in brake force values as the ABS system modulates the brake forces applied for each corresponding wheel.

This can identify:

ABS ECU failure

Wiring and connections

Brake pedal sensor function

Pressure sensor failure

Wheel sensor signals

Hydraulic pump failure

Modulated brake force value – detects disks/pads with too low force, e.g. counterfeit brake pads/discs or oily

Hydraulic system integrity – leakage

Note:

The ABS system relies on the ability of each wheel sensor to provide an accurate value to the system ECU to allow changes in the applied brake forces to individual wheels to provide safer braking and vehicle control.

Therefore, the ability to check the functionality of the ABS system through the assessment of the wheel sensor signals and the ability of the ABS system to modulate brake force values are key test criteria.

4.1.4.2 Electronic Stability Control (ESC) – level 3

Diagnostic communication and ESC and ABS systems functionality test:

Via the OBD port, communicate with the ESC ECU:

Send control signals to read out the steering angle, yaw sensor, accelerator, road speed inputs. Use brake tester to verify system functionality through a check of the change in brake force values as the ESC/ABS system modulates the brake forces applied for each corresponding wheel.

This can identify:
- ESC ECU failure
- ABS ECU failure
- Hydraulic pump not working correctly
- Hydraulic modulator valves not working correctly
- Pressure sensor not working correctly
- Twisted hydraulic pipes
- Wheel speed sensor signals are correct
- Steering angle sensor operates correctly
- Twisted wheel senor signals
- ESC system functioning correctly
- Hydraulic system integrity – leaking
- Accelerator position sensor not operating correctly

Note:
The ESC system relies on the ability of steering angle, vehicle speed, yaw sensor and accelerator position sensors to provide information that allows the ESC system ECU to change the applied brake forces to individual wheels and control the engine torque to prevent a vehicle skid developing and to provide safer vehicle control.
Therefore, the ability to check these various sensor signals and the ability of the ESC/ABS system to modulate brake force values and engine torque are key test criteria.

4.1.4.3 Electronic Braking System (EBS) – level 3

Diagnostic communication and EBS system functionality test	
	Via the OBD port, communicate with the EBS ECU:
	Send control signals for each wheel/axle. Turn the steering wheel Use brake tester to verify system functionality through a check of the change in brake force values as the EBS system modulates the brake forces applied This can identify: EBS ECU failure Wiring and connections Brake pedal sensor function Pressure sensor failure

Wheel sensor signals
Hydraulic pump failure
Modulated brake force value
Hydraulic system integrity – leakage
Hydraulic valves damaged
Steering angle sensor
Twisted hydraulic pipes
Twisted sensors

Note:
The EBS system relies on the ability of the brake pedal sensor and each wheel sensor to provide an accurate value to the system ECU to allow changes in the applied brake forces to individual wheels to provide safer braking and vehicle control.
Therefore, the ability to check the functionality of the EBS system through the assessment of the brake pedal sensor and the wheel sensor signals and the ability of the EBS system to modulate brake force values are key test criteria.

4.1.4.4 Electronic Power Steering (EPS) –level 3

Diagnostic communication and EPS system functionality test
Via the OBD port, communicate with the EPS ECU:
Turning steering wheel 45 degrees left and 45 degrees right in order to measure the run-out on turns. This can identify: EPS ECU failure Steering angle sensor Wiring and connections Hydraulic pump failure Hydraulic actuator damaged

Note:
The EPS system relies on the ability of the steering wheel angle sensor and vehicle speed signals to provide an accurate value to the system ECU to allow changes in the applied steering torque to provide safer steering and vehicle control.
Therefore, the ability to check the functionality of the EPS system through the assessment of the steering wheel sensor signal and the ability of the EPS system to modulate steering force values are key test criteria.

4.1.4.5 Supplementary Restraint Systems (SRS) - Level 2a

Diagnostic communication: reading information
Reading PTI relevant failure information (no fault codes, pending codes, all components present…)
Reading parameters: Status of MIL (on/off/…) read on the ECU versus the visual MIL Read PTI relevant failure information, including stored DTCs and readiness

codes (Sensors and actuators)
Identification of any general communication fault with ECU and/or sensors

This can identify:
ECU –failed, missing or damaged
MIL not functioning correctly
Airbag missing
SRS system sensor failures
SRS system sensor and pyrotechnical actuator(s) presence, wiring and connections
SRS system sensor and pyrotechnical actuator(s) values (resistances and status)

Note:
In the event of a substantial vehicle crash, the SRS system relies on the ability of each sensor to provide an accurate value to the system ECU to provide trigger signals to be sent to the restraint components, which deploy to minimize potential injuries to the driver and vehicle occupants. Therefore, the ability to check the various system components and sensor connections verifies the ability of the SRS system to operate correctly when required. Direct functionality testing is not possible.

4.1.4.6 Automatic Emergency Braking Systems (AEBS) – level 3

Diagnostic communication and AEBS system functionality test
Via the OBD port, communicate with the AEBS ECUs:
Driver alert using target Increase the subject vehicle to the test speed in the test lane. Approach the target vehicle at the test track within the same lane (the target vehicle shall be moving on the axis of the test course at a constant speed). The AEBS shall warn the driver This can identify: HMI aggregate Active lamp/ warning on dashboard Active buzzer Camera damaged Radar/LIDAR emitter damaged or not operating correctly Radar/LIDAR receiver damaged or not operating correctly Radar/LIDAR not calibrated or not operating
Braking system activation test Continue approaching the target in the test lane. The AEBS system should activate the service brake and/or steering to avoid a collision. This can identify: AEBS ECUs failure, missing or damaged: ABS/ESP ESC Body EPS

Check artificial vision calibration
Using a wheel alignment system and target it's possible check the camera's calibration.

This can identify:
Camera/Radar/LIDAR is not calibrated correctly

Note:
The AEBS system relies on the ability of the camera/LIDAR/Radar sensors to provide an accurate value to the AEBS ECU to allow changes in the steering and applied brake forces to individual wheels to provide safer braking and vehicle control.
Therefore, the ability to check the functionality of the AEBS system through the assessment of the input sensor signals and the ability of the AEBS system to control the vehicle steering and to modulate brake force values are key test criteria.

4.1.4.7 Headlight control systems – level 3

Diagnostic communication and other equipment:

	combination of triggering a system (e.g. decreased light level) and measurement of the outcomes using a headlamp tester; comparison against a predictable behaviour
	for multi-LED-systems: combination of triggering a system (e.g. decreased light levels) comparison of the illuminated LEDs against a predictable behaviour
	read sensors during a short test drive (yaw rate, levelling sensors), checked against wheel speed- and steering sensors
	for Automatic headlight dip system: simulation of oncoming light to have high beam switched off or masked
	for Automatic high beam (high beam assist) systems: check the correct setting of the camera and the headlight system This can identify: ECU – failed, missing or damaged Wiring and connectors – missing or damaged Height levelling sensor – not operating correctly Headlamp operation – not operating correctly Auxiliary driving lamps – not operating correctly Yaw rate sensor – not operating correctly Steering angle sensor – not operating correctly Speed sensor – incorrect signal Light intensity sensor – not operating correctly Windscreen camera – not operating correctly Switches - not operating correctly

Note:
The advanced front lighting systems (AFS) use high intensity light sources, whilst relying on sensors to detect other road users, or the dynamic activities of the vehicle to control the level, direction or intensity of the headlamp illumination. This control is through a combination of both

electronic and mechanical functions. These systems provide enhanced lighting functions, but pose a risk to other road users if the illumination is not correctly controlled.

Therefore, the ability to check the functionality of the headlamp system through the assessment of the input sensor signals and the ability of the headlamp system to control the level, direction and intensity of the forward illumination are key test criteria.

4.1.4.8 Tyre Pressure Monitoring System (TPMS) – level 3

Diagnostic communication and functionality testing of the ECSS system:

Identify the ECU and software version
Activate each wheel pressure sensor (if fitted)
Read sensor signals (sensor ID, RF pressure, temperature and battery status) and compare to ambient values.

This can identify:
ECU – failed, missing or damaged
Wiring and connectors – missing or damaged
Built-in transceiver not operating correctly
Pressure sensor not functioning correctly

Note:
The tyre pressure monitoring systems provide an indication to the driver that the inflated pressure of one or more tyres has changed. This can be achieved by fitting pressure sensors directly to each wheel, or through the monitoring of the wheel speed sensor frequencies to identify changes in the rolling circumference if a tyre becomes deflated.

Therefore, the ability to check the detected pressure values and communication of the pressure sensors, or the signals from the wheel speed sensors are key test criteria.

4.1.5 Selected tools

From the initial list of tools available for laboratory testing defined in WP1, universal tools which had been developed to inspect most ECSS and specialist tools which were more developed for the inspection of particular ECSS, e.g. Tecnomotor for Tyre Pressure Monitoring System (TPMS), were identified. These are highlighted with shading in an excel spreadsheet shown in Annex 3 ‘Available tools for laboratory testing’. As many of these as possible were taken forward into laboratory testing.. .

4.1.6 Selected failures and vehicles

A list of vehicle failures that, in general, do not activate the MIL was compiled by WP1 and can be found in Annex 2. From this list, key failures for development of the concept methods were selected taking into factors such as the expected likelihood of this failure in the real world and the ease that it could be implemented on a vehicle. These are highlighted with shading in Annex 2.

4.2 Summary

The work of WP2.1 evaluated the concept inspection methods proposed by WP1 and selected the best methods and tools to take forward into laboratory testing (WP2.2).

The selection of the inspection methods was based on a benefit to cost rating and used the data gathered by WP1 detailed in Annex 1. These data included the cost of the test equipment, the time taken to conduct the test, the severity of the ECSS failures which could be identified and the likelihood of being able to identify a range of failures within the specific ECSS.

The test tool selection was based on the several key criteria, which included the ease of use when selecting the various ECSSs, the speed of use when conducting the inspection methods and the depth of coverage for the various ECSS systems across a range of vehicle manufacturers.

5 Laboratory tests

The laboratory test work consisted of two main tasks. The first was to develop the concept inspection methods proposed by WP1 and selected by WP2.1 into a form that could be used and assessed in the laboratory. This was done iteratively, i.e. the methods were updated using knowledge gained from the laboratory tests performed. The second task was to show that the methods worked and were capable of detecting expected failures, i.e. proof of concept of method.

The following section is divided into two main parts; the first describes the developed concept inspection methods and the second the laboratory testing results which show that the methods work and are capable of detecting expected failures, i.e. proof of concept of method.

5.1 Description of inspection methods

As specified in the contract, inspection methods were developed for testing of the following ECSS:

- Braking related
    - Anti-lock Braking System (ABS)
    - Electronic Stability Control (ESC)
    - Emergency Brake Assist (EBA, also known as Brake Assist System (BAS)).
    - Electronic Braking System (EBS)
- Electronic Power Steering
- Supplementary Restraint System (SRS)
    - Airbag
    - Seat belt load limiter
    - Seat belt pre-tensioner
    - Other related components (e.g. seat occupancy sensor)

In addition, inspection methods were developed for the following two ECSS:

- Lighting automatic functions such as levelling and bending.
    - These functions are becoming more prevalent on current cars and are likely to become increasingly so in the near future.
- Tyre Pressure Monitoring System (TPMS)
    - Mandated for new types M1: 1st Nov 2013
    - Mandated for new registrations M1: 1st Nov 2015

All methods are to be combined with a visual inspection as already described in 2010/48/EU.

5.1.1 Brake Testing

5.1.1.1 Background

A lot of ECSS use the wheel brakes to stabilize vehicle movement, e.g. Anti-lock Braking System (ABS) and Electronic Stability Control (ESC). For the correct operation of these systems, especially for ESC, it is important to have sufficient brake efficiency at the axles and the correct distribution of brake force between the front and rear axles.

By monitoring the value of the internal brake pressure sensor, it is possible to enhance the quality and accuracy of current brake performance testing by ensuring that sufficient brake system hydraulic pressure exists when the functionality of the electronically controlled systems is being tested.
The accuracy of the method depends on the accuracy of the vehicle built-in brake pressure sensors. If no brake pressure sensor is installed, an alternative procedure (e.g. pedal force) could be used. Ongoing studies have determined as a preliminary result, that the quality of the (vehicle) internal pressure sensor is sufficient for this purpose.

The theoretical idea is to combine together an ABS and ESC test on a roller brake tester. This could be extended for testing of other ECSS brake related functions such as Emergency Brake Assist (EBA) and Electronic Braking Systems (EBS). Also, some measure of the brake system hydraulic pressure could be added to help detect failures related to low friction of the brake pads, such as oil contaminated or counterfeit pads as well as the incorrect brake force distribution front-rear.

The amount of time needed for such a combined test depends essentially on the processing speed of the individual components. Automation at least for each axle could be made possible as soon as the automatic transmission (on a network) of the braking values from the roller brake tester to the PTI mode scan tool was achieved. Therefore, the time required in the future is, after a suitable conversion of such a combined test, possibly only slightly higher than the current time required for the PTI brake test.

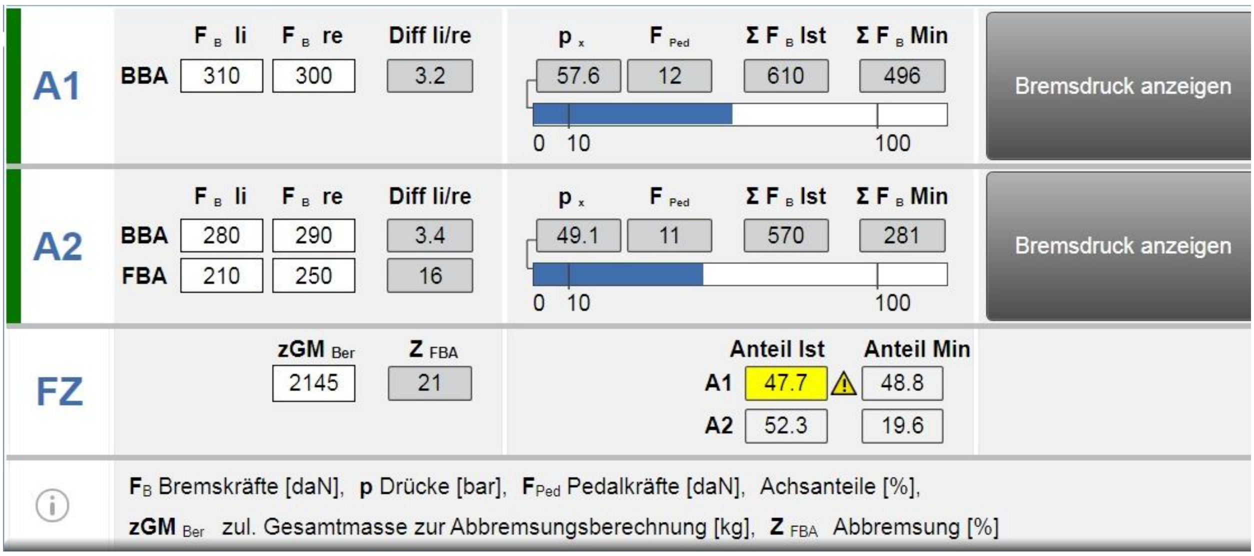


Figure 1: Advanced brake efficiency test method (implementation of the method by EGEA member).

The advanced brake efficiency test method uses reference braking force (brake system pressure and wheel brake force generated) values to assess brake efficiency at each individual wheel. It also uses threshold values to assess the distribution of brake force between the front and rear axles. This method can provide better testing of the brake related ECSS functionalities, but this is only possible if the braking force and threshold values are available from the vehicle manufacturers to both PTI test centres and PTI test equipment manufacturers.

5.1.1.2 Proposed Method for brake testing with direct focus on ECSS (ABS, ESC, EBS)

1) Select vehicle data via the PTI mode scan tool manually or automatically to provide the data needed (sensor data, speed values, etc.).

2) Connect PTI mode scan tool to the OBD connector.
3) Turn ignition on, read out all ECSS used in the vehicle (Level 1).
4) Read out status and activating of the MIL (Level 2a/2b).
5) Drive vehicle onto the roller brake tester.
6) Test front axle by applying the service brake. Compare the brake forces measured on the roller brake tester for left and right side with the legal requirements for the vehicle (Level 3).
7) With the service brake still applied, use the PTI mode scan tool to actuate the brake modulation valves front (separately for each wheel) to reduce braking force significantly or to zero and assess reduced brake force (Level 3).
8) Release brake pedal, actuate brake pressure (over ESC pump) front (separately by wheel), monitor increasing brake force (Level 3).
9) Examine signal from wheel sensor whilst running on RBT and check speed left to right (Level 2a).
10) Still on the running RBT without actuating the brake pedal, hold the vehicle straight by slightly adjusting the steering wheel, measure actual zero-point for the steering wheel sensor, check for correct calibration (Level 2b) by using the PTI mode scan tool.
11) Repeat step 6 to 9 for rear axle.
12) Test the parking brake efficiency.
13) Drive out of RBT and then when the vehicle is at a standstill and is level, using the PTI mode scan tool, check that the zero-point value of both the acceleration and yaw rate sensors (level 2b test).
14) Calculate the total deceleration force (of the front and rear axles) based on the total weight of the vehicle and make a comparison with the legal requirements.
    Note: This step is included because if not met, can also affect the correct functionality and objective assessment of the brake related ECSS.
15) Automatic collection of stored errors, if any (level 2a test).
16) Evaluate the overall results for the combined test (no defect, minor defect(s), major defect(s), dangerous defect(s). The opportunity to repeat the individual steps of the combined test should be available on the PTI mode scan tool.

Step 12 can be after Step 9 in the case of a parking brake at the front axle (this needs to be confirmed before starting the process or be done automatically by software).

Using these test steps at least the following failures can be detected:

- Hydraulic pipe/circuit blockages
- partly blocked brake-hose
- Modulator valve problems
- Wheel speed sensor problems (failure, internal resistance not correct, assembly/connection errors),
- toothed wheel fracture,
- hydraulic pump function/system pressure
- accelerator position sensor (position and rate of change) problems
- brake pedal sensor (position and rate of application) problems

5.1.1.3 Additional test Method to detect failures related to non-ECSS components, but relevant to ECSS performance

Replace step 6) by:

Individually, test both front and rear axles by applying the service brake. Measure brake system pressure by using the PTI mode scan tool. Compare the wheel brake forces measured on the roller brake tester for left and right side with the reference braking value for efficiency (brake system pressure and wheel brake force generated) for each axle of the vehicle (Level 3)

Replace Step 14 by:

Calculate the actual brake force distribution between the front and rear axles and make a comparison with vehicle specific thresholds.

Note: if for technical reasons a brake tester cannot be used (see 2014/45/EU, 1.2.2), measurements from the brake efficiency test (test drive with direct measurement of deceleration) are combined with a read-out of brake pressure or pedal brake force and the results compared with the reference values in the following manner.

A PTI mode scan tool is connected to the OBD connector, or a brake pedal pressure sensor is used to monitor the brake system pressure generated throughout the test. During a short test drive reaching a speed of about 20 km/h the vehicle service brake is applied to achieve the maximum braking effect (but below the point when the wheels lock) and a decelerometer (which is interconnected to the PTI scan tool or brake pedal sensor) is used to measure the braking deceleration generated. A calculation can then be made automatically for the correlation between the vehicle's x-axis deceleration force and the brake pressure values to reference values (pressure or pedal force and deceleration) for the vehicle (Level 3 test).

Using these additional test steps at least the following failures can be detected:

- counterfeit brake pads.
- oil-contaminated brake pads or otherwise impaired friction.
- insufficient braking power, even by axle.
- faulty brake force distribution, (the latter only applicable for certain types of brake tester).

In addition to improved failure detection, using the additional test steps (i.e. reference braking forces) also has a benefit regarding:

- outcomes do not depend on tyre load.
- outcomes do not depend on state of roller surface.
- outcomes do not depend on weather conditions.

Also reference braking forces can be used for brake efficiency testing. The basis of efficiency testing with reference braking values are the legal requirements (i.e. reference braking forces for M1 vehicles with first registration later than 01.01.2012 must show an efficiency of 58% related to the maximum authorised mass). If all axles reach at least the minimum figures for the respective axle, the brake efficiency for the complete vehicle is deemed sufficient. The brake force distribution to the axles can be assessed using thresholds for minimum brake force portions for the respective axle. For PTI a tolerance, of typically 30% will be granted for the constructive brake force distribution. This is because of acceptable degradation and measurement inaccuracies in the field. The brake force distribution is considered correct, if for each axle at least the minimum braking force portions are reached[7].

An example brake force distribution is listed below (provided by the VM):

Passenger car, two axles, constructive brake force distribution 79% front, 21% rear,

[7] For further information on reference braking forces see CITA document WG1_04_2014_46 presented at CITA WG1, 17 March 2014, Gothenburg http://www.cita-vehicleinspection.org/LinkClick.aspx?fileticket=VhTAl6uBRi8%3d&tabid=418

- Minimum braking force portions for front axle 55% (resulting maximum brake force rear axle 45%)
- Minimum braking force portions for rear axle (21% * 0.7 =) 15% (resulting maximum brake front axle 85%)

From this it can be seen that the measured brake force distribution is acceptable between 55% / 45% and 85% / 15% (front / rear axle).

5.1.1.4 Test methodology addition for inspection of EBA

Emergency Brake Assist EBA otherwise known as Brake Assist System (BAS) is defined by the COMMISSION REGULATION (EC) No 631/2009 of 22 July 2009, into three different types / categories:

- Category A Brake Assist System

A system which detects an emergency braking condition based on the brake pedal force applied by the driver. The trigger for this type of brake assist is a pedal force which is related to 3.5 ... 5 m/s^2

- Category B Brake Assist System

A system which detects an emergency braking condition based on the brake pedal speed applied by the driver. The trigger for this type of brake assist is a rapid pressing of the brake pedal, but it is normally based on a design which detects this rapid application and increased brake force by using mechanical components of the brake master cylinder.

- Category C Brake Assist System

A system which detects an emergency braking condition based on multiple criteria, such as the rate at which the brake pedal is applied, or the time between releasing the accelerator and applying the brakes. This may also form part of the vehicle ESC system and the trigger can be increase of pressure and/or brake pedal speed and/or time between releasing accelerator pedal and hitting the brake pedal. The ESC then increases brake system pressure using the ABS system hydraulic pump.

Cat. A design systems are not electronically controlled and therefore cannot be tested using a PTI mode scan tool/electronic test method.
Cat. B and C design systems - all additional sensors used for EBA are tested at level 2b as part of the proposed methodologies for Brake System (5.1.1.2 or 5.1.1.3) and Electronic Power Steering (5.1.2).

Any additional level 3 functional testing would only identify software related failures and would only be possible if detailed technical information was available from the vehicle manufacturer to allow vehicle speed/yaw sensor signals to be generated, whilst simultaneously triggering simulated emergency braking actions. Because, this information was not available to this project, it was decided to test Cat. B and C design EBA at level 2b only as part of the braking and electronic power steering inspection methods. Therefore no test methodology additions were proposed for inspection of EBA.

Using this test method it allows the following features to be tested:

- Hydraulic pump function/system pressure.
- Maximum applied brake force.
- Accelerator position sensor (position and rate of change) problems.
- Brake pedal sensor (position and rate of application) problems.
- Steering angle sensor value.

- Yaw angle sensor.
- Modulator valve problems.
- Wheel speed sensor problems (failure, internal resistance not correct, assembly/connection errors).
- Toothed wheel fracture.
- Hydraulic pipe/circuit blockages.
- Partly blocked brake-hose.

5.1.2 Electronic power steering

5.1.2.1 Background

EPS is defined as being both the steering support itself and the electronically controlled "active steering", where the steering ratio changes depending on e.g. vehicle speed.

For both systems, the correct calibration of the steering angle sensor is vital. The related test (Step 6 in connection with Step 5) is also described in ESC-testing as step 10.

5.1.2.2 Method

1) Manual or automatic selection of the vehicle via the PTI mode scan tool to provide the needed data.
2) Connect PTI mode scan tool to OBD connector
3) Turn ignition on, read out which ECSS are fitted (Level 1)
4) Read out status and activating of the MIL (Level 2a/2b)
5) Drive onto Roller Brake Tester
6) While on the running RBT without actuating the brake pedal, hold the vehicle straight by slightly adjusting the steering wheel, measure actual zero-point for the steering wheel sensor, check for correct calibration (Level 2b).
7) Leave RBT, during a short test drive (~50 m, 90° bend, >15 km/h) cross-system consistency check data from:
    - wheel speed sensors
    - yaw speed sensor
    - steering angle sensor
    - current and direction of EPS (Level 2b)
8) Whilst the vehicle is at a standstill and the engine is switched off, turn the steering wheel

Start the engine, turn steering wheel; the effort must be significantly lower. If possible, measure the current draw provided by the EPS and compare the values when turning the steering wheel greater than 90 degrees left and right (Level 3).

Additional test for Active Steering

9) With engine on, turn the steering wheel from lock to lock and record the number of rotations.
10) With engine switched off and steering wheel turned from lock to lock, record the number rotations, which should be significantly higher (Level 3)

Using these test steps at least the following failures can be detected:

- incorrect EPS calibration
- defect sensors and / or wrong sensor values
- incorrect power steering control

5.1.3 SRS (airbags and belt tensioners)

5.1.3.1 Method

1) Manual or automatic selection of the vehicle via the PTI mode scan tool to provide the data needed.
2) Connect PTI mode scan tool to OBD connector
3) Turn ignition on, read out which ECSS are fitted and observe if the SRS MIL illuminates. (Level 1)
4) Read out system status and using the PTI mode scan tool, activate the MIL to ensure correct functionality (Level 2a/2b)
5) While the inspector sitting on the driver´s seat, read out the occupancy status via OBD (where possible); test the passenger seat occupancy sensor accordingly by pressing down on the seat or by sitting on it.
6) Switch off Passenger Airbag (where possible), check indicator lamp, read out status via OBD (Level 2a); return the passenger airbag switch back to its original position
7) Close seat belt buckles, read out their status via OBD (Level 2b)
8) Read out the SRS components via OBD and compare to the SRS components which are actually installed in the vehicle (Level 2b).
9) Read out via OBD stored failures and (where possible) the information if components had already been used (fired) (Level 2a/2b).

Using these test steps at least the following failures can be detected:

- defect SRS-system or defect sub-system
- correct configurations of replacement airbags/SRS system components
- manipulation and incorrect replacement of systems

It should be noted that generally, in most ECSS systems, if the system has been tampered with, the functional (level 3) test methods proposed should be able to identify it. However, for the SRS system where functional testing is not possible, tampering is an increasing issue, resulting in the system being unable to provide the designed safety function(s). In particular, this may apply to SRS components, such as air bags, seat belt pre-tensioners and seat occupancy sensors. When correctly fitted, these components provide a known resistance value to the ECSS ECU, but by replacing the component with a resistor of the correct value, the ECU will not be able to detect if the component is correctly fitted, replaced or has been tampered with. Without disassembly, it is difficult to identify if tampering has taken place and functional testing of a pyrotechnical component is not practical in PTI testing. Therefore, the only practical solution is to have an embedded electronic function in the component and for it to be ‘coded’ to the vehicle system and be verified as part of the system check (e.g. every time the ignition is turned on). This would support assessment of the correct replacement of components where appropriate and for the components of the SRS system to be checked as part of a PTI test. However, for this solution to be implemented, it is likely that type approval legislation will be needed to mandate it.

5.1.4 Lighting

5.1.4.1 Background

The lighting equipment of vehicles is important for the driver to be able to see in low light conditions/at night and for other road users to be able to see the vehicle. Due to the advances in headlight development from halogen headlights to gas discharged headlights and LED headlights in conjunction with AFS headlights and dynamic aiming functionality, the basis for assessment in today's PTI needs to be updated.

The PTI-inspector normally performs the PTI-test alone. Without a second person, a pedal lock and/or the use of large suitable mirrors it is difficult to have the light equipment modules correctly in sight. Even with the use of mirrors the functionality of individual LED segments is difficult to assess. This can be solved by external switching of individual lighting functions, for e.g. by use of a PTI mode scan tool.

The aiming ranges of Advanced Front Lighting Systems are difficult or impossible to check with non-diagnostic methods.

The dynamic automatic levelling of the low beam depends on the level sensor(s). With load on the rear axle the functionality of the sensor/system can be checked with a headlight tester.

Alternatively, the load can be simulated by the upward and downward movements of the vehicle body.
By changing the voltage values at the sensor combined with a headlamp aiming device, the electronic function of the levelling device can be assessed. Precondition for this is the verifiability of the headlight range control with no vehicle movement.

5.1.4.2 Method External control of the lighting functions

1) Manual or automatic selection of the vehicle via the PTI mode scan tool to provide the needed data.
2) Connect PTI mode scan tool to OBD connector
3) Turn ignition on, read out which ECSS are fitted (Level 1)
4) Read out status and activating of the MIL where applicable (Level 2a/2b)
5) Trigger lighting functions one after another and check the results for complete and correct functioning of all lights and bulbs (Level 2b)
6) Trigger rear light functions all together with flashing direction indicators, measure flashing frequency and check the results for complete and correct functioning of all lights and bulbs (Level 3)
7) Trigger all read lights functions at the same time, check for ground faults
8) Check related switches for function.
9) Use headlamp tester to assess the correct aiming of the beams (Level 3).

Using these test steps at least the following failures can be detected:
- defective lighting equipment
- wrong circuit
- wrong signal colour
- wrong frequency
- ground fault,
- etc.

5.1.4.3 Method External control of the automatic levelling and bending of headlamps

1) Manual or automatic selection of the vehicle via the PTI mode scan tool to provide the needed data.
2) Connect PTI mode scan tool to OBD connector.
3) Turn ignition on, read out which ECSS are fitted (Level 1).
4) Read out status and activating of the MIL where applicable (Level 2a/2b).

5) Switch on headlamps.
6) Trigger bending/matrix control of the headlamps to move through the complete range of possible movement (mechanical and/or electronic), check for correct control/direction/intensity by using an electronic headlight tester to verify the correlation between input signals and the corresponding system function.
7) Read out sensor data of level sensor (s) while standing still, sensor data must be (almost) unvaried (Level 2a).
8) Read out sensor data of level sensor(s) while moving the vehicle by sitting into it, releasing it from the lifter, ...; the sensor value must change significantly (Level 2a).

Using these test steps at least the following failures can be detected:

- incorrect setting
- incorrectly installed or defective sensors (levelling, bending light, matrix control)
- wrong circuits
- interrupted pathways
- defective subsystems
- control of the light direction
- control of the light intensity

5.1.5 Tyre Pressure Monitoring System

There are two main types of Tyre Pressure Monitoring Systems (TPMS). The first is active in which the tyre pressure is measured directly using a sensor mounted directly in the wheel. The second is non-active, (also called passive or indirect) in which the tyre pressure is measured indirectly by using the wheel speed sensors to detect a wheel speed difference caused by a change to the rolling circumference of the tyre when the tyre pressure changes.

5.1.5.1 Active TPMS

There are two sub types of active systems.
The first is where the wheel tyre pressure sensors can be activated directly by the vehicle TPMS ECU to verify their functionality and transmitted value.

In the second type of system, the wheel tyre pressure sensors have to be triggered by an external tool, but their transmission and value can then be read through the vehicle's TPMS ECU.

Please note that it is possible to test both sub types of TPMS using the same tool.

5.1.5.1.1 Test method 1 (Active TPMS) – if vehicle TPMS is active and supports direct control functionality:

1. Connect the PTI mode scan tool to the vehicle 16 pin connector, turn on the ignition, but do not start the engine. Select the correct vehicle/model/TPMS and communicate with the vehicle's TPMS ECU to verify its identity.

   If communication and verification is possible, this establishes that the system ECU is fitted and is working. (Level 1 test).

2. Once correctly identified, use the appropriate command to check if any stored, or pending, fault codes exist. (Level 2a/2b test).

3. Check that the TPMS MIL light functions correctly by either monitoring the status, or if possible, triggering the MIL and observing the correct response (Level 2a/b).

4. Use the appropriate command to sequentially trigger all TPMS wheel sensors. (Level 2b).

5. Verify that all wheel sensors can communicate with the TPMS ECU and provide a pressure value by displaying the pressure values on the test tool. (Level 2a and 2b).

6. Compare each wheel sensor value to establish that each sensor is able to provide an appropriate tyre pressure value. (Level 2b test).

7. Terminate communication with the TPMS ECU.

   Identification of the following failures would therefore be possible:

- TPMS ECU is fitted and active.
- Correct operation of the TPMS MIL.
- That the wheel sensor signals are active, provide appropriate values and correspond to the correct wheel.

5.1.5.1.2 *Test method 2 (Active TPMS) – if vehicle TPMS is active and does NOT support direct control functionality:*

This involves two electronic test tool functions (which could be individual test tools or a single test tool with a combined functionality):

1. Connect the test tool to the vehicle 16 pin connector, turn on the ignition, but do not start the engine. Select the correct vehicle/model/TPMS and communicate with the vehicle's TPMS ECU to verify its identity.

If communication and verification is possible, this establishes that the system ECU is fitted and is working. (Level 1 test)

2. Once correctly identified, use the appropriate command to check if any stored, or pending, fault codes exist. (Level 2a/2b test)

3. Check that the TPMS MIL light functions correctly by either monitoring the status, or if possible, triggering the MIL and observing the correct response. (level 2a/2b test)

4. Using a TPMS wheel sensor activation tool, activate each wheel sensor in turn to transmit the value of the tyre pressure and read the pressure on the display of the TPMS tool. (level 2a and 2b)

5. Compare each wheel sensor value to establish that each sensor is able to provide an appropriate tyre pressure value. (Level 2b test)

   Identification of the following failures would therefore be possible:

- TPMS ECU is fitted and active
- Correct operation of the TPMS MIL
- That the wheel sensor signals are active, provide appropriate values and correspond to the correct wheel

5.1.5.2 Non-active (indirect / passive) TPMS

Non-active (indirect) TPMSs are based on the continuous monitoring of the wheel speed sensors when the vehicle is being driven to identify if the frequency of one of the sensor signals changes due to the change in rolling circumference of the tyre if the tyre pressure decreases. If this occurs, then a warning light or message is displayed to the driver on the vehicle dashboard or information screen indicating a pressure loss in one or more of the tyres. As there are no direct pressure sensors fitted to the wheels, then during a PTI test the following test routine should be adopted:

1. Using a calibrated tyre pressure measurement device, measure the pressure of one of the vehicle's tyres and check that it is within 20% of the recommended pressure.

2. Connect the test tool to the vehicle 16 pin connector, turn on the ignition, but do not start the engine. Select the correct vehicle/model/TPMS and communicate with the vehicle's TPMS ECU to verify its identity. If communication and verification is possible, this establishes that the system ECU is fitted and is working. (Level 1 test).

3. Once correctly identified, use the appropriate command to check if any stored, or pending, fault codes exist. (Level 2a/2b test).

4. When the wheels are rotating (e.g. as part of the brake test) monitor all wheel sensor signals to establish that they exist and are providing the same frequency values. (level 2a test).

5. Check that the TPMS MIL light functions correctly by either monitoring the status, or if possible, triggering the MIL and observing the correct response. (level 2a/2b test).

Identification of the following would therefore be possible:

- ECU that manages TPMS is fitted and active
- Correct operation of the TPMS MIL
- That the wheel sensor signals are active, provide appropriate values and correspond to the correct wheel (depending on specific system design).

5.2 Results of laboratory tests (proof of concept)

The vehicles used for laboratory testing are shown below.

Table 7: Vehicles used for laboratory testing.

No.	Make	Model	VIN	Year	Location of testing
1	BMW	325d (3-series E91)	WBAUX91030A75722 4	May-10	BASt
2	BMW	X5 (X70)	WBAFF410X0LZ0046 3	Nov -06	BASt
3	Opel	Astra (A-H/SW)	W0L0AHL3565084692	Jan-06	BASt
4	VW	Passat (3C)	WVWZZZ3CZ9E0096 28	Apr 08	BASt
5	Ford	Fiesta 1.4 TDCI	WFODXXGAJD7C111 53	Feb-07	BASt
6	Mercedes	Sprinter 215 CDI	WDB90661315289461	Dec-07	BASt
7	VW	Passat (3C) VII	WVWZZZ3CZCE0615 97	Oct-12	BASt
8	Dacia	Duster	UU1HSDACN4373253 6	Oct-10	BASt
9	Toyota	Prius	JTDKB20U803196088	Jun-06	BASt
10	VW	Golf VII	WVWZZZAUZDP039 141	Feb-13	BASt
11	Hyundai	i30 (GD)	Crashed vehicles; used for SRS tests only; no VIN available	>Mar-12	BASt
12	Fiat	500		>Jul-10	BASt
13	Mercedes	E 250 (212)		>Feb-12	BASt
14	Seat	Ibiza ST		>May-10	BASt
15	VW	Touran (1T3)		>May-10	BASt
16	VW	up! (121)		>Nov-12	BASt
17	Smart	Forfour	WME4540321B008122 5	Jun-04	FSD
18	Mercedes	E class	WDD2120821A579729	Dec-11	FSD
19	Audi	A4 Avant	WAUZZZ8K8DA1160 65	Aug-12	Beissbarth

These vehicles were selected from vehicles available to the project and attempted to include a range of vehicle manufacturers from various countries to ensure that any different ECSS design philosophies that may be used in the European fleet were included in the laboratory testing. The Smart had particular modifications (direct access to CAN bus, additional sensors, etc.) and equipment (steering automat, etc.) implemented on it which made it difficult to transport and hence the vehicle was only available at FSD.

5.2.1 Tests performed at BASt

The tests at BASt were performed with test equipment provided by EGEA or BASt and test vehicles owned by FSD or BASt.

5.2.1.1 Braking system

With a view to the brake tests the following failures (as recommended by WP1) were implemented on vehicles to check that the proposed concept method described in Section 5.1.1 above could detect them and therefore proved that they work:

- partly blocked brake-hose.
- counterfeit brake pads on front axle.
- oily brake pads on rear axle.
- air gap between wheel speed sensor and tooth rim too large.
- left and right wheel speed sensor interchanged on rear axle.
- internal resistance of speed sensor altered in steps at rear axle.

The method proposed in Section 5.1.1.2 together with the test method extra steps proposed in Section 5.1.1.3 were used to detect the failures. It should be noted that Steps 8 and 13 of method described in Section 5.1.1.2 were not included for this work. This was because the methods were upgraded in an iterative manner throughout the course of the laboratory testing and these steps had not being included in the method when this particular piece of work was performed. However, these steps were included in the work performed at FSD.

For several vehicles with specially implemented failures, additional tests were conducted at FSD facilities (see Section 5.2.3) because these specially prepared vehicles could not be transported and it was not possible to implement the failures on vehicles at BASt.

During the tests, all failures were detected by the proposed method, at least in principle.

The following failures were detected by method described in 5.1.1.2:

- Generic: Hydraulic pipe blockages (in principle only). *
- ABS/ESC: Modulator valve problems (in principle only). **
- ABS/ESC: Wheel speed sensor problems (failure, internal resistance not correct, assembly errors), [MIL was activated.]
- ABS/ESC: toothed wheel fracture (in principle only).**
- partly blocked brake-hose, [MIL was not activated].
- Generic: insufficient braking power in relation to the total weight.*

Using the additional test steps detailed in Section 5.1.1.3 the following remaining failures were detected:

- Generic: counterfeit brake pads.*
    - Generic but in particular for ESC: oil-contaminated brake pads or otherwise impaired friction.*
- insufficient braking power, even by axle.*
    - faulty brake force distribution.*

Notes:
* MIL not activated because mechanical type of failure.
** Not possible to assess whether or not failure would activate MIL.

These failures were detected with every PTI scan mode tool which could display the current brake pressure in the system for the tested vehicle.

In summary, the test method described in Section 5.1.1.2 detected a large proportion of the implemented ECSS failures, but the additional steps described in Section 5.1.1.3 were needed to detect the mechanical and friction related failures. However, it should be noted that brake pressure reference value information is required for these additional steps. Compared to a conventional brake test, these additional steps enable the detection of more failures related to mechanical brake parts which can have a substantial effect on the ability of ECSS such as ESC to perform correctly as designed.

Regarding reference braking force values, it is interesting to note that a field test performed by FSD, with more than 570 vehicles of 250 different models, has shown that the accuracy of the internal brake pressure sensors was for ~80 % of the tested vehicles within an accuracy range of 1 % (related on 250 bar) for all vehicles below 2 % (related on 250 bar), although according to information of automotive suppliers, it could possibly be up to 5-6% related to full scale output (source: FSD study, not published). For the small minority of vehicles which are not equipped with a brake pressure sensor, the brake pedal force could be used for reference (see Figure 2). Currently, the distribution of reference values for the braking system European-wide is yet to be determined.

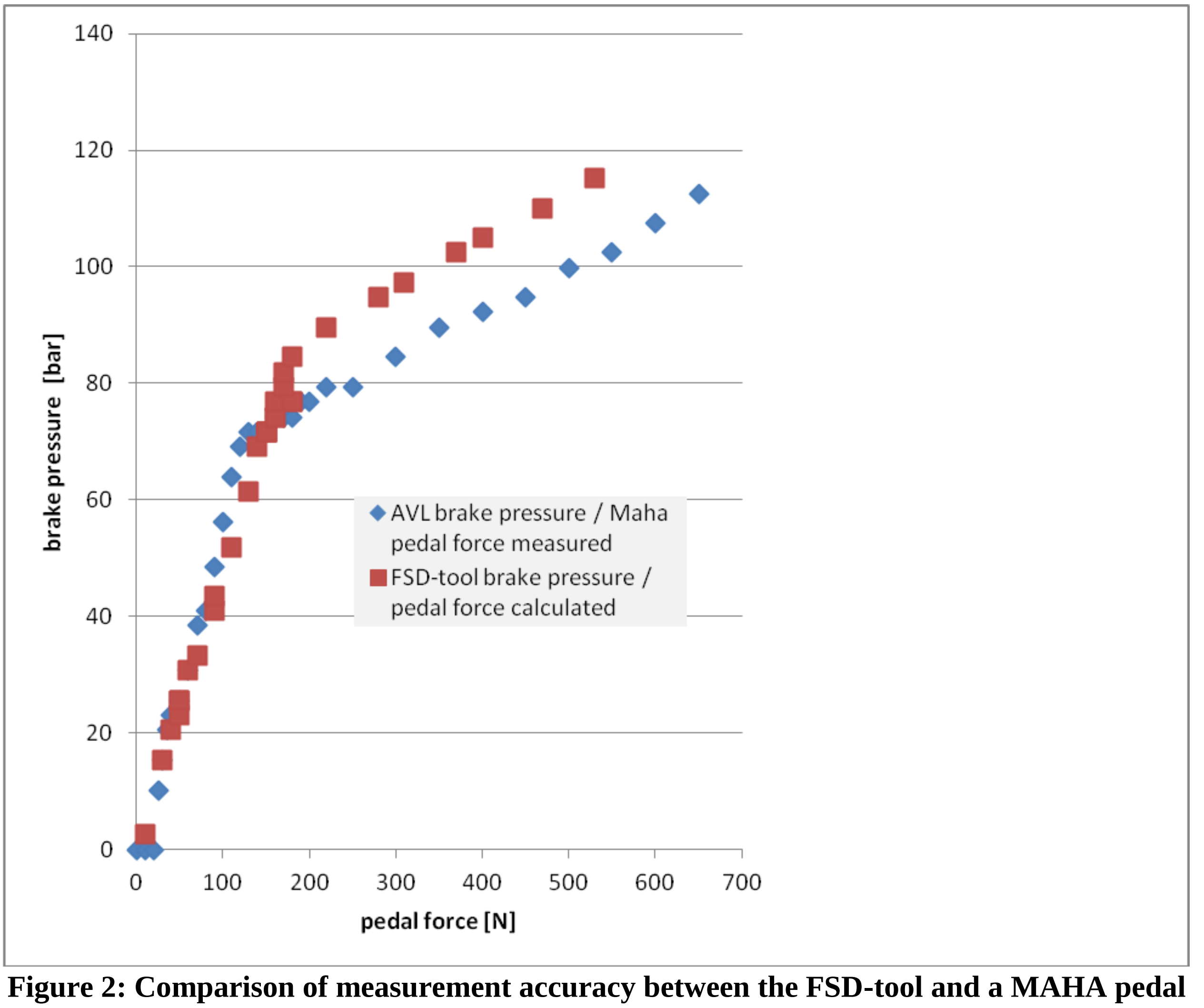


Figure 2: Comparison of measurement accuracy between the FSD-tool and a MAHA pedal dynamometer in combination with an AVL tool (BASt).

Despite these restrictions, the method with additional steps described in Section 5.1.1.3 appears to be the more promising method, but only if ‘brake reference values’ are available.

The reference brake force method was tested at BASt and later in field tests at TÜV Rheinland to prove that it can be used to evaluate brake efficiency. A BMW 325 d was tested with standard and counterfeit brake pads fitted to the brakes on the rear axle. The original brake force distribution (with standard pads), 65% on the front axle to 35% on the rear axle, changed to 50% on the front axle and 50% on the rear axle (see Table 8). This will have an effect on all braking manoeuvres. Also, from this point, the electronic brake force distribution can be affected and may change their control characteristics to the disadvantage of the driving stability of the vehicle.

vehicle: BMW 325 d	brake force on front axle left (daN)	brake force on front axle right (daN)	brake pressure front (bar)	brake force distribution front axle (%)	brake force on rear axle left (daN)	brake force on rear axle right (daN)	brake pressure rear (bar)	brake force distribution rear axle (%)
counterfeit brake pads (laboratory tests)	170	0:00	30	49,3	180	190	30	50,7
	190	200	35	49,4	190	210	35	50,6
	210	220	40	50,6	200	220	40	49,5
	300	300	57	51,3	280	290	57	48,7
counterfeit brake pads (field test)	340	340	53,8	47,9	370	370	87,1	52,1
original brake pads (laboratory test)	300	320	36	62	180	200	35,8	38

Table 8: Detection of implemented failures (counterfeit brake pads versus original brake pads)

The differences between the brake force distribution values between the laboratory and field tests highlighted in light grey in Table 8 were most likely caused by the different installations of roller brake testers, in the laboratory at BASt a truck roller brake tester used, whereas in the field tests a car roller brake tester was used.

5.2.1.2 Electronic Power Steering (EPS)

The proposed method for Electronic Power Steering described in Section 5.1.2 was assessed at BASt with regard to steps 1-4 and 9-10. The other steps were assessed at the FSD facilities (see Section 5.2.3.2) because, as mentioned previously, the specially prepared vehicles could not be transported and it was not possible to implement the failures on vehicles at BASt.

The steering wheel sensor of the BMW 325d (E91) was calibrated incorrectly (AVL) and the steering wheel then turned from lock to lock position with engine on and off. As a result the MIL was activated and the failure was detected by all PTI mode scan-tools which were able to read out the sensor values (Autocom, AVL, Hella Gutmann, TEXA)[8] . By using the additional test for Active Steering the following failures can be found:

- incorrect EPS steering wheel sensor calibration [MIL activated].

[8] Note: This BMW was equipped with active steering and had two redundant sensors for position of the steering wheel installed. In a similar test with another vehicle (with just one steering wheel sensor) at FSD the MIL was not activated (see Section 5.2.3).

- damaged sensors and/or incorrect sensor values (if reference values are available) [MIL activated].

In principle the method was proven at BASt.

5.2.1.3 Supplementary Restraint System (SRS)

Passive safety related systems were tested using the method described in Section 5.2.1.3 (SRS: airbags and seat belt pretensioners). Wherever possible the complete test procedure of the method was tested with more than six vehicles at BASt.

A missing airbag was replaced by a resistor (within the range of the reference values for a standard airbag). In that case neither the MIL nor the PTI mode scan tool detected any failure. By using a resistance value outside (greater than) the reference values the failure was displayed by the MIL and detected by the PTI mode scan tool.

Wherever applicable, the data recorded by the ECU (possible entries were “no crash” or “number of front, rear and side impacts”) were read out. This can only be checked by a PTI mode scan tool, because the MIL is not affected. Provided that the memory was not cleared before read out, it was found that data on the upper storage level allows conclusions to be drawn about the existence of any previous serious accidents.

Following the method described in Section 5.2.1.3 the function of the seat occupancy sensor was checked and its resistance values read out. This was done for a Golf VII. Different resistance values of the seat occupancy sensor were measured by using different weights put onto the seat. Depending on the weight of a person, the seat occupancy sensor provides information for triggering the airbag(s). The correct functionality of the seat belt buckles was also checked by a PTI mode scan tool (Bosch KTS).
Using the method described in Section 5.2.1.3 the following failures were detected by a combination of determining the status of the MIL and activating the MIL:

- damaged SRS-system or sub-system.*
- correct configurations of replacement airbags/SRS system components.*
- manipulation and incorrect replacement of systems.*

Notes:
*After a failure was implemented, MIL was reset by a scan tool so that it was not illuminated before inspection commenced.

It should be emphasized that in some cases, the manipulation could only be detected by a combination of individual tests. Also, if tampering involves replacement of a component with a rogue one which simulates the original component well the methodology reaches its limits and cannot detect the manipulation.

5.2.1.4 Adaptive and automatic headlamp systems

The two methods proposed for inspection of the lighting were assessed in the laboratory tests.

The method described in Section 5.2.1.4 uses an external control device to switch on the different kinds of lighting. This was tested at BASt for several vehicles. By using the eight test steps the following failures were detected:

- defective lighting equipment [lamp monitoring if available].

- wrong circuit [lamp monitoring if available].
- wrong signal colour [no MIL].
- wrong frequency of direction indicator [indicator light shows wrong frequency].
- problems with faulty ground connection [lamp monitoring if available].

In general, the detectable failures are the same as for when the PTI inspector switches the lighting functions by hand on and off one by one. However, this external control of the lighting functions negates the need for a second (person) inspector and thus can increase quality and reduce the inspection time, assuming that the external control routine is capable of conducting the test very quickly.

The method described in Section 5.1.4.3 “External control of the automatic levelling and bending of headlamps” was used to test three cars with dynamic levelling and bending light at BASt. The implemented failure of a dismounted or an incorrectly mounted automatic levelling sensor on the rear axle was not detected by the MIL. The sensor data were read out by using a PTI mode scan-tool. By moving the vehicle body or by sitting in the car the sensor value changed significantly. By using a headlight tester it could be seen that the beam was moving in the wrong direction (upwards instead of downwards).
A mechanically blocked headlight moving range implemented failure was detected by the MIL and the PTI mode scan-tool.
Step 6 of the proposed method described in Section 5.1.4.3 was not completely tested at BASt because test vehicles with AFS were not available (MIL mandatory; ECE-R 48), so measuring of the intensity was performed at FSD. Irrespective of that the following failures were detected with the method described in Section 5.1.4.3:

- incorrect setting.
- incorrectly installed or defective sensors (levelling, bending light, matrix control).
- wrong circuits.
- interrupted wiring.
- defective subsystems.
- control of light direction.
- control of light intensity.

It should be noted that this method only works with a suitable headlight tester in combination with a sufficiently flat levelled surface for the test vehicle and the tester.

5.2.2 Tests performed at Beissbarth

5.2.2.1 Braking system

Tests at Beissbarth factory in Munich were performed on the 15th of January 2014 to demonstrate the possibilities of how the braking inspection method could be integrated into the current PTI test and automated. The equipment was installed on a “laboratory test lane”, which is similar to a PTI test lane. The Roller Brake Tester worked together with an OBD-Tool and communicated via a network connection. An integrated software has been especially designed for PTI and already includes the implementation of some steps of the method described in Section 5.1.1.2 (Proposed Method for brake testing with direct focus on ECSS (ABS, ESC) and additional steps described in Section 5.1.1.3 (Test Method addition for inspection to detect failures related to non-ECSS components but relevant to ECSS performance). The process is shown in Figure 3.

The tests were carried out with an Audi A4. The activation of each wheel brake cylinder was checked and made visible to the inspector. In addition, the measured values allow conclusions on the run-out of the brake discs to be made and, in principle, should allow a software based assessment of the ovality. This could be used to improve the quality the current subjective assessment on the roller brake tester by the inspector. The software-based interpretation of the responding transient behaviour of the braking force caused by the pressurized brake unit of each wheel can be used to draw conclusions about the tightness of the hydraulic system. If for example the response of a brake unit takes place very slowly when stepping on the brake pedal this could be detected in combination with reference values for the expected corresponding behaviour ($\Delta p/\Delta t$).

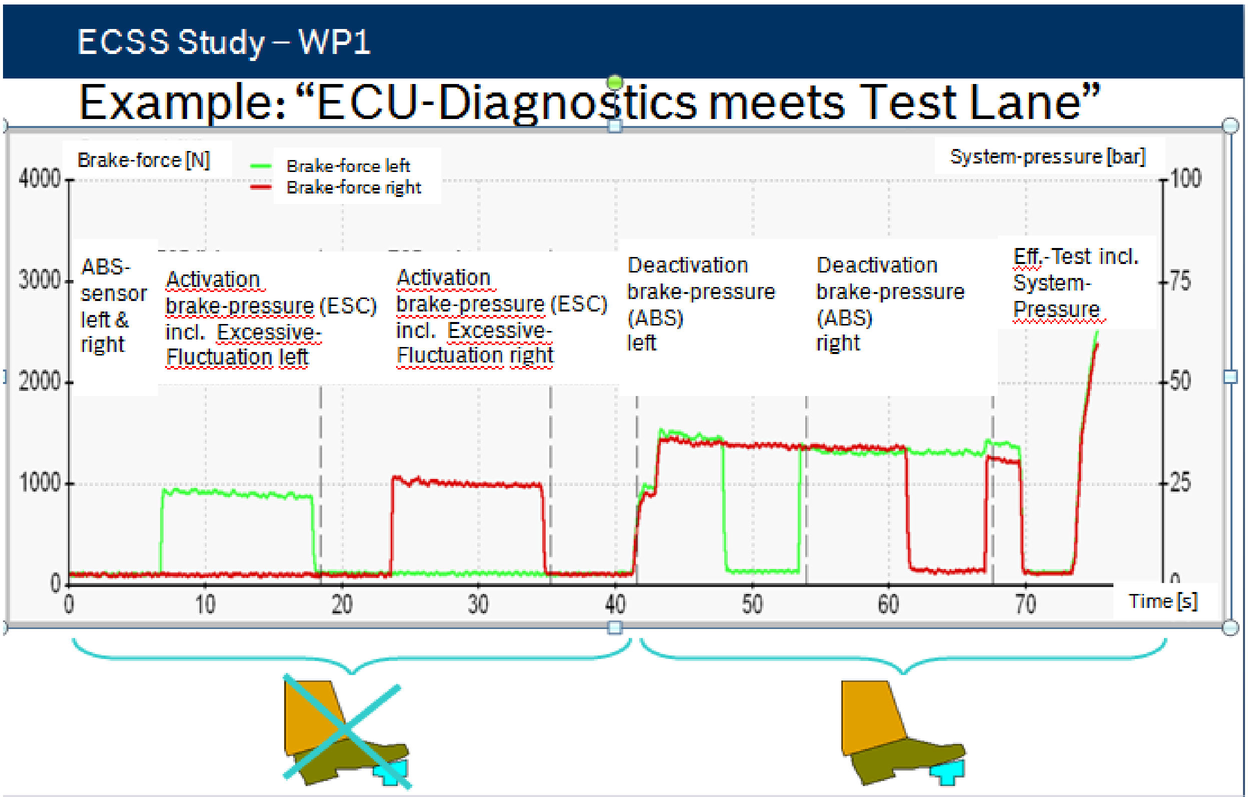


Figure 3: Measurements from braking system test with additional steps using brake hydraulic pressure measurements and automation of some steps.

During the tests an incorrect activation of a brake cylinder was tested and immediately found by the implemented software. The methodologies of 5.1.1.2 (without step 8, 10 and 13) and 5.1.1.3 were shown to work by the tests at Beissbarth both in terms of conception and integration of the functional tests.

5.2.3 Tests performed at FSD facilities

5.2.3.1 Braking system

The brake tests at Beissbarth (see Section 5.2.2) using the Beissbarth scan tool were repeated with a Mercedes E 250 and a Smart For Four using the FSD PTI mode scan tool at the FSD facilities, Radeberg on 23rd January 2014. The actual zero or straight ahead point for the steering wheel angle sensor was measured by using a PTI mode scan tool with the front axle wheels on the running RBT (without pressing the brake pedal, hold the vehicle straight by slightly adjusting the steering wheel). After driving out of the RBT and when the vehicle was at a standstill, the readings of acceleration sensor and yaw rate sensor were recorded. This was combined with cross-system consistency check while driving with more than 4 km/h outside of the test lane. The yaw rate and lateral acceleration sensor signals were checked whether or not they were plausible.

This verified the remaining steps (steps 10 and 13) of the braking methodologies described in Sections 5.1.1.2 and 5.1.1.3. Within the brake tests, steps 5 to 7 from Section 5.1.2 (Method EPS) were also verified.

Also, in case of the Smart ForFour, the steering angle sensor was calibrated incorrectly (note MIL was not illuminated). A test drive showed a substantial problem with the performance of the ESC. In gentle left hand bends the ESC braked wheels because the car ‘thought’ it was understeering because of the mis-calibration of the steering wheel sensor.

5.2.3.2 Electronic Power Steering (EPS)

The proposed complete method for Electronic Power Steering (EPS), described in Section 5.1.2, was assessed at the FSD facilities. The steering wheel sensor of a Mitsubishi IMIEV test car was calibrated incorrectly. The calibrated angle was -15 degree instead of zero. The MIL was not illuminated. The failure was detected by a PTI mode scan tool (Mitsubishi). During a test drive on a normal road it was clearly demonstrated that ESC was working incorrectly. The ESC intervention took place too early or too late, depending on the curve direction. The driving behaviour was very difficult to control for inexperienced drivers.

The following failures were found (MIL not activated):

- incorrect steering wheel sensor calibration.
- incorrect sensor values (reference values were available).
- incorrect power steering control.

5.2.3.3 Tyre Pressure Monitoring System

The TPMS test method described in Section 5.1.5.1 was evaluated at the FSD facilities using a Mercedes Viano. The tyre pressure was reduced to a low value. This was detected by the MIL (after driving with the vehicle for more than 10 min) and by the PTI mode scan tool (Tecnomotor) immediately. The tyre pressure sensors were triggered and it was checked if the appropriate pressure values from the corresponding tyre/wheel assembly were provided to the display of the PTI mode scan tool. It was concluded that the following failures can be detected using the method described in Section 5.1.5.1:

- TPMS ECU is fitted and working.
- Correct operation of the TPMS MIL.
- Tyre pressure sensors communicate with the ECU, provide appropriate pressure values and signals corresponding to the right tyre/wheel assembly.

It should be noted that it was also found that communication for the TPMS test could be performed using a wireless access over ISM band without an OBD connector (see Figure 4).

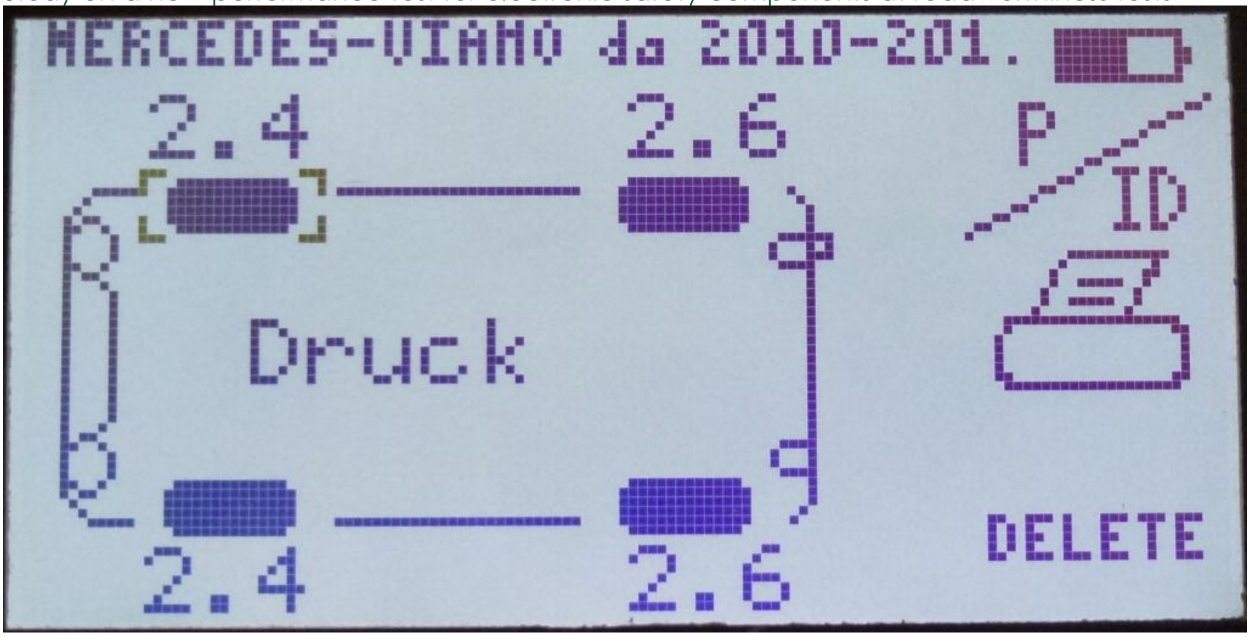


Figure 4: Check of tyre pressure sensor (system) by an external device at FSD facilities.

5.2.3.4 Lighting

The step 6 of method 5.2.1.4 “External control of the automatic levelling and bending of headlamps” was verified using a test vehicle with an AFS (Advanced Frontlighting System) system. The bending light was triggered by a PTI mode scan tool to move from right to left and back. The complete range of the bending light was visible in the headlight tester. By using an electronic headlight tester the intensity of the beam was measured in principle. It was not possible to trigger the different light distributions of an AFS system and measure the intensities according to Annex 3 of UN-ECE Regulation No. 123.

5.3 Summary

In the laboratory testing, starting from concepts developed in WP1, methods for inspection of the following ECSS were developed:

- Braking related
    - Anti-lock Braking System (ABS)
    - Electronic Stability Control (ESC)
    - Emergency Brake Assist (EBA, also known as Brake Assist System (BAS)).
    - Electronic Braking System (EBS)
- Electronic Power Steering (EPS)
- Supplementary Restraint System (SRS)
    - Airbag
    - Seat belt pre-tensioner
    - Other related components (e.g. seat occupancy sensor)
- Lighting automatic functions such as levelling and bending.
- Tyre Pressure Monitoring System (TPMS), both passive and active.

It should be noted that:

- For EBA it was not possible to develop a specific functional level 3 test. However, all additional sensors used for electronically controlled EBA are tested at level 2b as part of the proposed braking and EPS methodologies.
- The TPMS method only works for active TPMS. For non-active TPMS whose function is based on software analysis of the wheel speed sensor signals only the correct function of the MIL can be checked. However, wheel speed sensor signals are checked as part of the braking inspection methodology.
- To implement methods into legislation, information is required from vehicle manufacturers to provide threshold values for plausibility checks and reference brake pressure values.

All of these inspection methods were trialled in the laboratory and it was shown that they work and can detect the following failures, many of which do not illuminate the MIL (mainly mechanical failures) but also some of which do illuminate the MIL (failures of the electronic systems ABS, ESC, SRS, TPMS and AFS; here the display of safety related failures is required by the corresponding UN Regulations):

- Braking
    - Generic:
        - Partly blocked brake-hose - MIL not illuminated
        - Impaired friction, oil contaminated or counterfeit brake pads – MIL not illuminated
        - Faulty brake force distribution – MIL not illuminated
        - Insufficient braking power in relation to the total weight - MIL not illuminated
    - ABS/ESC:
        - Modulator valve problems (in principle only)
        - Wheel speed sensor problems (failure, internal resistance not correct, assembly errors) – MIL illuminated
        - Toothed wheel fracture (in principle only)
- Electronic Power Steering (EPS)
    - Incorrect EPS steering wheel sensor calibration – MIL illuminated and not illuminated depending on degree of mis-calibration
    - Damaged sensors and/or incorrect sensor values (if reference values available) – MIL illuminated
- Supplementary Restraint System (SRS)
    - damaged SRS-system or sub-system
    - correct configurations of replacement airbags/SRS system components
    - Some manipulation and incorrect replacement of systems – MIL not illuminated
- Lighting automatic functions
    - Incorrectly mounted automatic levelling sensor – MIL not illuminated
- Triggering of lighting functions
    - defective lighting equipment [lamp monitoring if available]
    - wrong circuit [lamp monitoring if available]
    - wrong signal colour [no MIL]
    - wrong frequency of direction indicator [indicator light shows wrong frequency]
    - problems with faulty ground connection [lamp monitoring if available]
- Tyre Pressure Monitoring System (TPMS)
    - TPMS ECU is fitted and working
    - Correct operation of the TPMS MIL

- o Tyre pressure sensors communicate with the ECU, provide appropriate pressure values and signals corresponding to the right tyre/wheel assembly

It should be noted that it was not possible to show that the methods could detect all the potential failures identified in WP1 and shown in Annex 2, because either it was not possible to implement these failures on vehicles or there were problems with communication between the vehicles and the diagnostic tools. However, the capability to detect most of the failures identified in Annex 2 was shown, at least in principle.

6 Elaboration of inspection methods for Field Testing

This section describes the work performed within WP3. The main part consisted of elaboration of the laboratory inspection methods and selection of tools for field testing. The other part consisted of the development of a plan for how to perform the field tests and analyse the results.

It should be noted that all of the output of this work, i.e. the elaborated methods and tools selected for field testing and the plan for field testing, was reviewed by the Project Steering Group (PSG) to ensure that it was impartial and independent. A copy of the document supplied to the PSG for the purposes of this review was also supplied to the European Commission to give the Commission the opportunity to check the project output and ensure the work was not biased in any way.

6.1 Elaborated methods and selection of tools for field testing

6.1.1 Elaborated methods

The method elaboration task consisted of elaboration of the methods into a form suitable for field testing, and development of a method to collect the data generated from the tests.

The outline inspection methods, detailed in Section 5.1 and proven in the laboratory testing, were elaborated into the following three test modules (groups):

- Module 1: Electronic Power Steering (EPS), Braking (ABS/ESC/EBS/(TPMS passive)). and Tyre Pressure Monitoring System (TPMS active).
- Module 2: Lighting (automatic levelling and bending).
- Module 3: Supplementary Restraint System (airbags, pretensioners, occupancy sensor).

This was done to improve the efficiency of the inspection methods overall by making best use of the overlap between the inspection methods for the individual ECSS. Excel spreadsheets were developed which contained the elaborated methods and could be used to collect the results of the tests. Specific spreadsheets were developed for each PTI organisation involved in the field testing in order to provide easier handling.

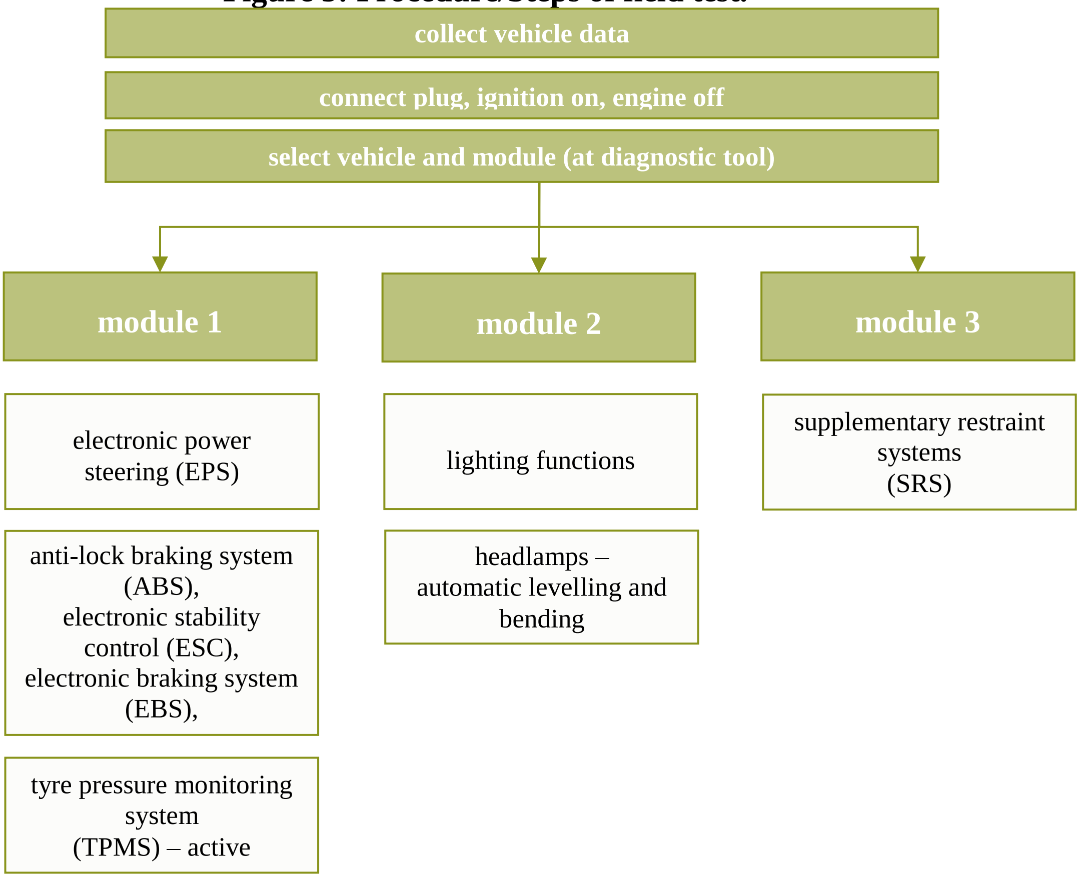
To ensure that the spreadsheets were fit for purpose before use in the field tests, they were trialled at inspection centres, feedback given to DEKRA, and updates made to resolve any issues reported. Some of the main improvements made using this process were:

- Implementation of data transfer from the test tools and the inspection lane. This was needed to ensure that in-lane inspection times would not become disproportional high.
- Changes to include START and STOP buttons to collect inspection time data. This information was needed for the cost benefit analysis.
- The individual test steps were grouped into clusters to simplify the spreadsheet and make it more user friendly for the field testing.
- Additionally some user support was implemented in order to make it more user friendly, e.g. format of panels and click options for input information.

With regards to the content of the data to collect, all stakeholders and in particular BASt (who performed the analysis of the data collected) were involved in this process.

The sequence of the elaborated test method starts with the collection of vehicle data, the connection of plug and the selection of vehicle and tool. This is followed by the individual modules.

Figure 5: Procedure/Steps of field test.



The final spreadsheet consisted of four tabs. The first tab was to collect data on the testing organization, the tool and the vehicle to be tested. The other tabs were for collecting data for the individual test modules, in particular time and result data, which was needed for the cost-benefit analysis and evaluation of the test methods.

The data collected for each tested vehicle is automatically stored in a separate file. As mentioned above, some of the data can be collected out of the test lane from reports and files produced by the software of the tool.

The final version of the elaborated methods and data collection spreadsheet is described in Annex 5.

6.1.2 Selection of tools

A proposal for tool selection was made by DEKRA based on the following criteria:

- That the necessary data can be collected, e.g. module 1 (braking and EPS) is performed with and without automation so that the effect of automation on inspection time can be assessed and also module 1 is performed with and without additional steps (reference braking force steps), so that value of these steps can be assessed. This criterion dictated the selection of at least three tools for module 1 testing, namely, the Bosch tool to assess the effect of automation because it was the only one available with automation, the FSD tool to assess module 1 with reference braking force steps because it was the only one available with this capability/access to reference values and two other tools to assess module 1 without reference braking force steps (AVL DiTest and TEXA were chosen to broaden the range of results).
- The range/number of vehicles that the tool can be used to test – wider/more is better because this increases the efficiency of field testing. Tool manufacturers supplied DEKRA with relevant information to make this assessment under a non-disclosure agreement because this information is commercially sensitive.
- The usability of the tool for field testing, i.e. performance and ease of use for chosen elaborated method module in the test lane. This was necessary to ensure that inspection times were sufficiently short to enable field testing to be performed, e.g. time limit of circa 10 minutes, ideally considerably shorter to ensure customer will allow additional inspection of their car and that the whole exercise is not excessively costly. This assessment was made based on the results from the laboratory tests performed by BASt and DEKRA's experience with the tools whilst elaborating the test methods.
- The availability of the tool. This included the availability of tools in the countries where the field testing would be performed (tool needs to be supplied with appropriate language capability) and the ability of tool manufacturers to deliver their tool in the required timescales with appropriate training and support.

This proposal was reviewed and agreed by WP3 and WP4 participants, in particular EGEA. In addition the tools were tested at the PTI organisations to confirm items such as usability, performance and vehicle coverage.

The final selection of tools made for testing the inspection method modules at each organisation is shown below (Table 9).

Table 9. Tool selection for field testing.

Inspection Centre	Bilprovningen	GOCA	TÜV Rheinland
Tools	**Autocom** Module 3	**Actia** Module 1 Module 2 Module 3	**Bosch** Module 1 with automation
	Texa Module 1 Module 2 Module 3	**AVL DiTest** Module 1 Module 2 Module 3	**Hella Gutmann** Module 2
		Tecnomotor Module 1 only TPMS	**FSD** Module 1 with reference braking Module 2

In summary, tool selection for field testing was made on the basis of practical considerations to enable the project to proceed in a timely manner with a sufficient range of tools tested (eight) to discover any issues and give meaningful results.

Hence it is transparent that the selection made was impartial and independent.

However, as the tools available were mostly based on existing workshop/diagnostic tools (with one exception) and although they provided good width and depth of vehicle/ECSS coverage, they did not have software designed to perform optimised PTI test methods on the selected ECSS. Both budgetary and time restraints did not allow any software development to be made, but if this was done in the future, faster PTI ECSS testing would be possible, using automated and interactive test routines. This was demonstrated using one of the tools (Bosch) which had been linked to a roller brake tester to show how this could be achieved, based on the testing of an ABS system.

6.2 Approach / plan for field tests with focus on data collection and data consistency

The objectives for the field tests were:

- To assess the suitability and robustness of the inspection methods / tools for use in a regulatory regime, i.e. in inspection centres.
- To help collect data for the cost benefit analysis.

Data from the test spreadsheet was collected and collated in a database spreadsheet to ensure easy handling and sufficient basis for further analysis.

The database excel spreadsheet consisted of the following five tabs:

- The tab “Overview” gives a global view of performed field tests and implies following data content: filename, test inspector, tool, vehicle data (VIN, manufacturer, type), fittings and a summary of performed systems in each module (time recording for start and end of test, the availability of the systems on used inspection tool and the result (test ok/not ok) of the inspection)
- The tab “General Data” according to the spreadsheet “General Data” for the field testing consists of filename, test inspector, tool, vehicle data (VIN, manufacturer, type, licence plate number, odometer reading, etc.) fittings and also information on indicator lamp check and the results of PTI test.
- The last three tabs “Module 1 Data Collection“, “Module 2 Data Collection“ and “Module 3 Data Collection“ collect data for the individual modules, in particular time and result data.

It was planned to collect test results for about 1000 to 1500 vehicles using the eight selected tools and using the spreadsheet described in Section 6.1. This equates to about 100 – 250 vehicles per tool. However, it should be noted that each inspection organisation was supplied with a number of each tool so that data collection could be performed quickly by using a number of test lanes and/or inspection centres.

It was planned that the field tests should be performed in two phases for the purpose of risk management. Firstly an initial phase should be conducted in which results should be collected for 10-20 vehicles. This should be followed by the main phase in which the remaining results should be collected. The data from the initial phase should be analysed as soon as collected to check that all information necessary was collected. In the event that it is found that this is not the case, this would give the opportunity to make any changes necessary before all results were collected.

It was planned that the consistency and the completeness of the data collected during the field tests should be checked on a continuous basis. The reasons for this were to give the opportunity:

- To add any data missing, correct inconsistencies
- To check that the distribution of vehicle make, age, kilometerage, etc, tested, and tools used were as required for the analysis.

6.3 Summary

Key points from Work Package 3 reported in this section are:

1. The elaboration and classification of the methods into a form suitable for field testing (three test modules/groups).
2. The development of an Excel spreadsheet with field test participants, containing the elaborated methods, for the use and collection of the result in the field testing.
3. The trial of the developed Excel spreadsheet at inspection centres to ensure the fitting for purpose.
4. The proposal for tool selection based on criteria and confirmation from PTI organisations, which was reviewed and agreed by WP3 and WP4 participants.
5. The collection of data from test spreadsheet in a database spreadsheet to ensure easy handling and sufficient basis for analyses.
6. The division of field test into initial and main phases for the purpose of risk management.

7. The review of the consistency and completeness of collected data to ensure suitability for the analysis.

7 Field Tests

7.1 Methodology

This section describes the way in which the field tests at PTI centres, namely TÜV Rheinland, Bilprovningen and GOCA, were conducted with the selected methods and tools. It also describes the problems discovered during the field tests and how they were resolved. The field tests were performed mostly to plan as described in Section 6.2. The elaboration of the inspection methods, the selection of tools per field test centre and the data collection during field test were already complete before the main bulk of the field tests started. On the part of the project management a weekly follow up by conference call between the members of primarily WG3 and WG4 and the project manager but also including WP1 and WP2 leaders was held to discuss and resolve any problems arising.

The most important issue for the test organisations who performed the field tests was that the tests should fit more or less into the current PTI test regime. The biggest problem arose from the fact that most of the tools selected for the field tests were tools designed for repairing purposes to be used in garages and not PTI oriented equipment. The result of this was that the time to perform the test took much longer than originally planned. It was originally planned that the additional time required to perform the ECSS tests should not be more than 10 minutes to ensure that the normal operation of the PTI centre was not disturbed too much and that customers would be happy to wait this additional time and allow the extra ECSS inspection of their vehicles.

To help try and resolve this problem DEKRA updated the Excel data sheet in order to reduce the time needed in the tests lane to input the data. This was achieved with clustering of some individual test steps and to help with the speed of collecting some data such as inspection time by the inclusion of START and STOP buttons to collect it. Also, the spreadsheet was arranged so that some data, such as vehicle registration and data stored on the test tool could be entered outside the test lane, therefore saving time in the test lane.

Even after these changes the test time was still much more than that desired. This was due to the following:

- Inspectors are not familiar with the vehicle architecture/design/functionality of some of the vehicle ECSSs. PTI inspectors are experts in vehicle roadworthiness testing, but not necessarily in vehicle architecture and system design. Most of the tools used followed the architecture of the inspected car. This means that interrogation of an ECSS may be different for each vehicle and sometimes the information and/or functions needed are not even in one ECU unit. The inspector has to know in advance which ECU unit he has to start the interrogation of the car with.
- The ECSS information / functionality is often stored in different ECUs each with their own menus, so that for each ECSS several menus need to be consulted.
- The test method asks for a combination of actuator testing and live (real time) parameters to be read out. In the scan tools these are stored in different menus so that the inspector has to perform many manipulations and switching many times between the different menus of the tool.

- Not all vehicles respond in the expected manner, so that vehicle ECU identification itself takes quite a long time before the test sequences can be started.
- Almost all vehicle manufacturers have a different philosophy for the allocation of menu items to functional groups which makes the initialisation of tests steps very time consuming.

Because of this problem, the main test phase was difficult, both for the inspection centres and their clients. In fact, one PTI test centre stopped testing due to this problem. However, the testing organisation in charge of this centre found an alternative centre in order to fulfil their commitment to the project.

In order to reach the target of performing a large number of tests (900 to 1800), the following actions were taken:

- The test drive in Module 1 was only conducted in those countries where a test drive is mandatory during the PTI test.
- Vehicles from dealers or personnel of the PTI centres were sometimes used, because this resolved the problem of keeping a customer waiting. However, for these vehicles no standard PTI test was performed, so no comparison of ECSS and standard PTI test results could be performed for these vehicles.
- Although it was agreed initially that each vehicle does not have to be tested for all three ECSS modules (Brakes, Lights and SRS) the PTI test centres tried to include as many ECSS modules as possible to increase the amount of test data collected.
- Additional test tools were sent by the WP1 tool manufactures to the PTI organisations in order to establish testing in parallel with a specific tool.

There was also one further problem. This was the number of tests that could be performed with vehicles with implemented failures. Originally it was planned that many of these tests should be performed. However, this was not possible because failures could not be implemented on customer cars because of liability issues and implemented failures that were useful, i.e. those that did not light the MIL and hence would not be detected by the current PTI, were difficult and /or time consuming to implement or repair.

During the field tests about ten vehicles were tested with implemented failures:

- Steering wheel sensor calibration misaligned (between 7° and 15°).
- Blocked brake hose failure using clamp.
- Implemented incorrect mounting of automatic levelling sensor at rear axle failure;
- Vehicle with counterfeit brake pads.

None of these failures were detected by the vehicle's OBD system, so did not light the MIL. However, they did cause safety or significant driving problems and were detected by the field tests.

7.2 Results

This section is divided into two parts; the first describes the characteristics of the data set collected and the second the analysis of it and the results.

7.2.1 Characteristics of data set collected

Data gathered during the field tests were filtered using criteria to obtain valid test data suitable for analysis. The following criteria were used:

- Completeness of main important data in a row of the spread sheet
- Plausibility of data in a row of the spread sheet
- Discarding of completely empty rows

Table 10: Characteristics of vehicles.

Manufacturer	Number of vehicles
VW (VW, Audi, Skoda, Seat)	345
Mercedes/Mercedes Benz	157
Ford	112
Toyota	84
Others	512

Registration date (year)	Number of vehicles
2000	5
2001	23
2002	18
2003	40
2004	43
2005	79
2006	70
2007	140
2008	98
2009	185
2010	111
2011	276
2012	42
2013	48
2014	17
Average registration date (Y/M)	2008/5

Odometer reading (1,000 km)	Number of vehicles
≤10	27
>10 to ≤25	44
> 25 to ≤50	106
>50 to ≤75	104
>75 to ≤100	101
>100 to ≤125	83
>125 to ≤150	77
>150 to ≤175	64
>175 to ≤200	37
>200	29
Average in km	97

Table 11: Characteristics of field tests conducted.

All tests by system	Number of tests
EPS	663
ABS/ESC/EBS/ (TPMS passive)	1213
TPMS active	663
Lighting	1166
Headlamps	663
SRS	663
Sum	**5031**

Valid tests by system	Number of tests
EPS	273
ABS/ESC/EBS/ (TPMS passive)	842
TPMS active	185
Lighting	731
Headlamps	174
SRS	449
Sum	**2654**

Valid tests by organization	Number of tests
Bilprovningen	615
GOCA	865
TÜV Rheinland	1174
Sum	**2654**

Valid tests by tool	Number of tests
Actia	482
Autocom	152
AVL DiTest	383
BOSCH Beissbarth	47
FSD	976
Hella Gutmann	151
Texa	463
Tecnomotor	0
Sum	**2654**

Availability of ECSS on tool	Number of tests
EPS	200
ABS/ESC/EBS/ (TPMS passive)	779
TPMS active	7
Lighting	204
Headlamps	67
SRS	362
Sum	**1619**

Availability of ECSS on tool	Vehicle coverage [%]
EPS	73
ABS/ESC/EBS/ (TPMS passive)	93
TPMS active	4
Lighting	28
Headlamps	39
SRS	81

Slightly more than 50 % of the tests were regarded as valid tests and used for analysis. An overall number of 1213 vehicles were tested and 5031 single ECSS tests for safety systems like ABS, ESC etc. were carried out. According to the criteria for validity, 2654 tests were identified as valid for analysis. One reason for the big number of invalid tests was the relative complicated and complex approach for collecting the data in combination with handling the diagnostic tool. A much bigger proportion of valid tests was gained with the use of the PTI tool (close to 100 %).

Table 10 illustrates the four major manufacturers of the vehicle test fleet during the field test. The part of “Others” contains French and Swedish as well as Korean VMs (see detailed distribution in Section 18, Annex 6, Table 28).
Based on different requirements on periodical technical inspections in different member states only a small proportion of the vehicles was newer than 2011, however those vehicles from 2012, 2013 and 2014 were taxies, rental cars or used cars, which needed a PTI for certain reasons. The distribution of vehicle age is shown in Table 10 and Section 18, Annex 6, Figure 14.

The mileages of vehicles revealed no abnormality and a good distribution. The age of the tested vehicles correlated to the mileages of the vehicles.
The distribution of the test tools handed to the three different organizations is shown in Section 18, Annex 6, Figure 15.
The FSD tool is a hardware-based solution especially developed for the PTI. The other tools are designed for repair and maintenance and definitely not optimized for PTI purpose. Nevertheless these devices provide the user with extensive diagnostic functions.
A large proportion of the tests with the FSD-tool involved the embedded test procedure for brake tests, which was used by many of the vehicle inspectors.

Three organisations from three different European Member States were involved into the field test. Section 18, Annex 6, Figure 16 shows the organisations in terms of field tests carried out. One organisation performed a larger proportion of the tests because they used the tool, which was optimised for PTI brake and light tests.

The three different test modules were conducted in different ways. For some the inspector only used one module in order to have a sufficient test time whilst for others the inspector used all modules or only parts of one of the modules. For the analysis single tests in terms of the different ECSS being checked were considered.

The results of the field tests were evaluated regarding a number of criteria and one of them was inspection time. For the evaluation of inspection time only tests were used; which recorded sufficient information about timing. For the individual ECSS estimated average inspection times are shown in Table 12.

Table 12: Samples– Module 1, 2 and 3.

Number of valid tests	Sample	Average time (mm:ss)
EPS	75	2:40
ABS/ESC/EBS/ (TPMS passive)	46	5:38
TPMS (active)	0	n/a
Lighting	98	1:37
Headlamps	98	0:43
SRS	420	2:32
SRS including ohmic resistance measurements	64	3:58

The average inspection times which are based on the use of the generic diagnostic scan tool varied from 43 seconds to 5 minutes 38 seconds for different types of ECSS. These times will be reduced significantly when using an optimized tool for PTI purpose.

7.2.2 Results of level 1 tests

A Level 1 test was defined in Section 3.1 and includes communication between tool and systems ECU and identification of the system. Results on coverage were different amongst the systems. For example, for the brake system about 93 % of vehicles could be checked by the scan tools used whereas only 4 % of active tyre pressure monitoring was covered by the scan tools used. For Level 1 nearly 81 % of the SRS systems were able to be tested (see Table 13 below).

Table 13: Vehicle coverage.

	Number of valid tests	Vehicle coverage [%]
Module 1		
EPS	200	73
ABS/ESC/EBS/ (TPMS passive)	779	93
TPMS active	7	4
Module 2		
Lighting	204	28
Headlamps	67	39
Module 3 – SRS	362	81

A detailed distribution of vehicle coverage with regard to the test tools used is shown in Section 18, Annex 6, Table 29. Failures could not be measured because there was no information available about the factory-provided fitment for the vehicles tested. However, that would be easily possible if this information is accessible from the vehicle manufacturer (VM).

7.2.3 Results of level 2 tests

7.2.3.1 Potential failures identified by Diagnostic Trouble codes (DTC)

A Level 2 test was defined in Section 3.1 and mainly consists of reading out system information in terms of values, status and diagnostic trouble codes. It should be noted that many DTCs are designed for maintenance and repair, and therefore it is difficult or impossible to use them for defining PTI relevant faults.

To help understanding, the format of diagnostic trouble or error codes are explained in brief below. OBD-II codes or rather Diagnostic Trouble Codes consist of a code letter and four digit number, e.g.: P0171. The following breakdown shows the meaning of the code letter and each digit of the code:

The first character identifies the system related to the trouble code.

P = Powertrain
B = Body
C = Chassis
U = Undefined

Second Digit - Code Type

The second digit identifies whether the code is a generic code (same on all OBD-II equipped vehicles), or a manufacturer specific code.
0 = Generic (this is the digit zero -- not the letter "O") (SAE J2012)
1 = Enhanced (manufacturer specific; not mandatory)
2 = manufacturer independent (ISO 15031-6 or SAE J2012)
3 = a) P3400-3999 manufacturer specific code
b) P3400-3999 manufacturer independent (ISO 15031-6 or SAE J2012)

Third Digit - Sub-System

The third digit denotes the type of sub-system that relates to the code.
1 = Emission Management (Fuel or Air)
2 = Injector Circuit (Fuel or Air)
3 = Ignition or Misfire
4 = Emission Control
5 = Vehicle Speed & Idle Control
6 = Computer & Output Circuit
7 = Transmission
8 = Transmission
9 = SAE Reserved
0 = SAE Reserved

Fourth and Fifth Digits These digits, along with the others, are variable, and relate to a particular problem. For example, a P0171 code means P0171 - System Too Lean (Bank 1).
(refer to: http://www.obd-codes.com/trouble_codes/)

For assessment of possible future use of DTCs in PTI, standardisation combined with information from the vehicle manufacturers is needed. Once this is complete, an assessment can be made whether or not (and possibly what kind of) DTCs could be used in PTI for systems where, due to technical reasons, functional tests are not possible.

EGEA members (tool manufacturers) analyzed the diagnostic trouble codes in terms of their relevance to the PTI. A distinction was made:

- No impact: error does not affect the safety-related electronic systems in the vehicle
- Possible impact: error may have influence on safety-related electronic systems in the vehicle
- Possible failure: possible failure in safety-related electronic systems in the vehicle

In this manner, two different categories were defined that indicated that a possible impact or failure may arise, e.g. for the SRS systems 2.4 % of the vehicles had DTCs, which indicate a possible impact on correct functionality of the ECSS and 3.6 % of the vehicles had DTCs which indicate possible failures, which most likely have an impact on correct functionality of the ECSS (see Table 14).

Table 14: Estimation of the relevance of diagnostic trouble codes (based on vehicles tested).

	with failures				failures/count of tests [%]		
Failure codes	No impact	Possible impact	Possible failure	Performed tests	No impact	Possible impact	Possible failure
Module 1							
EPS	0	7	8	273	0.0	2.6	2.9
ABS/ESC/EBS/ (TPMS passive)	0	17	22	842	0.0	2.0	2.6
TPMS active	0	1	1	185	0.0	0.5	0.5
Module 2							
Lighting	0	1	1	731	0.0	0.1	0.1
Headlamps	0	0	0	174	0.0	0.0	0.0
Module 3 - SRS	1	11	16	449	0.2	2.4	3.6

Within the field test the memory content of 78 vehicles was evaluated. All other vehicles of the field test had no diagnostic trouble codes or the communication with the vehicle was not possible.

The results (see Table 15) of this analysis are as follows:

- All (100 %) of the DTCs with relevance to the Electronic Power Steering (EPS) could have a possible impact.
- Nearly 32 % of the ABS/ESC/EBS/(TPMS passive) DTCs had a possible impact and 68 % of them represented a possible failure.
- Only six DTCs with relevance to Lighting functions were found. Half (50 %) of them had a possible impact and half (50 %) of them could represent a possible failure.
- More than 61 % of the DTCs with relation to SRS had a possible impact; nearly 37 % showed a possible failure and 2 % had no impact.

Table 15: Estimation of the relevance of diagnostic trouble codes (based on DTCs found).

	with failures				failures/count of DTCs [%]		
Failure codes	No impact	Possible imapct	Possible failure	Number of DTCs	No impact	Possible imapct	Possible failure
Module 1							
EPS	0	21	0	21	0.0	100.0	0.0
ABS/ESC/EBS/ (TPMS passive)	0	21	45	66	0.0	31.2	68.2
TPMS active	0	4	0	4	0.0	100.0	0.0
Module 2							
Lighting	0	3	3	6	0.0	50.0	50.0
Headlamps	-	-	-	-	-	-	-
Module 3 - SRS	1	30	18	49	36.7	61.2	2.0

Many error codes referred to a low voltage of the power supply system of the tested vehicles. If failure codes are to be used as part of a PTI of a vehicle in future, the power supply must be assessed at the time of the test. Also other aspects need to be clarified (thresholds of the manufacturers, historic or deleted failure codes etc.). All of this raises the question whether failure codes should be considered as part of a PTI at all.

7.2.3.2 Potential failures identified by level 2a plausibility thresholds

The sample of 75 tests of Electronic Power Steering (EPS) within module 1 includes measurement values between – 22.5°and +21.1° for the steering angle. Here no fault codes were recorded. The data included no values for the upper and lower limit. In principle, however, it was clearly shown that in the presence of limit values, a review would be possible.

For eleven stationary vehicles a lateral acceleration between -17.6 m/s² and 0 m/s² was read out. For these cases a lateral acceleration of nearly zero was expected. Considering that the acceleration of gravity is 9.81 m/s² any read-out values without a zero in front of the decimal point - even when considering the offsets - were likely not plausible. However, threshold values were not available. Within the sample the value of the yaw rate was recorded for ten vehicles (nine times 0°/s and one time -0.31°/s was recorded). One value seemed to be incorrect, but again threshold values were not available.

With regard to the SRS igniters the resistance values of 63 vehicles ranging from 2 to 4 Ohm were read out. Some differed from this value, maybe because of transmission errors in the data sheets. In the absence of limit values, it is obvious that zero Ohm is the value for an SRS replaced by a cable link or an airbag that was ignited (measured on crashed vehicles in the laboratory tests). A higher value can also point to an ignited airbag during a vehicle crash. For an assessment the knowledge of the upper and lower limit is necessary. This cannot detect the manipulation and replacement of an airbag by a simple resistance with the same value, but it would make manipulation a little more difficult.

Although no thresholds were available from the VMs during the field tests an estimation was made based on common sense and the experience from the field tests. Table 16 shows the proportion of SRS igniter resistance values measured outside an assumed threshold of 2 to 6 Ohm.

Table 16: Estimation of "Out of Range" SRS igniter resistance values.

Threshold (data: 73 tests)	Number of entries	N/A	under lower limit	above upper limit	Pass (test ok)	Number of valid values	Pass (test ok) [%]
SRS belt pretensioner igniter rear co-driver (Ohm)	24	11	1	2	10	13	76.9%
SRS belt pretensioner igniter rear driver (Ohm)	24	11	0	3	10	13	76.9%
SRS belt pretensioner igniter rear middle (Ohm)	13	11	0	2	0	2	0.0%
SRS belt pretensioner igniter front co-driver (Ohm)	67	1	0	2	64	66	97.0%
SRS belt pretensioner igniter front driver (Ohm)	67	1	0	2	64	66	97.0%
SRS airbag igniter (level 1) co-driver (Ohm)	71	3	2	1	65	68	95.6%
SRS airbag igniter (level 1) driver (Ohm)	72	4	0	0	68	68	100.0%
SRS airbag igniter (level 2) co-driver (Ohm)	46	8	0	5	33	38	86.8%
SRS airbag igniter (level 2) driver (Ohm)	48	7	0	6	35	41	85.4%
SRS knee airbag igniter front co-driver (Ohm)	12	11	0	1	0	1	0.0%
SRS knee airbag igniter front driver (Ohm)	26	10	0	3	13	16	81.3%
SRS head airbag igniter front co-driver (Ohm)	46	4	0	1	41	42	97.6%
SRS head airbag igniter front driver (Ohm)	47	3	0	1	43	44	97.7%
SRS side airbag igniter rear co-driver (Ohm)	14	11	0	0	3	3	100.0%
SRS side airbag igniter rear driver (Ohm)	15	12	0	0	3	3	100.0%

Threshold (data: 73 tests)	Number of entries	N/A	under lower limit	above upper limit	Pass (test ok)	Number of valid values	Pass (test ok) [%]
SRS side airbag igniter front co-driver (Ohm)	51	2	1	0	48	49	97-0%
SRS side airbag igniter front driver (Ohm)	42	2	0	1	39	40	97.5%

Based on the test data available, an analysis of the relationship between plausibility values and Diagnostic Trouble Codes was not sufficiently meaningful.

7.2.4 Results of level 3 tests

A Level 3 test was defined in Section 3.1 and consists mainly of combining ECSS information sent and received via the vehicle communication interface (VCI) with information and measurements received from external test equipment.

7.2.4.1 Potential failures identified by using thresholds for brake efficiency

Braking efficiency is described in Section 5.1.1.3. The definition of reference braking forces is the brake force of a wheel related to the associated brake hydraulic pressure being applied. Brake force distribution is defined as the ratio between front and rear axle braking forces at the wheels, generated at the same brake pressure. The reference braking values are available in Section 18, Annex 6, Table 30. These values are based on specific values and are made available for each vehicle individually by car manufacturers.

Using these values, the brake system can be assessed for

- Brake efficiency of each axle and
- Minimum braking force portions for individual axles (in accordance to constructive brake force distribution; not applicable for air braked vehicles)

The results of brake testing (module 1) were evaluated for 473 vehicles. With evaluation of the braking force distribution, 13 vehicles, (2.7 %) failed to reach the brake force distribution threshold.

Using threshold values specific for each vehicle about 1.5 % of the front axle and 1.9 % of the rear axle would fail the brake test (see Table 17).

Table 17: Detection of insufficient brake forces.

	Brake force distribution Front/ rear axle	Brake efficiency front axle (see Annex 6)	Brake efficiency rear axle (see Annex 6)
Number of tests	473	473	473
Ok (Pass)	460	466	464
Not Ok (Fail)	13	7	9
Ok (Pass) [%]	97.3	98.5	98.1
Not Ok (Fail) [%]	2.7	1.5	1.9

A vehicle has passed if all three criteria are fulfilled. A number of vehicles failed more than one criterion. Because of this overlap (i.e. some vehicles failed a number of criteria), effectively an additional failure rate of 4.8% was seen by application of the proposed new method, which includes enhanced inspection of brake efficiency.

Criteria for the brake efficiency were available for detailed analysis for 401 of the 473 tested vehicles (see Annex 6). For these vehicles, results are shown in figure 6 and 7. However, overall pass/fail results are shown in Table 17.

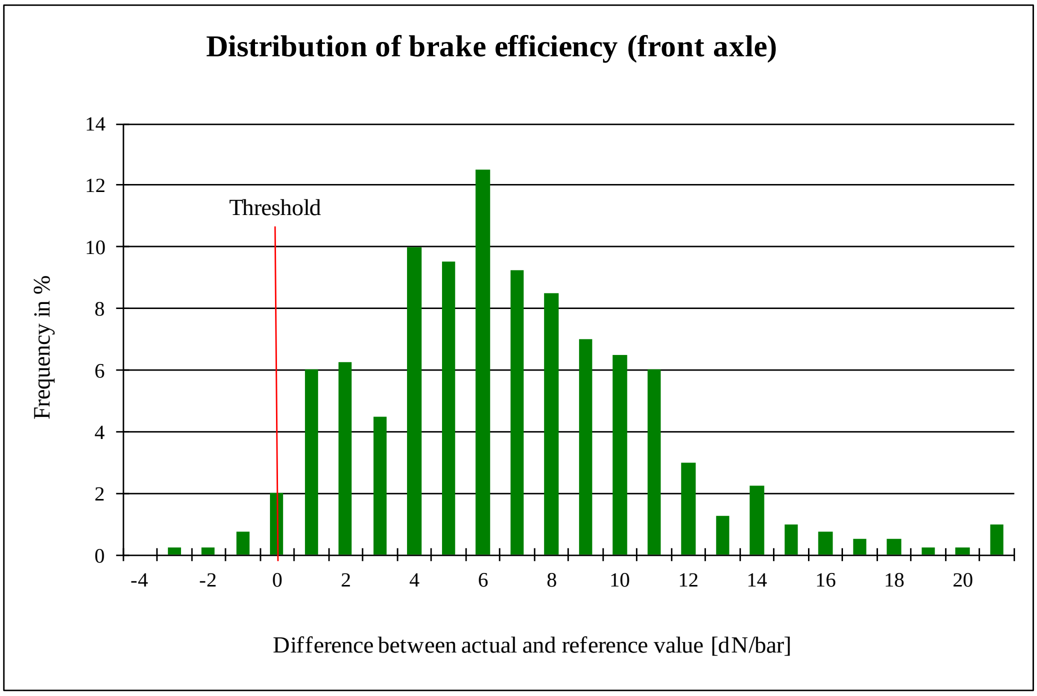


Figure 6: Frequency distribution of brake efficiency (front axle) of 401 vehicles

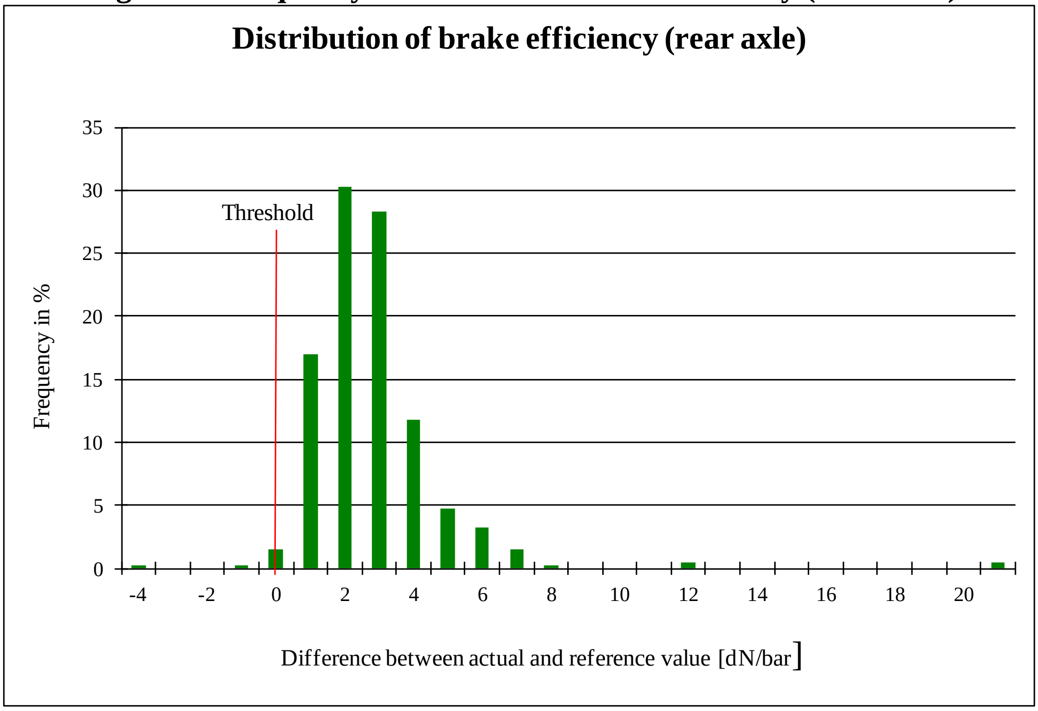


Figure 7: Frequency distribution of brake efficiency (rear axle) of 401 vehicles

Within 779 valid tests for ABS/ESC/EBS/(TPMS passive), braking pressure was read for 473 vehicles (FSD tool) and for 63 vehicles by different tools (Actia, AVL, Hella-Gutmann, Texa). Vehicles were tested with one tool only. For 243 vehicles (31%), hydraulic braking pressure could not be read. However, the FSD tool could read the hydraulic pressure for 94 % of the vehicles. From a technical point of view this should be possible for each tool if information from the VM is available.

7.3 Summary

Key points from Work Package 4 reported in this section are:

Methodology

1. The implementation of field tests at PTI centres in Germany (TÜV Rheinland), Sweden (Bilprovningen) and Belgium (GOCA) with the selected methods and tools.
2. The occurrence of problems with performing the field tests namely: an increase in the time required because of tool design, unfamiliarity with the vehicle architecture of some ECSS, the search ability of information in different ECUs, the obtaining of Actuator tests and real time values, the duration of vehicle identification or lack implementation of failures in customer cars due to liability issues.
3. The implementation of the following actions to perform a large number of tests: the performance of test drive in module 1 only in countries where this is mandatory for the PTI, the use of vehicles from dealer or staff of the PTI centres were used but no standard PTI test was performed, testing in parallel with additional test tools and testing of vehicles with implemented failures.

Results - Characteristics of data collected

1. A well distributed sample of vehicle makes (manufacturers) was collected. However Korean, French and Italian manufacturers were slightly under-represented.
2. No abnormality in the mileages of vehicles
3. Distribution of tests was spread on three Member States of the EU, in contrast to Belgium and Sweden the focus was set on Germany.
4. Distribution of the different tools for field tests was consistent regarding the different jobs. Some jobs were more accurate by certain tools, so for level 3 testing there was a focus on a tool especially developed for PTI while the rest was used accordingly. Some tools were not used for all types of ECSS.

Results – Level 1, 2 and 3

1. Level 1: Purged of nearly 50% of invalid tests, the tool vehicle coverage was in a range of 4 % (TPMS active) to 93 % (ABS/ESC/EBS/TPMS passive) depending on the type of ECSS checked.
2. Level 2:
    - Potential failures identified by DTCs:
      Expectation of possible failures ranged from 0.1 % (Lighting) to 2.6 % (ABS/ESC/EBS/TPMS passive) to 3.6 % (SRS); However, for integration into PTI standardization is necessary to, for example, be able to identify historic / deleted failures as well as failures resulting from low voltage of the supply system.
    - Potential failures identified by level 2a plausibility thresholds:

No conclusions on read-out values were possible because thresholds from the VMs were not available. However, for SRS systems thresholds were estimated for different types of SRS. 77 % to 100 % of the SRS modules were found to be within these limits.

- The plausibility between the results of a current PTI, the Diagnostic Trouble Codes and the read out values and their thresholds could not be evaluated and needs further justification and research.

3. Level 3: About 5% additional vehicles with problems related to brake efficiency and brake force distribution (front to rear axles) were detected using the new inspection method. Vehicles fitted with counterfeit brake pads, which did not offer the friction levels of manufacturer specified pads, were also detected.
4. Performance of tools used
   The average inspection times measured in the field tests for modules 1 to 3 were very high. This was because the majority of the tools were diagnostic tools and not developed for PTI. However, all of them showed potential to be improved and developed for PTI purposes. Inspection time should then be reduced substantially.

8 Final inspection methods, requirements for tools and information required from vehicle manufacturers for testing

8.1 Inspection methods

Inspection methods have been developed for the following ECSS:

- Braking system: ABS, ESC, EBS, EBA (otherwise called BAS)
- Steering system: EPS
- Tyre Pressure Monitoring System (TPMS)
- Supplementary Restraint System (SRS): Airbags, pre-tensioners, occupancy / belt sensors,
- Lights: automatic levelling and bending functions

Descriptions of the individual methods, including all the steps can be found in Section 5.1. The description of the methods used in an inspection centre environment during the field tests can be found in Section 17 Annex 5.

8.1.1 Recommendation for future legislative text revision

As the Directive 2014/45/EU refers in Annex II to an ‘electronic vehicle interface’ (also commonly known as a vehicle communication interface (VCI)) which shall be used to communicate with the electronically controlled safety systems, it is suggested to consider the following recommendation for any future revision of the European roadworthiness legislation for inclusion of the inspection methods developed in this project (Note that a possible approach for this could be amendment by the ‘Delegated Acts’ of Directive 2014/45/EU):

> An ‘electronic vehicle interface’ (also generically known as a vehicle communication interface (VCI)) shall be used to communicate with a vehicle’s electronically controlled safety systems.
> This interface will communicate with a PTI mode scan tool to support verification that the electronically controlled safety systems originally included in the vehicle at end-of-line or first registration are fitted and operational, before conducting an electronic control of the malfunction indicator lights followed by an assessment, actuation and control of the system’s components to provide system functionality tests, using additional test equipment where appropriate.
> The inspection method will use vehicle manufacturer technical information to support automatic and sequential vehicle system testing, using interactive communication with additional test equipment where appropriate.
> The vehicle manufacturer technical information (that is scheduled to be defined by ‘Implementing Acts’ in accordance with Art. 4(3) of Directive 2014/45/EU.) shall be provided in a standardized, machine readable format (e.g. ODX for technical information, OTX for test sequences), via a single point of access and will include the decision criteria, e.g. reference* and threshold values of the components, to support efficacy testing of the system.

*Vehicle manufacturers' information, including brake force reference values that support an enhanced brake system inspection method will be made available to all competent authorities, PTI test centres and test equipment manufacturers to ensure harmonised test methods.

8.2 Requirements for tools

PTI scan tools and their integration into the national or body specific PTI-systems need not necessarily follow a certain hardware architecture, but should be considered on their **functionality**. Possible solutions include:

- The vehicle communication interface (VCI) and the operating and display unit (ODU) can be integrated into one tool or a modular tool cluster (closed system).
- The VCI and the ODU can be separated hardware parts (connected with a cable or wirelessly).
- The VCI can be an optimized modular supplement to the already available PTI body computer hardware which would then represent the ODU (connected with a cable or wirelessly).

Therefore, a PTI scan tool, which is the basis for an objective assessment of the various vehicle electronically controlled safety systems (ECSS), is a solution which (in one or more hardware components) fulfils the following minimum functional requirements:

a) general

- Contains or have local real-time access to all relevant PTI test functions for the different ECSS of the various makes and models of vehicles.
- Relevant PTI information and test functions are stored in a secure form which is not externally accessible (e.g. encrypted).
- Operates in temperatures between -5 degrees C and +35 degrees C.
- Supports simple (and where necessary secure) software/firmware updating procedures
- Contains sufficient (preferably updateable) memory capacity (including RAM) to support various applications, including vehicle PTI test requirements, vehicle data (test and result), data configuration/reporting etc. (to be defined)
- Supports the capability to securely store test results and their subsequent transfer to an external storage device.

b) vehicle communication interface (VCI)

- The standardisation of the VCI interface (API) to the PTI test application to provide the widest choice of platforms
- Is capable of being powered by both the vehicle 16 pin connector and an internal/independent power source.
- Has a multiplexer to ensure immediate and flexible pin assignment for all types of vehicles.
- Can monitor the vehicle´s voltage to avoid under-voltage or adaption problems.
- Is able to meet the requirements of EN 60068-2-31 (2008) to withstand a drop of 1.0m onto a solid concrete surface.
- If separate from the operating and display unit, it may provide an extra display to provide relevant information for IT administration/support

- Is able to support commonly used standardised communication protocols (e.g. ISO 15765, SAE J1939, ISO 14229-X etc.)
- Supports communication with the vehicle through a standardised physical connection (ISO 15031-3 connector or other standardised connector for alternative standardised communication formats) or a standardised wireless connection.
- Can be operated when a vehicle inspector is wearing protective gloves.

c) operating and display unit (ODU)

- Includes a display that is readable in both sunlight and low light conditions, which is able to display the information necessary for PTI tests (e.g. at least 12 lines of text with 200 characters per line and be able to display graphics).
- Have sufficient memory and processing capability to support the test data and test method requirements, together with the storage of the test results and the secure transmission of these test results to an external facility.
- Be able to communicate with the VCI in a reliable and secure manner. If wireless communication is used, then an alternative physical connection must also be available.
- Is able to communicate bi-directionally with other PTI test equipment (e.g. brake tester or headlamp tester) to support automated and interactive ECSS functionality testing.

8.3 Information required from vehicle manufacturers

In PTI, vehicles are inspected in terms of the installation, condition, function, and the efficiency of its components and systems. For vehicles with electronically controlled safety systems (ECSS), these tests require additional vehicle manufacturer data/information concerning the assessment of these ECSS:

- A list of electronically controlled safety systems or -functions (ECSS) which are installed end-of-line (and identified by VIN or other unequivocal identification method), including hard and software variant/version of relevant ECUs together with any data/information necessary to identify and communicate with an ECU and its version/variant coding.
- Any data/information necessary to enable complete functionality testing (where appropriate), including any additional hardware or software protocol information (e.g. location of the diagnostic connector and connector details, voltage, physical bus type, transport protocols, diagnostic protocols).
- A list of all available live data parameters including scaling, interpretation, access information and criteria to assess deficiencies.
- A list of all available functional tests including device activation or control, the means to access them and the criteria to assess deficiencies and support efficacy testing.
- All details of how to obtain all component and status information and criteria to assess deficiencies.
- A description of tests to confirm ECSSs functionality, at the component or in the harness, and criteria to assess deficiencies and support efficacy testing.
- Specific on-board PTI procedures, including any automated or sequential system testing, to check the ECSS (if applicable), including a description and criteria to assess deficiencies and support efficacy testing.
- Proposals for PTI procedures using a PTI mode scan tool or other test equipment where appropriate, including a description, test parameters, component information and criteria to assess deficiencies and support efficacy testing.

- Vehicle manufacturer technical information shall include the threshold values of the system components to support efficacy testing.

The data/information shall be provided in a standardized, machine readable format (e.g. ODX for diagnostic information, OTX for test sequences) via a single point of access.

The data/information shall be provided for offline-usage by the VM, on a VIN-based access (for that purpose, VIN shall not be considered as a privacy information) or other unequivocal identification method.

For a detailed list of the technical information required from vehicle manufacturers to implement the test methods proposed in this project, including system components and functionality testing, please see Annex 7.

8.4 Summary

Key points reported in this section are:

- A description of the inspection methods developed suitable for recommendation for future revision of the EU roadworthiness legislation.
- A list of minimum requirements for a PTI mode scan tool to allow objective assessments of the various vehicle electronically controlled safety systems (ECSS) using the inspection methods developed. This should also help enable a competitive market for these tools.
- A generic list of the technical information required from vehicle manufacturers to enable inspection of vehicle electronically controlled safety systems (ECSS) using the inspection methods developed.

9 Cost Benefit Analysis

9.1 Methodology

9.1.1 The Assessment Method

The cost-benefit analysis (CBA) provides a sophisticated approach for evaluating the socio-economic impact of the introduction of new performance tests. The CBA allows the determination of the overall impact of the technology instead of a mere business related perspective. The CBA is chosen because it forms an objective methodological framework for the discussion of the impact.

Theoretically, the CBA is based on the approach of welfare economics which evaluates economic policies by estimating their effects on the society's well-being. Assessments in welfare economics follow the strict Pareto Criterion which claims that the introduction of a measure has to improve at least one individual's situation without worsen someone else's situation. This strict assumption however is hardly realizable as the identification of all winners and losers requires complete information about all stakeholders and how they are affected.

Consequently, the Hicks-Kaldor Criterion (HKC) loosens this strict condition and allows positive assessment of measures if the amount of gains that is generated for individuals, i.e. the society, exceeds the losses that have to be faced. By generating a net benefit, winners can compensate losers which does not necessarily have to be a cash transfer (Boardman, Greenberg, Vining, & Weimer, 1996, pp. 29-34)[9]. From this, we can derive the criterion that a measure is advantageous if the socio-economic benefits exceed the costs, i.e. if the benefit-cost ratio is bigger than 1.

In consequence, the benefit-cost ratio has been introduced for the socio-economic CBA which provides a reliable indicator for the cost-effectiveness of a measure. It helps to minimize costs and maximize the benefits and furthermore to avoid bad decisions or investments. The CBA assesses benefits in form of the saved costs and costs as a loss of benefit. The central question thus is whether resources can be saved.

The benefit-cost ratio is expressed as follows

$$BCR = \frac{\sum_{t=0}^{T-1} B_t (1+i)^{-t}}{\sum_{t=0}^{T-1} C_t \ (1+i)^{-t}}$$

With:

BCR:	benefit-cost ratio
t:	examination time period
B:	benefits
C:	costs
i:	interest rate

By distinguishing three grades of BCRs, the ratio comprehensively transports the information about the cost-effectiveness of projects:

0 < BCR < 1 poor ratio, socio-economic inefficiency

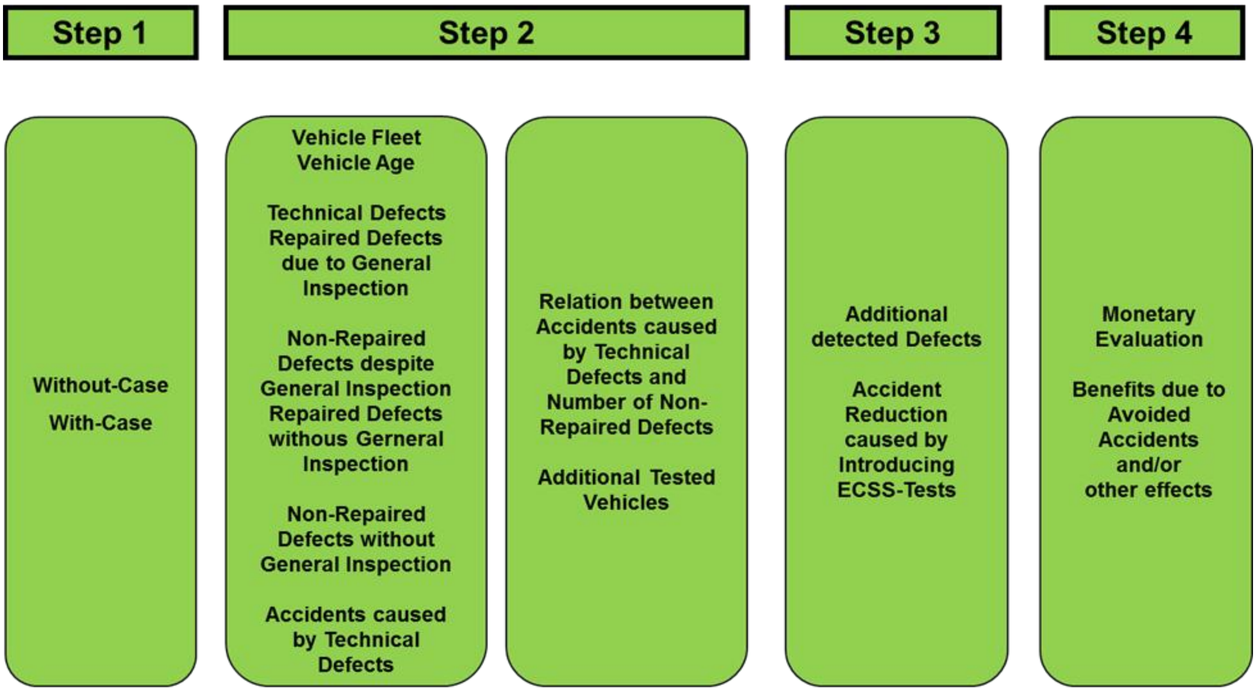
[9] Boardman, A. E., Greenberg, D. H., Vining, A. R., & Weimer, D. L. (1996). *Cost benefit analysis: Concepts and practice*. Upper Saddle River, NJ: Prentice Hall.

1 ≤ BCR < 3 acceptable ratio, positive net benefit
BCR ≥ 3 excellent ratio

9.1.2 Steps of the CBA

The cost-benefit analysis is based on a four-stage framework as illustrated in Table 10.

Table 18:Steps of the CBA



Source: Own illustration.

Step 1: Definition of the 'without' and 'with' cases.
We first define the current situation which is the current state of PTI in Europe. Thus, we have the 'without' case which is the situation in which the new technology has not yet been adapted. This means that additional defects in the ECSS are not detected by the PTI procedure.

Step 2: Identification of the relevant impact channels and definition of the parameters.
We now start the definition of the 'with' case which means the situation in which new PTI measures are applied. Therefore, vehicle data are obtained. For the calculation, we considered the vehicle fleet and vehicle age. Furthermore, causes and effects were identified and empirically determined. This allowed a quantification of the effects. Non-safety effects in this case are not considered because of the underlying input data. As safety effects, the following parameters are considered: technical defects of an ECSS detected due to a general inspection, non-repaired defects despite a general inspection, accidents caused by technical defects, ratio accidents caused by technical defects and number non-repaired defects, additionally tested vehicles.

Step 3: Quantification of the physical effects.
In this step, the previously defined cases ('without' and 'with') are calculated. The results reflect the quantified amount of resource changes. In this case, we quantified the number of additionally detected defects and the resulting reduction of accidents. On the cost side, relevant categories are

identified and quantified. We therefore include hardware and software cost. As the software cost are strongly influenced by further conditions (such as costs of access) a best case scenario (costs as low as possible) and a worst case (high costs) are calculated.

Step 4: Monetization of benefits and costs.
Whereas the previous step focused on a quantification of the physical effects, in this step monetary values are assigned to the quantities. Here, the typical cost/unit rates are applied.

Finalization: Calculation of a benefit-cost ratio.
This last step aims at comparison of the costs and benefits. For this purpose a ratio is formed that serves as a clear indicator for the effectiveness of the new test measure.

9.1.3 Methodological Validation

The economic CBA-model used here has been applied previously in the following projects:

HEATCO, Developing Harmonized European Approaches for Transport Costing and Project Assessment, Deliverable 2, State-of-the-art in project assessment (HEATCO, 2005).

SEiSS (Exploratory Study on the potential socio-economic impact of the introduction of Intelligent Safety Systems in Road Vehicles. Study for the Directorate-General Information Society) (SeiSS, 2006).

AUTOFORE (Study on the Future Options for Roadworthiness Enforcement in European Union, Study for the Directorate-General for Transport and Energy) (AUTOFORE, 2007).

eIMPACT (Assessing the Impacts of Intelligent Vehicle Safety Systems, Contract no: 027421, Sixth Framework Programme DG Information Society and Media) (eIMPACT, 2008a;2008b).

Handbook on estimation of external costs in the transport sector. Produced within the study Internalisation Measures and Policies for All external Cost of Transport (IMPACT), Version 1.1, Delft 2008 (Maibach 2007; 2008).

Ökonomische Bewertung von Umweltschäden, Methodenkonvention zur Schätzung externer Umweltkosten (UBA, 2007).

Directive 2009/33/EC on the promotion of clean and energy-efficient road transport vehicles.

Resulting from this experience and by basing this CBA on the same assumptions, it can be ensured that these results are comparable with other national and European projects.

9.1.4 Impact Channels

The introduction of the new performance tests allows checking the ECSSs which shall cause an increase in ex-ante defect detection rates. Vehicles thus become safer and more reliable.

Several socio-economic impact channels can be identified, categorizing them mainly into safety- and non-safety-critical effects.

The following figure gives an overview of both relevant impact channels

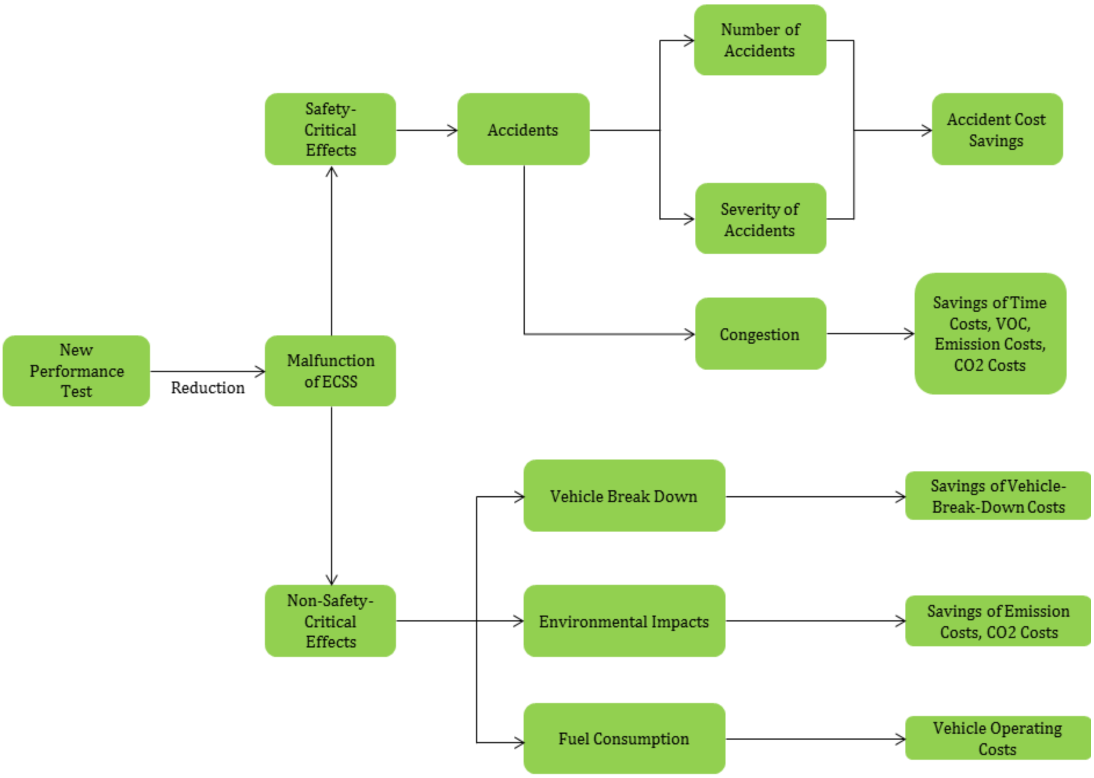


Figure 8: Impact Channels of New PTIs

Safety-critical effects in this case are marked by a direct impact channel. Accident risks are diminished by as the number of defects is reduced.
Non-safety critical effects have a rather indirect impact channel as an increase in the defect detection rate can affect vehicle breakdowns, congestion, emissions as well fuel consumption.

9.1.5 Data Limitations

The cost-benefit analysis faces some data limitations which have to be considered. In general, it has to be clear that the empirical knowledge with regard to the impact channels is limited. In consequence, not all potential beneficiary effects can be considered. In this project, we especially lack information on the non-safety-critical.

Empirical data for safety-critical effects were generated via field tests. The field tests however did not provide information on non-safety-critical effects. Already the AUTOFORE (2007)[10] study suggested that further field tests should focus more on the non-safety-critical effects. However, these kinds of data have not been generated yet. As significant benefits from this channel have to be expected, we use estimations and conclusions from other fields, such as ITS research. By forming analogies, we can simulate possible non-safety-critical effects and in consequence reduce the data limitations. Nevertheless, it has to be kept in mind that the safety-critical effects are based on a direct empirical basis which makes them more reliable and robust than the data on non-safety-critical effects that are merely based on analogies.

[10] AUTOFORE (2007). Study on the future options for roadworthiness enforcement in the European Union.

9.2 Input data generated by study (Own input data)

9.2.1 Change in inspection time for inclusion of proposed ECSS methods into today's PTI

As input for the Cost Benefit analysis, an initial estimation of the additional time needed for inclusion of the proposed methods into today's PTI was made by GOCA, Dekra, Bilprovningen and FSD based on experience gained in the field tests. These estimations were discussed in a telephone conference, where the participants agreed on a first estimation, which took into account that tools would be designed for the PTI and automated. Following this, the estimate was revised to take into account that inclusion of the ECSS inspection methods should also save time within steps of the today's PTI. The following time savings were estimated:

In today's current PTI, the braking ratio must reach 58% related to the maximum authorised mass. According to a survey by FSD, only ~60 % of passenger cars reach these figures under laboratory conditions when they are not loaded. Loading and unloading cars takes about 2 min if it is performed in an optimum manner. Using the ECSS inspection method with the reference braking values, the braking efficiency can be tested without loading / unloading the cars, so this time can be saved.
For the lighting, external control of the lighting functions using the PTI mode scan tool was estimated to save the inspector about 10 sec minimum compared to doing it by hand as in today's PTI.
Taking these time savings into account, leads to an overall time saving of 20 sec for the inclusion of the proposed methods into a standard PTI according to 2010/48/EU. In fact, even further time reduction seems probable by fully integrating the ECSS test steps into today´s PTI (e.g. by using predetermined motion time system PMTS). The details and justifications of the time estimations for each step of the additional ECSS methods are shown in Annex 8.

On the basis of this estimate and the fact that in some countries in Europe (e.g. Belgium, UK) the car is not loaded and unloaded in today's PTI, it was decided to perform the cost benefit analysis with the following two addition inspection times (labour costs):

- Zero: This should represent the most likely outcome because in Directive 2014/45/EU it states in point 1.2.2 regarding braking efficiency that, 'Test with a brake tester ..... to establish the braking ratio which relates to the maximum authorised mass'. This will require loading and unloading of some M_1 vehicles. Therefore, because loading / unloading vehicles will be mandatory in Europe shortly, when this Directive is implemented, the fact that by using the ECSS test enables the braking efficiency to be tested without loading and unloading some vehicles represents a time saving for all countries relative to Directive 2014/45/EU.
- 2 minutes: This represents the additional time in comparison to the current PTI in countries that do not load and unload vehicles for brake efficiency testing at present.

9.2.2 Defect and detection rates

Estimates of defect and detection rates were required for the cost benefit analysis. Two detection rates were required, namely the current detection rate and the new (increased) detection rate following the introduction of the proposed methods. It was the increase in the detection rate and associated number of defects that will be detected that was used as the basis to calculate the benefit of the introduction of the proposed methods.

Defect rates were obtained from measured defect rates from year 2013 and referred to as baseline in Table 11. Detection rates were estimated as follows. The current detection rate was estimated using expert judgement based on the knowledge of what defects the current PTI test is capable of detecting and what proportion these are of all possible defects. This was performed for each major safety system (i.e. brakes, steering and lighting) by building up from the sub-systems, e.g. brakes, pad/disc efficiency and electronic safety sub-systems ABS, ESC. For example, in current PTI brake pads are checked visually and information about the brake forces measured by the RBT. Detailed information about the efficiency of pad and disk is currently not available. Because of this lack of information the effectiveness of detection was estimated to be about 85 %. With the new test method additional information about the ratio between hydraulic brake pressure and brake force will be available and hence a 10 % increase in detection rate was estimated. Another example is for brakes, electronic sub-systems such as ABS and ESC. For electronic sub-systems the current PTI inspection only performs a visual inspection of components and checks the MIL. On this basis, the effectiveness of detection for the current PTI was estimated to be low at 50 %. With the new inspection method information from the VCI like status and values will be available, so an increase of 40 % in effectiveness of detection was estimated.

The defect and detection rate estimates made by system and sub-system are shown in Table 19 below.

Table 19: Measured and estimated defect and detection rates by system / sub-system for cost benefit analysis.

Type of technical defect	Electronically Controlled Safety System (ECSS)	Base-line (Measured defect rate)	Estimated effectiveness of detection	Increased effectiveness of detection by new test method
BRAKE		20,57%	83%	11%
BRAKE DRUMS / BRAKE DISKS	Anti-lock Braking System (ABS) Electronic Stability Control (ESC) Brake Assist System (BAS) sometimes called Emergency Brake Assist (EBA) Electronic Braking System (EBS)	3,70%	85%	10%
BRAKE HOSES		2,68%	85%	5%
BRAKE LINES		2,49%	85%	5%
BRAKE PADS		2,11%	85%	10%
SERVICE BRAKE		2,00%	85%	10%
PARKING BRAKING		1,98%	85%	10%
ABS-WARNING LIGHT		0,16%	100%	0%
ELECTRONIC SAFETY COMP.		0,08%	50%	40%
OTHERS		5,37%		
STEERING		3,16%	78%	8%

Type of technical defect	Electronically Controlled Safety System (ECSS)	Base-line (Measured defect rate)	Estimated effectiveness of detection	Increased effectiveness of detection by new test method
PUSH RODS / TRACK RODS	Electronic Power Steering (EPS)	1,98%	85%	0%
STEERING GEAR / STEERING SYSTEM – GAITER		0,43%	85%	0%
POWER STEERING / HYDRAULIC PIPES		0,36%	85%	0%
STEERING GEAR		0,15%	85%	0%
ELECTRONIC SAFETY COMP.		0,03%	50%	40%
OTHERS		0,21%		
LIGHTING		27,87%	86%	8%
LOW BEAM HEADLIGHT	Headlight Control Systems	8,61%	95%	0%
NUMBER PLATE LAMPS		4,56%	95%	0%
ADDITIONAL HEADLIGHTS (FOG-;		3,30%	95%	0%
SIDE LIGHTS / PARKING LAMPS / DAYTIME RUNNING LIGHTS		2,98%	95%	0%
ELECTRONIC SAFETY COMP.		0,03%	50%	40%
OTHERS		8,42%		
AXLES, TYRES		13,82%	77%	8%
AXLE – AXLE MOUNTING	Tyre Pressure Monitoring System (TPMS)	4,84%	90%	0%
AXLE – SUSPENSION / ANTI-ROLL-BAR		3,36%	90%	0%
AXLE – SHOCK ABSORBERS		1,12%	60%	0%
TYRES – SIZE / TYPE / LABEL		1,08%	95%	0%
ELECTRONIC SAFETY COMP.		0,01%	50%	40%
OTHERS		3,41%		
OTHER EQUIPMENT		2,38%	58%	22%
WARNING TRIANGLE / WARNING LAMPS / FIRST AID BOX	Supplementary Restraint System (SRS)	1,39%	95%	0%
SAFETY BELTS, SRS SYSTEMS		0,60%	60%	30%
SIGNAL HORN		0,22%	95%	0%
DRIVABILITY SYSTEMS WITH BRAKE/STEERING CONTROL		0,07%	20%	40%
ELECTRONIC SAFETY COMP.		0,02%	20%	40%

9.2.3 Equipment costs

The cost of the PTI scan tools includes three key aspects:

9.2.3.1 Hardware costs of the scan tool.

There are a variety of generic or bespoke platforms which could be used to meet the requirements for the test tools defined in section 8.2 to provide the PTI test functionality, together with the interface with both the test inspector and other PTI test equipment requirements. Focusing only on the lowest cost may not provide the best match to these requirements, as robustness, reliability and longevity are also important within the PTI test environment. Therefore the cost of 300 Euros is based on a platform that meets the requirements defined in section 8.2, whilst fulfilling the practical demands of the PTI working environment.

9.2.3.2 Vehicle communication interface (VCI).

The proposal for the vehicle communication interface is based on existing diagnostic tool interfaces, which provide the required communication functionality, without the need to design a dedicated PTI solution. This avoids additional development costs, whilst maintaining proven functionality and compliance with existing vehicle communication standards. Although there may be some additional firmware costs, which will be determined by the specific implementation of the test methods using vehicle manufacturer technical information, the indicated cost of 600 Euros provides a proven, flexible and practical solution.

9.2.3.3 Vehicle manufacturer's technical information

The cost of acquiring and processing PTI technical information is the greatest variable related to the PTI scan tool. It is therefore critical that the format and structure of the data, as well as the access and cost of acquiring this PTI technical information is defined, preferably in the legislation. Note that work is currently ongoing to define these data and their format following the Implementing Acts in accordance with Art. 4(3) of Directive 2014/45/EU.
Although vehicle manufacturer PTI technical information may be as simple as a single threshold value (e.g. the 'plate value' for diesel emissions), to support automated and interactive ECSS testing much greater depth and width of data is needed. This data must also be compatible with the PTI mode scan tool at the point of conducting the roadworthiness test, so significant detailed definitions will be required to ensure accurate information is accessible by VIN, or other unequivocal identification method. The vehicle manufacturers are the only source of this information, therefore, the cost of acquiring, processing, implementing and using this vehicle manufacturer information for testing the ECSS must be controlled to avoid high software costs as part of the PTI mode scan tool.

Exactly what form these data will be supplied in is unknown at present although it is intended that they should be supplied in a standardised data format that requires no or little additional processing. Note that work is currently ongoing to define these data and their format following the Implementing Acts in accordance with Art. 4(3) of Directive 2014/45/EU. To account for this uncertainty, the following two costs for software were derived:

- Optimistic: assume data supplied in format which requires no or little additional processing, i.e. it was assumed that the vehicle manufacturers' data will be made

available in a pre-defined, machine readable format, with standardised data content and structure that requires minimum subsequent processing to support PTI testing of a vehicle's ECSS and will be made easily available to test equipment manufacturers or competent authorities at the lowest possible cost.
Estimate 250 Euro per year.

- Pessimistic: assume data supplied in a format which requires significant processing and is charged for, i.e. it was assumed that vehicle manufacturers' data will be made available in a similar way and cost as for non-standardised repair and maintenance information under the (EC) No 715/2007 Euro 5 Regulation for test equipment manufacturers.
Estimate 1,225 Euro per year

9.2.3.4 Summary of total equipment costs

Table 20 below summarises annual equipment costs assuming an amortization period of five years for the hardware and VCI costs.

Table 20: Summary of total equipment costs

Equipment	**Cost (Euro)**	**Annual cost (Euro)**	
Scan tool hardware	300	60	
Vehicle communication interface (VCI)	600	120	
Software (VM technical information)		250	1,225
Total		**430**	**1,405**

9.3 The Calculation Model

9.3.1 The Model

The general calculation process is undertaken for the time horizon from 2015 up to 2030. This means annual benefits and annual costs are derived. The annual view is important because dynamic effects have to be considered, which indeed will have an important impact on the amount of the BCR. Dynamic effects can be assumed because of following facts:

- The starting equipment ratios of passenger cars with ECSS in the year 2015 are different. Even TPMS and EBA will not reach in the 2030 an equipment ratio, which is higher than 90 percent. The potential benefits therefore will be higher over time with rising equipment ratios for ECSS.

- A five-year dynamic effect is introduced on the cost-side because of taxation. The annual software costs are so high that the used software is a commercial good, which can be amortized over five years. That means that the annual costs reach their maximum value in the fifth year. That is still an economic advantage which is a little similar to the well-known capacity effect of depreciation (Bebel & Bernstein, 1958; Schneider, 1992)[11]

Starting point is the passenger car stock for EU28. Based on the AUTOFORE-model the annual number of inspected passenger cars is derived for the starting year 2015. As a general assumption the growth of vehicle stock is assumed to be 2 percent per year.

Generally, the light grey shaded boxes indicate that empirical values are used to enable the next calculation step. Knowing the number of inspected passenger cars per year under the information on the equipment ratios for each system over the time period from 2015 to 2030 it is possible to calculate the defect rates. The systems at this stage can be matched to the accident relevant categories (brake-, steering-, lighting- and tyre- system).

The dark grey shadedboxes indicate empirical results derived by the field tests of the ECSS-study. The overall effectiveness of PTI is increased. That leads to an additional number of detected passenger cars with defects. Based on German study empirical relations are given which allow the calculation of avoided fatalities, avoided injuries and avoided congestions due to the additional detected passenger cars with defects.

The AUTOFORE-study pinpointed the general lack of empirical data in the fields of technical defects. However, the DEKRA study (Schulz & Schuldenzucker, 2010) provided the missing information on the relation between detected defects and reachable safety benefits for reducing the number of accidents. However, empirical relations are still missing for the effect on the accident severity. This means that accident severity as an essential effect cannot be included in the calculation. As a result, the accident effects are underestimated in the cost-benefit analyses performed in this study because of this lack of data, i.e. estimated accident effects < real accident effects.

This main benefit field represents the non-safety effects, which can be reached by a significantly increased effectiveness of PTI by ECSS. For this reason this study tries like other studies (All Ways Travelling) a guess on the non-safety critical benefits by using following relations (Conference of European Directors of Roads (CEDR), 2012)[12].

- Time cost savings per accident cost savings,
- Emission cost savings per accident cost savings,
- Vehicle operating cost savings per accident cost savings.

At the end there is a more complete picture on the potential benefits by ECSS. On the cost side it is important to consider that the total amount of additional costs is determined always by the

[11] Bebel, A., & Bernstein, E. (1958). Der Briefwechsel zwischen Friedrich Engels und Karl Marx, 1844-1883. *Zeitschrift für handelswissenschaftliche Forschung, 10*(1913).
Schneider, D. (1992). *Investition, Finanzierung und Besteuerung*. Wiesbaden.

[12] Conference of European Directors of Roads (CEDR). (2012). *Meeting of the Amsterdam Group (ASECAP CEDR POLIS C2C-CC), 19. April 2012, Task 7: Business models, cost-benefit analysis*.

whole number of inspected passenger cars. The amount of the costs is independent from the number of detected effects.

The following illustration pictures the calculation model and summarizes the included effects.

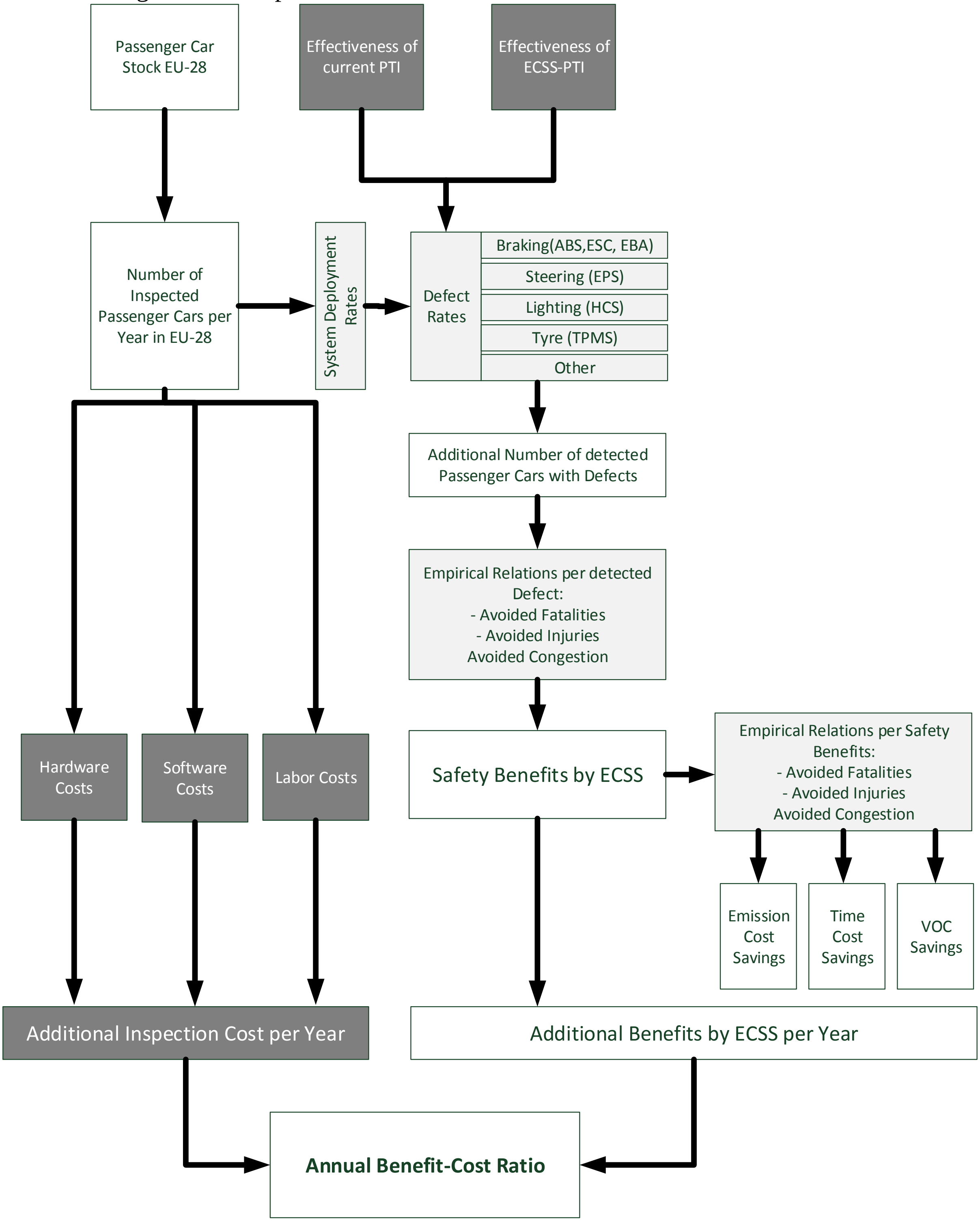


Figure 9: The Calculation Model

Source: Own illustration.

9.3.2 The Variables and Applied Cost-Unit Rates

This chapter presents the basic assumptions, the relevant variables, the applied cost-unit rates and the respective databases.

Variable	Source	Explanation
Inspected vehicles	AUTOFORE (2007)[13]	
Defect rate per system	Own field tests.	
Effectiveness current PTI per system	Own field tests.	
Effectiveness new PTI per system	Own field tests.	
Share of fatal accidents caused per ECSS	Schulz and Schuldenzucker (2010)[14].	
Share of accidents with injuries caused per ECSS	Schulz and Schuldenzucker (2010).	
Share of accidents with property damage per ECSS	Schulz and Schuldenzucker (2010).	
Cost-unit-rate	European Commission (2003)[15]	
Accident relevance per system	European Commission (2003)	
Emission cost	European Commission (2003)	
Time cost	European Commission (2003)	
Vehicle operation cost	European Commission (2003)	
Software costs	Own estimations.	
Hardware costs	Own estimations.	
Sales tax (European average)	European Commission (2014)[16].	
Average profit rate	Own estimation.	
Return on sales hardware	Own estimation.	
Return on sales software	Own estimation.	

Source: Own table.

Number of inspected vehicles

A central variable is the **number of inspected vehicles** that profit from the new PTI. The derivation of this variable is based on the AUTOFORE (2007) study. Assuming an annual growth rate of 2% (i.e. 1.02) the starting year is 2010 with 71 million passenger cars.

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[13] AUTOFORE. (2007). Study on the future options for roadworthiness enforcement in the European Union.

[14] Schulz, W. H., & Schuldenzucker, U. (2010). Gesamtwirtschaftliche Nutzen-Kosten Analyse für die Hauptuntersuchung bei Pkw, Studie für Dekra e.V., . Köln.

[15] European Commission. (2003). Proposal for a Directive of the European Parliament and of the Council Amending Directive 1999/62/EC on the Charging of Heavy Goods Vehicles for the Use of Certain Infrastructure.

[16] European Commission. (2014). Die Mehrwertsteuersätze in den Mitgliedstaaten der Europäischen Union. Brussels.

From the total number of inspected vehicles, the specific numbers of vehicles that are equipped with an ECSS have to be estimated.

*Number of inspected cars per ECSS = total_number_inspected_vehicles*equipment_rate (per ECSS)*

The total number of inspected vehicles depends on European and national regulatory conditions with regard to the periodic vehicle inspections. Consequently, an increase in the periodicity of test cycles directly affects the number of vehicles inspected. A higher inspection rate leads to a higher detection rate which in turn reduces the number of vehicle defects.

Accident effects

The calculation of the **accident effects** (including avoided fatalities, severe injuries, slight injuries as well as property damage) can only be conducted if an empirical relation between the number of accidents and the respective accident causalities can be proven and estimated. The following table gives a summary of the number of accidents (according type of accident) and the accident causality.
The effects as shown in the following table are also weighted with the share of urban and non-urban roads (European Commission, 2013).

Table 21: Weighted accident effects

	Fatalities	Injuries	Property Damage
Lighting	0.00022559	0.00015829	0.00011839
Tyre	0.00496945	0.00351381	0.00355712
Brake	0.00077785	0.00090394	0.00068293
Steering	0.00088188	0.00166169	0.00122935

Source: Schulz and Schuldenzucker 2010

By transforming the accident effects into monetary values, a clear structure of the benefits can be given that shows the benefits caused by a reduction of accidents resulting from a defect in an ECSS.

Cost-unit rates

At this step, the application of cost-unit rates is required. In order to include price increases the cost-unit rates are weighted with the inflation rate until 2015. The following table summarizes the applied cost-unit rates.

Table 22: Cost-Unit Rates for Accident Effects

Accident effect	Cost-Unit Rate in €
Fatalities	1,317,593 €
Severe injuries	163412 €
Slight injuries	21420 €
Injuries	92416 €
Property damage	6132 €
Congestion fatalities	18,513 €

Accident effect	Cost-Unit Rate in €
Congestion injuries	5,971 €
Congestion properties	1,195 €

Source: European Commission (2003 and 2013), own calculations.

Based on the analysis of Schulz and Schuldenzucker (2010) each accident effect to a certain share caused by one of our ECSS as shown in the next table(exemplar for fatal accidents).

Table 23: Accident Causality

Accident causality	Share	
Brake ECSS total	0.00077785	relation
ABS	0.00019446	relation
ESC	0.00019446	relation
EBA	0.00019446	relation
EBS	0.00019446	relation
Steering EPS	0.00088188	relation
Lighting HCS	0.00022559	relation
Tyre TPMS	0.00496945	relation
Other	0.00039693	relation

Source: Schulz and Schuldenzucker (2010)

Effectiveness of the new PTI

In order to create a without and with scenario, it is necessary to know whether and how the application of new PTI technology would actually increase the roadworthiness test effectiveness. Field tests have shown that the number of detected defects at one of the ECSSs significantly increases for all systems.

Table 24: Overview of the effectiveness

System	Detection Rate old	Detection Rate new	Effectiveness Δ
Brake ECSS total	0.5000	0.9000	+0.4
ABS	0.125	0.225	+0.1
ESC	0.125	0.225	+0.1
EBA	0.125	0.225	+0.1
EBS	0.125	0.225	+0.1
Steering EPS	0.5000	0.9000	+0.4
Lighting HCS	0.5000	0.9000	+0.4
Tyre TPMS	0.5000	0.9000	+0.4
Other	0.2000	0.6000	+0.4

Source: ECSS study estimations (see Section 9.2.2).

The results clearly show that the new methods lead to a significant increase in the detection rate. Whereas the traditional PTI only detected 50% of the braking system defects of ABS, ESC; EBA and EBS, the new system leads to an increase of 40 percentage points to a detection rate of 90%.

Cost calculation

Cost estimations include hardware costs that are amortized over 5 years and software costs. For the software cost a best and a worst case are assumed. This scenario approach is useful in order to overcome the uncertainty with regard to the software cost development.

Scenario 1 is based on the European Commission's Directive 2014/45/EU which claims:
"The technical information referred to in point (a) of the first subparagraph shall be made available, free of charge or at a reasonable price, by the manufacturers to testing centres and relevant competent authorities, in a non-discriminatory manner."
Therefore to ensure minimum costs, the vehicle manufacturers should provide the technical information required for the analysis of the OBD data and the functionality testing of a vehicle's electronically controlled safety systems (ECSS). The technical information required for the functionality testing should be provided in a defined data format and structure and which matches the defined requirements in the PTI test tool.

Scenario 1 will therefore support the lowest cost of provision and implementation for ECSS testing (annual software costs of 250 €).

Scenario 2 assumes that the vehicle manufacturers provide the technical information to the test equipment manufacturers or PTI test centres in a similar manner as in the Euro 5 Regulation (EC) N°715/2007. The technical information is provided under a B2B contract and is in a non-standardised format which requires further processing to create the application required for the analysis of the OBD data and the functionality testing of a vehicle's electronically controlled safety systems (ECSS). Scenario 2 therefore imposes high and on-going software costs for the test equipment manufacturers and PTI test centres (annual software costs of 1,225 €).

Sales tax rate

Profit rates and taxes may not be included in a cost-benefit analysis as taxes are a cost on the one side and a benefit on the other side. A similar logic is applied for profit rates. This is why we reduce the hardware and software cost by a European average sales tax and an assumed average profit rate.

Table 25: Sales Tax Rate per European Country

MEMBER STATE	SALES TAX RATE
Belgium	21%
Bulgaria	20%
Denmark	25%
Germany	19%
Estonia	20%
Finland	24%
France	20%

MEMBER STATE	SALES TAX RATE
Greece	23%
Croatia	25%
Ireland	23%
Italy	22%
Latvia	21%
Lithuania	21%
Luxembourg	15%
Hungary	27%
Malta	18%
Netherlands	21%
Austria	20%
Poland	23%
Portugal	23%
Romania	24%
Sweden	25%
Slovenia	22%
Slovak Republic	20%
Spain	21%
Czech Republic	21%
United Kingdom	20%
Cyprus	19%
AVERAGE	22%

Source: European Commission (2014)

9.4 Results

The calculation started with the simulation of the equipment ratios in order to get an idea of the number of vehicles expected to be inspected. This number is important for clear picture of the importance of the new PTI. Based on the algorithm that is also used for the estimation of equipment ratios in the project DRIVE C2X.

For all systems, an increasing equipment rate is expected to increase. We however expect the rate to remain smaller than 100% as there will also be a certain share of vehicles not equipped with the respective technology, such as old-timers.

Table 26: Estimated equipment rate per system based on the DRIVE C2X algorithm

Year	ABS	ESC	BAS/EBA	EBS	EPS	HCS	TPMS
2010	0.87011236	0.3	0.0106	0.011909117	0.67557449	0.11878788	0.01213737
2011	0.88	0.4	0.0106	0.018465389	0.78042976	0.14000000	0.01547833
2012	0.89	0.50	0.02	0.028506787	0.86661292	0.16500000	0.0188193
2013	0.94997386	0.60	0.03	0.043746991	0.93262371	0.18052179	0.02393622
2014	0.97111136	0.70	0.04	0.066573602	0.98048046	0.21013599	0.02905315
2015	0.98527045	0.78	0.06	0.1	0.98048046	0.29188205	0.0368193
2016	0.99437273	0.83	0.09	0.147463175	0.98048046	0.38883558	0.04458545
2017	0.9943727	0.88	0.13	0.211918745	0.98048046	0.49398949	0.0562175
2018	0.9943727	0.91	0.19	0.294358333	0.98048046	0.59753960	0.06784955
2019	0.9943727	0.93	0.26	0.392134399	0.98048046	0.69028316	0.08488307
2020	0.9943727	0.94	0.35	0.498180418	0.98048046	0.76651139	0.1019166
2021	0.9943727	0.95	0.44	0.602609031	0.98048046	0.82489735	0.12610303
2022	0.9943727	0.97	0.54	0.696139405	0.98048046	0.86722621	0.15028945
2023	0.9943727	0.97	0.62	0.773014345	0.98048046	0.89669604	0.18313491
2024	0.9943727	0.97	0.69	0.831895639	0.98048046	0.91664807	0.21598038
2025	0.9943727	0.97	0.74	0.874583614	0.98048046	0.93001307	0.25799019
2026	0.9943727	0.97	0.78	0.904303456	0.98048046	0.93860486	0.3
2027	0.9943727	0.97	0.80	0.924424762	0.98048046	0.95464286	0.34982502
2028	0.9943727	0.97	0.82	0.937903148	0.98048046	0.95464286	0.39965004
2029	0.9943727	0.97	0.83	0.946567825	0.98048046	0.95464286	0.45368929
2030	0.9943727	0.97	0.84	0.962741889	0.98048046	0.95464286	0.50772854

Source: Own calculation.

The equipment ratios served as a reliable basis for the calculation of the inspected vehicles over time. Clearly, the number of inspected vehicles increases with the equipment rate. The field tests have shown that the effectiveness of the PTI significantly increases by the application of the new technology. Based on these field test data and the number of inspected vehicles between 2010 and 2030, we were able to calculate the number of avoided fatalities, injuries and property damages. We find slight increases per year. A weighting with the cost-unit rates already shows the benefits resulting from less fatalities/injuries/property damage. The estimated development is shown in the following figure.

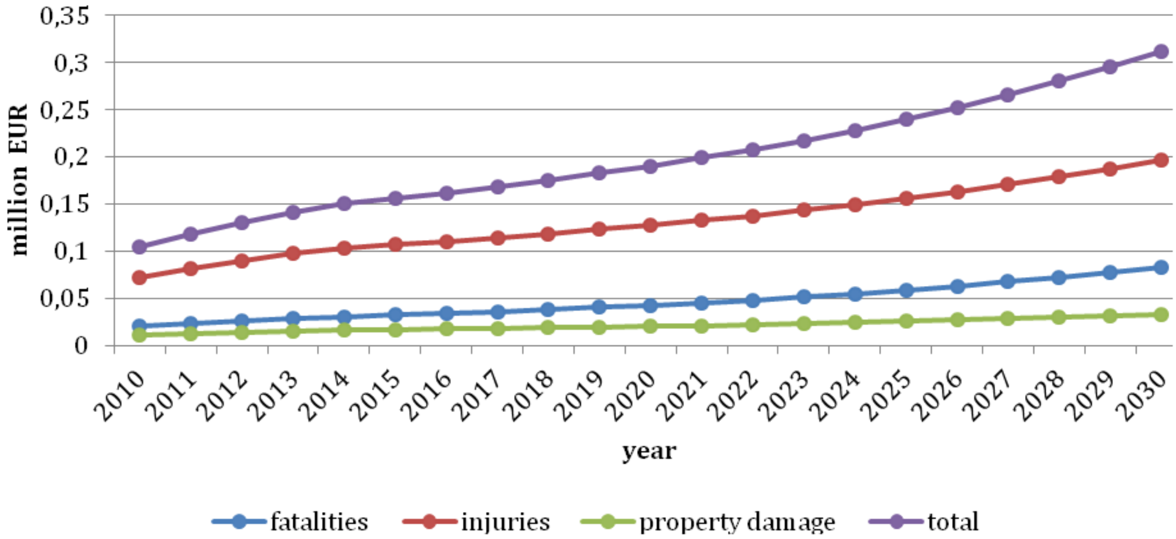


Figure 10: Estimated development of the benefits caused by a reduction in congestion per effect

Source: Own calculation.

A clear positive effect on the accident effect development can be assumed by the introduction of the new PTI technology that allows the additional detection of defects in the ECSSs.

The benefits significantly increase when adding up the benefits of decreased accident effects themselves. This brings us to a benefit development that follows the graph in the next figure.

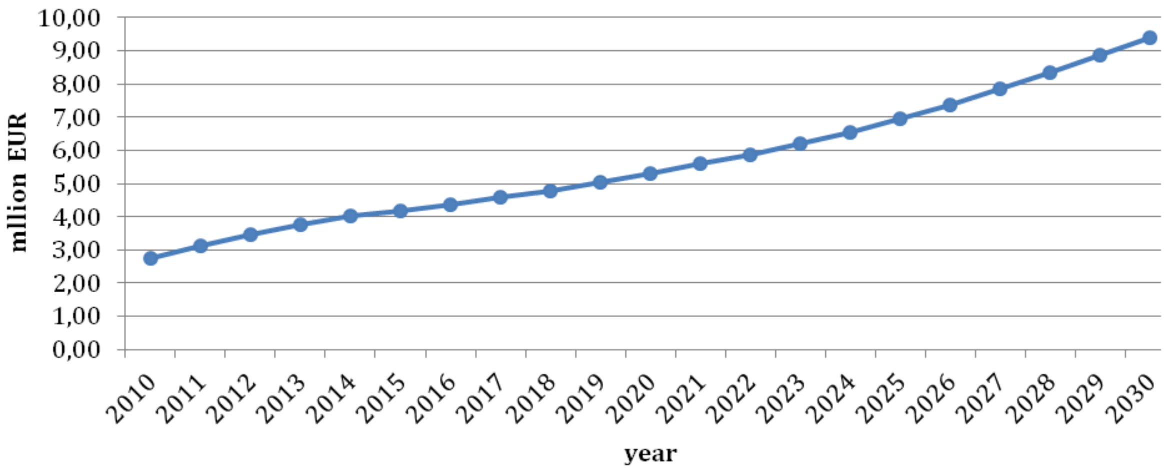


Figure 11: Estimated development of the benefits due to safety effects

Source: Own calculation.

On the benefit side furthermore reductions in emissions, time (e.g. due to less congestion) and vehicle operating costs were considered following the analysis used in the project All Ways Travelling (Eisenkopf et al., 2014)[17].

[17] Eisenkopf, A., Geis, I., Haas, C. A., Enkel, E., Kenning, P., & Jochum, G. (2014). All Ways Travelling

On the cost side we considered two scenarios as described in the previous chapter (assuming lower software costs of 250 EUR and higher costs of 1,225 EUR per year). The hardware costs remained constant in both cases 900 EUR in total and 180 EUR per year (amortization over 5 years).

Also for the software costs, we applied an amortization as the software is rather expensive which allows application of the rules of commodities. Therefore, an amortization of 5 years is applied to the software costs. This leads in turn to reduced software costs in the first five years of market introduction.

Additionally, the labour costs have to be considered. Estimates made show that either zero or 2 minutes additional inspection time will be needed for the ECSS tests depending on whether or not time saving can be made in the brake testing in today's standard PTI (see Section 9.2.1) The ratio of benefits and costs with the consideration of additional labour costs is shown in the following figure. We see that in both cases (Scenario 1 – low software costs and scenario 2 – high software costs) that although the BCR remains above 1 at all times, it drops to 1.26 in 2019 for the pessimistic case but increases in later years.

For the optimistic case in which the software costs are lower, the lowest BCR is 2.35.

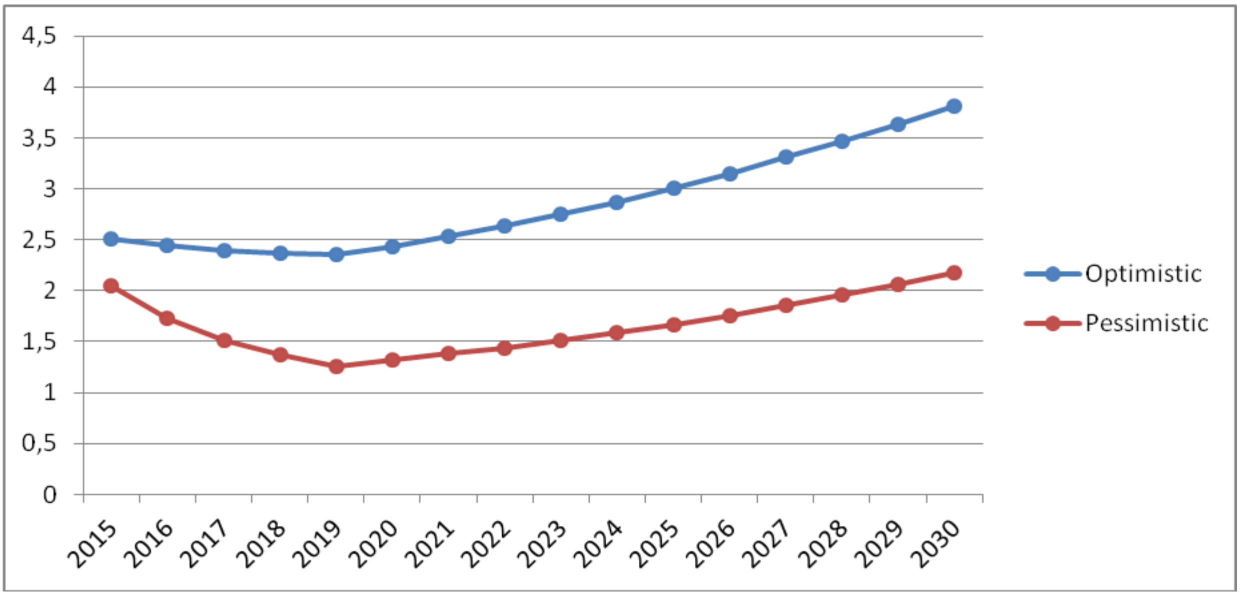


Figure 12: Benefit-Cost Ratio with additional labour costs (2 mins additional time).
Source: Own calculation

A further scenario considered and calculated which assumes that no additional labour costs occur. This assumption also has its authorization and may not be underestimated in its weight. The introduction of a new technology might first take more time, however, on the long run we usually find learning effects that can now not be captured within the field tests. However, the occurrence of these learning effects could lead to a clear reduction of additional time needed. This effect could furthermore be strengthened by the fact that new technology might lead to network effects at other stages of the PTI such that the additional time is decreased by reducing the current PTI time and thus compensates potential additional time for the ECSS check. This is why we conducted an analysis excluding the additional labour costs.

The following figure shows that development of the BCR. It is remarkable that the BCR now significantly improves. In the pessimistic case (high software costs) the lowest BCR over time is at 1.97 but again increases afterwards and passes the limit of 3 (excellent BCR) in 2028. In an optimistic case the BCR moves within an excellent BCR at any time.

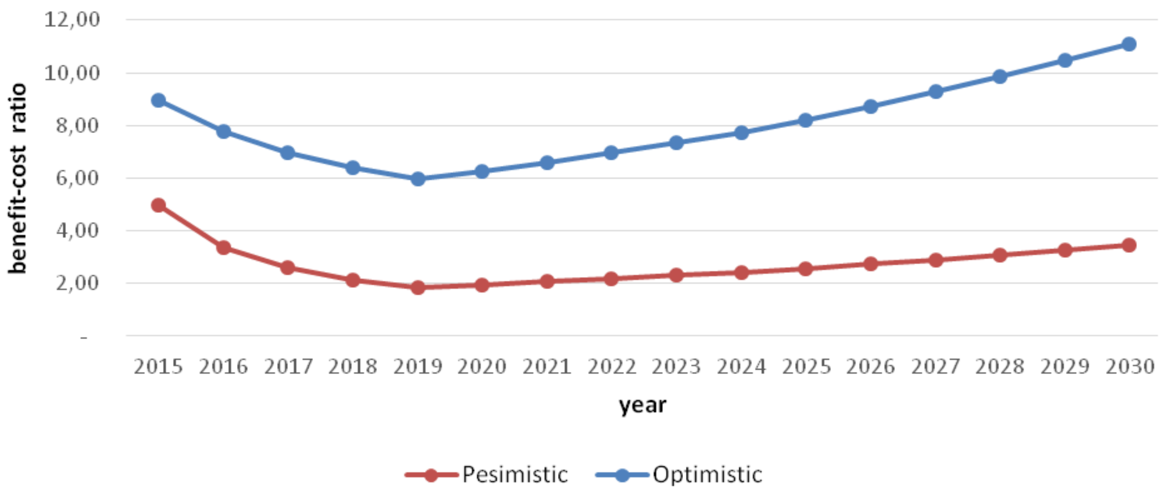


Figure 13: Benefit-Cost Ratio without additional labour costs

Source: Own calculation.

The calculations make clear that the introduction of a new PTI comes along with important benefits especially for safety effects. However, the costs lay an important role and always impact the benefits. Therefore, it is undisputable that the costs have to be carefully kept in mind and kept as low as possible.

9.5 Summary

The benefit to cost ratio (BCR) was calculated for the introduction of the ECSS inspection methods developed in this study into today's standard PTI, namely braking (ABS, ESC, EBA, EBS), steering (EPS), tyres (TPMS), lighting (automatic levelling and bending) and the supplementary restraint system (SRS).

The calculation used a socio-economic model which evaluated both safety and non-safety critical impact channels. The safety critical channels evaluated the effect of the proposed measures on accidents whereas the non-safety critical effects evaluated the effect on items such as the environment and fuel consumption.

A number of calculations were performed because of uncertainties in the input data, specifically equipment costs and labour costs (i.e. the additional inspection time needed for the inspection of ECSS compared to today's PTI). The BCR was calculated for the years 2015 to 2030. For all calculations, for all years the BCR was estimated to be greater than 1, i.e. the benefits are greater than the costs. For each calculation the BCR was at a minimum in 2019 and a maximum in 2030. The 2019 minimum BCR calculated ranged from 1.26 to 5.97 corresponding to the pessimistic and optimistic assumptions of high and low equipment and labour costs, respectively. Similarly, the 2030 maximum BCR calculated ranged from 2.18 to 11.11.

It should be noted that variation in equipment and software costs was caused by uncertainty in how the data required from vehicle manufacturers would be supplied, its cost and how much post-processing would be necessary. The equipment and software cost basis of the two cost projections (pessimistic and optimistic) assumed that the hardware costs will be similar in both cases, but that there may be a significant variation in the costs of accessing and subsequently processing the vehicle manufacturers' technical information.

In the **pessimistic** projection, the cost of the software was based on the typical costs of accessing non-standardised vehicle repair and maintenance information under the (EC) No 715/2007 Euro 5 Regulation for test equipment manufacturers, together with the costs of subsequent processing.

In the **optimistic** projection, it was assumed that the vehicle manufacturers' data will be made available in a pre-defined, machine readable format, with standardised data content and structure that requires the minimum subsequent processing to support PTI testing of a vehicle's ECSS and will be made easily available to test equipment manufacturers or competent authorities free of charge or at the lowest possible cost.

The EC are currently putting legislation in place to help ensure that vehicle manufacturers' data will be accessed and supplied free of charge or at the lowest possible cost (i.e. the optimistic case). For this case the following BCRs ranges were calculated:

- For 2019 minimum BCR range from 2.35 to 5.97 depending on labour costs.
- For 2030 maximum BCR range from 3.81 to 11.11 depending on labour costs.

10 Summary of Conclusions

10.1 Inspection methods

Starting from an expansive review of vehicle test equipment, vehicle safety system design, functionality, communication and control requirements, inspection methods were developed to inspect the ECSS shown in Table 27 below.

Table 27: ECSS for which inspection methods were developed within this project.

No	ECSS	Level of testing achieved (Level of testing desired at start of project)
	Braking	
1*	Anti-lock Braking System (ABS)	3 (3)
2*	Electronic Stability Control (ESC)	3 (3)
3*	Electronic Braking System (EBS)	3 (3)
4*	Electronic Power Steering (EPS)	3 (3)
5	Emergency Brake Assist (EBA)	3 (3)
	Supplemental Restraint Systems (SRS)	
6*	Safety Belt Load Limiter	1 (2)
7*	Safety Belt Pretensioner	1 (2)
8*	Airbag	1 (2)
	Other	
9	Tyre pressure monitoring system (TPMS)	3*(2)
10	Headlight control systems	3 (2)

* Note: Active system level 3, passive system level 2

The testing levels are defined in Section 3.1.

These inspection methods were assessed as part of the WP2 laboratory testing across a range of both vehicles and ECSSs and it was confirmed they worked. This was achieved by testing vehicles where the ability to monitor as well as actuate and control ECSS components was possible, or where vehicles were pre-configured with faults and the system functionality was then tested to allow the pre-configured fault to be identified.

Having established the inspection methods worked, they were elaborated 3 modules to optimize them for field testing:

1. Braking/steering/TPMS
2. SRS
3. Lights

These testing modules formed the basis of the WP4 field testing, as they provided optimized inspection efficiency in terms of overlap between individual test methods, allowing shared components to be tested once, reducing the test duration by using the results across more than one ECSS assessment. This grouping of ECSS also provided a better selection of both the test tools (i.e. those that provided the best coverage for the systems within the group) and the selection of the systems from the menu, further reducing the time needed to conduct the testing. Further testing efficiencies were also considered possible through the implementation of automated and sequential test methods.

A substantial part of the module one testing was conducted using the brake force reference values test method. This test method uses the correlation between generated brake system pressure and the measured braking force values at each wheel. This can identify additional failures, such as the balance between front and rear axle brake forces, counterfeit brake pads etc. which would affect the performance of the ECSS (i.e. correct braking efficiency, stability control etc.)

For the AEBS (automatic electronic braking system) and the BAS (brake assist system) it was not possible to conduct field testing beyond level 2, due to the problems of vehicle configuration and a validated level 3 test method.

It was decided to include TPMS into module one, as although the active systems can be controlled and actuated via the OBD port, the passive TPMS systems used the wheel speed sensors as the basis of their functionality and these sensors were being assessed as part of the module one braking checks.

For module two (SRS) level 3 testing is not appropriate, but the problem of being able to identify if the system components actually existed, or whether they had been replaced with a rogue component that could misguide the vehicle's OBD system, were very apparent. It was felt that this could only be addressed through better design of components and system monitoring to block the tampering and manipulation issues.

For the lighting systems testing in module three, level 2a, level 2b and level 3 testing was successfully conducted for levelling and bending of the headlight beams. However, for the next generation of advanced forward lighting (AFL) systems, the ability of the automatic control of the direction and intensity needs to be tested and a new test method needs to be investigated, as these systems are camera based (see section 11 on further recommendations).

10.2 Requirements for tools

Requirements for tools were defined in terms of their functionality because they do not necessarily need to follow one single hardware architecture solution. A detailed list of requirements is itemised in Section 8.2.

10.3 Field tests

Field tests were performed at PTI centres in Germany (TÜV Rheinland), Sweden (Bilprovningen) and Belgium (GOCA) with the optimized methods and selected tools. Major problems were caused with the length of time that the inspection took mainly because the majority of the tools used for the tests were designed to be used in garages for diagnostic repair purposes and not as PTI equipment.

Even with this problem, 2,654 ECSS tests were performed which produced results suitable for analysis. The analysis concluded:

- Level 1 tests
    - Tool vehicle coverage defined as, availability of a test vehicle on all tools based on all valid tests for a certain type of ECSS and its accessibility, was assessed. It was found to vary widely depending on the type of ECSS inspected from 4 % (TPMS active) to 93% (ABS/ESC/EBS/TPMS passive).
- Level 2 tests
    - Potential failures identified by DTCs:
      Although a possible failure could be expected from 0.1% (lighting) to 2.6 % (ABS/ESC/EBS/TPMS passive) to 3.6 % (SRS), many of the DTCs were caused by a low voltage of the supply system of the vehicles. Also it could not be identified whether historic respectively deleted failure codes were among the memory content of the vehicles looked at. With the information available, it could not be assessed if DTCs could be used at PTI.
    - Potential failures identified by level 2a plausibility thresholds:
      Due to the lack of thresholds from the VMs no conclusions could be made from the EPS tests. For the ESC tests, some values read out for the lateral acceleration were implausible and one value of the yaw rate seemed to be incorrect. In all cases thresholds were not available, so no definite conclusions could be made.
      It was seen that some SRS system igniter values differed from an observed mean range of 2 to 4 Ohms. In the absence of thresholds no validation of these outliers could be made.
- Level 3 tests
    - Potential braking failures identified by reference brake testing and thresholds for brake force distribution
      By applying reference values for braking force and the related pressure to the brake tests of 473 vehicles it was found that ~5% of vehicles had an incorrect brake force distribution (front/rear axle) and/or a brake efficiency below the thresholds. Also the use of counterfeit brake pads on a specially prepared test vehicle and their influence on brake force distribution was detected using this test method.
      Although the particular tests analysed were conducted with a tool developed especially for PTI purpose (FSD tool) many of the other tools used were also capable of measuring braking hydraulic pressure and therefore it is very likely that these tools could also be adapted easily to perform this test.

10.4 Information required from vehicle manufacturers

In PTI, vehicles are inspected in terms of the installation, condition, function, and the efficacy of its components and systems. For vehicles with electronically controlled safety systems (ECSS), these tests require additional vehicle manufacturer data/information concerning the assessment of these ECSS:

- A list of electronically controlled safety systems (ECSS) or functions which are installed end-of-line (and identified by VIN or other unequivocal identification method), including hard and software variant/version of relevant ECUs together with any data/information necessary to identify and communicate with an ECU and its version/variant coding.

- Any data/information necessary to enable complete functionality testing (where appropriate), including any additional hardware or software protocol information (e.g. location of the diagnostic connector and connector details, voltage, physical bus type, transport protocols, diagnostic protocols).
- A list of all available live data parameters including scaling, interpretation, access information and criteria to assess deficiencies.
- A list of all available functional tests including device activation or control, the means to access them and the criteria to assess deficiencies and support efficacy testing.
- All details of how to obtain all component and status information and criteria to assess deficiencies.
- A description of tests to confirm ECSSs functionality, at the component or in the harness, and criteria to assess deficiencies and support efficacy testing.
- Specific on-board/off-board PTI procedures, including any automated or sequential system testing, to check the ECSS (if applicable), including a description and criteria to assess deficiencies and support efficacy testing.
- Proposals for PTI procedures using a PTI mode scan tool or other test equipment where appropriate, including a description, test parameters, component information and criteria to assess deficiencies and support efficacy testing.
- Vehicle manufacturer technical information shall include the threshold values of the system components to support efficacy testing.

The data/information shall be provided in a standardized, machine readable format (e.g. ODX for technical information, OTX for test sequences) via a single point of access.

The data/information shall be provided for offline-usage by the VM, on a VIN-based access (for that purpose, VIN shall not be considered as a privacy information), or other unequivocal identification method.

For a detailed list of the requirements for the technical information to be provided by the vehicle manufacturers for each vehicle ECSS to support the proposed test methods, including system components and functionality testing, please see Annex 7.

10.5 Cost benefit analysis

The benefit to cost ratio (BCR) was calculated for the introduction of the ECSS inspection methods developed in this study into today's standard PTI, namely braking (ABS, ESC, EBA, EBS), steering (EPS) and the supplementary restraint system (SRS), but also including tyre pressure monitoring (TPMS) and lighting (automatic levelling and bending) systems as examples of future PTI test requirements.

The calculation used a socio-economic model which evaluated both safety and non-safety critical impact channels. The safety critical channels evaluated the effect of the proposed measures on accidents whereas the non-safety critical effects evaluated the effect on items such as the environment and fuel consumption.

A number of calculations were performed because of uncertainties in the input data, specifically equipment costs and labour costs (i.e. the additional inspection time needed for the inspection of

ECSS compared to today's PTI). The BCR was calculated for the years 2015 to 2030. For all calculations, for all years the BCR was estimated to be greater than 1, (i.e. the benefits are greater than the costs). For each calculation the BCR was at a minimum in 2019 and a maximum in 2030. The 2019 minimum BCR calculated ranged from 1.26 to 5.97 corresponding to the pessimistic and optimistic assumptions of high and low equipment and labour costs, respectively. Similarly, the 2030 maximum BCR calculated ranged from 2.18 to 11.11.

It should be noted that variation in equipment cost was caused by uncertainty of how the data required from vehicle manufacturers (VMs) would be supplied, its cost and how much post-processing would be required. Therefore estimates were made for optimistic and pessimistic equipment cost cases. The EC are currently putting legislation in place to help ensure that data required from VMs will be accessed and supplied at the lowest reasonable cost (i.e. the optimistic case). For this case the following BCRs ranges were calculated:

- For 2019 minimum BCR range from 2.35 to 5.97 depending on labour costs.
- For 2030 maximum BCR range from 3.81 to 11.11 depending on labour costs.

11 Recommendations for Way Forward

On the basis of the work performed within this project, recommendations for the way forward are given below:

1) Recommendation to implement the inspection methods developed by this project into legislation (see 8.1) as soon as possible

The following inspection methods are recommended for implementation into legislation:

- Electronic Power Steering EPS: Level 3 test
- Braking (ABS/ESC incl. TPMS passive/EBS): Level 3 test
- Tyre Pressure Monitoring System (TPMS active): Level 3 test
- Lighting (triggering of lighting functions, automatic levelling and bending): Level 3 test
- Supplementary Restraint System (airbags, pretensioners, occupancy sensor): Level 1 test

As inspection methods also use on-board diagnostic routines, technical information is needed from the VM; e.g. the measured values and the read out sensor data compared to threshold values (see Recommendation to implement the delivery of all technical information necessary for PTI). The implementation of the methods into legislation will support efficient and robust automated test methods using a PTI mode scan tool linked to other existing PTI test equipment.

2) Recommendation to further develop and expand the scope of the inspection methods listed above

The methods developed within this project should be continuously adapted to technical progress, e.g.:

- lighting systems
  - inclusion of inspection of Automatic headlight dip system
  - inclusion of inspection of Active/adaptive/dynamic headlight direction control system
- SRS
  - Development of methods to test installation, condition, and to detect manipulation

3) Recommendation to implement further systems and functions into the scope of PTI

For all vehicle systems or functions which may increase active, passive and preventative safety (incl. AEBS, Car2x-functionality and ECall), as well as for emission relevant systems (e.g. Electric drives or traction battery management of Alternative Propulsion Vehicles - APV) and autonomous driving functions, test methods should be developed and continuously adapted to technical progress.

In this sense, systems or functions should be considered relevant as soon as they are introduced into the market.

Where possible, the same methodology (test for installation, condition, function, and their efficacy) should be used to develop inspection methods for these systems.

As many new additional systems may use existing actuators or information from existing sensors, a major part of the respective functional chains may already be inspected with the test methods proposed in this document.

4) Recommendation to implement the delivery of all technical information necessary for PTI

The implementation of vehicle safety systems is leading to an increasingly complex interaction between the systems' control units, input sensors and actuators.
As a mandatory part of future Type Approvals, vehicle manufacturers should design vehicles to enable roadworthiness inspection and provide all technical data necessary to do this on a regular basis. The data delivery should follow the rules laid down in "8.3 Information required from vehicle manufacturers" and Annex 7 of this project report.
The communication between the PTI mode scan tool and the relevant systems should be further standardised.

5) Recommendation for continuous improvement of inspection methods

Whenever Member States have developed equivalent methods (Art.6 No.2 2014/45/EU) for inspection methods developed by this project, or test methods for future systems (see Recommendation to implement further systems and functions into the scope of PTI), these methods should be discussed on a regular basis and be considered for usage in all Member States. The Roadworthiness Committee could be used to help facilitate this process. New and / or improved inspection methods could be implemented in the legislation and amended using 'Delegated Acts'..

12 Glossary

ABS:	Anti-Lock Braking System
BAS	Brake Assist System
BCR	Benefit to Cost Ratio
Body:	ECU managing the vehicle body relevant systems
CBA	Cost Benefit Analysis
DTC:	Diagnostic Trouble Code
EBA	Emergency Brake Assist otherwise known as Brake Assist System (BAS)
EBS:	Electronic Brake System
EC	European Commission
ECSS:	Electronically Controlled Safety System(s)
ECM:	Engine Control Module
ECU :	Electronic Control Unit
EGEA	European Garage Equipment Association
ESC:	Electronic Stability Control
EPS:	Electronic Power Steering
MIL:	Malfunction Indicator Light
OBD	On-Board Diagnostics
ODU	Operating and Display Unit
PTI:	Periodic Technical Inspection (Roadworthiness Test)
SRS	Supplementary Restraint System
TCM:	Transmission Control Module
TPMS	Tyre Pressure Monitoring System
VCI:	Vehicle Communication Interface
VM	Vehicle Manufacturer

13 Annex 1: Summary of ECSS functionality and proposal of concept methods to inspect them

13.1 Anti-lock braking system (ABS)

Description of faults according to 2010/48/EU:

- Warning device malfunctioning
- Warning device shows system malfunctioning
- Wheel speed sensor missing or damaged
- Wirings damaged
- Other components missing or damaged

DESCRIPTION

Electromechanical system using wheel sensors to provide the identification of different wheel speeds to allow modulated brake force to be applied, using a high pressure pump and modulator valve assembly, controlled by an ABS electronic control unit.

The system automatically prevents wheel-locking during braking by selective reduction of the wheel brake force (e.g. in accordance with ECE-R 13; 71/320/EEC).

ABS is considered as a stand-alone system in the case of this study.

FAILURES IDENTIFIED

The scale of '0' is low and '10' is high is used below.

The figure against each level of testing indicates the probability to identify the fault at a specific test level (the levels are described after this section):

1. Brake pedal sensor:

Check if the pedal sensor is active.
Check if the pedal sensor functions correctly
Safety potential – 9
Level 1 - 0
Level 2a – 9
Level 2b - 0
Level 3 - 10

2. Wheel speed sensor failure:

Check for stored wheel sensor DTCs
Dynamic check of wheel speed sensor signal relative to the other wheel sensors
Wiring – damaged or missing
Sensor - damaged or missing
Toothed Rim – damaged or contaminated
Twisted connection of wiring (e.g. left/right)
Safety potential – 9
Level 1 - 0
Level 2a – 9
Level 2b - 0
Level 3 – 10

3. Pump failure:

Check if the pump activates correctly
Safety potential – 9
Level 1 - 0
Level 2a – 6
Level 2b - 9
Level 3 – 10

4. Pressure sensor:
Check if the sensor operates correctly
Safety potential – 9
Level 1 - 0
Level 2a – 7
Level 2b - 0
Level 3 – 10

5. System hydraulic integrity:
Visual inspection of the hydraulic system
Safety potential – 9
Level 1 - 0
Level 2a – 0
Level 2b - 2
Level 3 – 10

6. ECU failure:
Check communication with the ABS ECU.
Safety potential – 9
Level 1 - 9
Level 2a – 9
Level 2b - 9
Level 3 - 10

7. Modulated brake force value:
System activation and dynamic check using brake tester to verify that all wheel brake force values vary appropriately.
Safety potential – 9
Level 1 - 0
Level 2a – 7
Level 2b - 0
Level 3 – 10

CURRENT BASELINE

PRESENCE	
	Visual inspection of the ABS system's components
MIL	
	Check if the MIL is connected and functioning, e.g. the MIL will turn on and then off.
	MIL used (- inclusion of ISO 2575 symbol relative to ABS)

Level 1

Via OBD port, send communication signal to the ABS ECU.
Test method: “ping” of ABS ECU.

This can identify:

- ECU – failed, missing or damaged
- Wiring and connecters – missing or damaged

Level 2a

Diagnostic communication – reading PTI relevant information

Via the OBD port, communicate with the ABS ECU:

Reading parameters:

- Status of MIL (on/off/…) read on the ECU versus the visual MIL
- Read PTI relevant failure information, including stored DTCs and readiness codes (Sensors, valves, pump,…)
- Identification of any general communication fault with ECU and/or sensors

This can identify:

- ABS ECU failure
- Brake pedal sensor function
- Pressure sensor failure
- Hydraulic pump failure
- Wheel speed sensors
- Wiring and connector – interruption of communication signals.

Level 2b

Diagnostic communication – system component activation

Via the OBD port, communicate with the ABS ECU:

- Trigger the MIL and visually check that the dashboard MIL illuminates correctly.
- Activate the ABS system hydraulic pump and use an audible check to verify if the pump is running.

This can identify:

- Objective test of the MIL functionality
- ABS ECU failure
- Hydraulic pump failure
- Hydraulic system integrity – leakage

Level 3

Diagnostic communication and ABS system functionality test

Via the OBD port, communicate with the ABS ECU:

- Send control signals for each wheel/axle.
- Use brake tester to verify system functionality through a check of the change in brake force values as the ABS system modulates the brake forces applied for each corresponding wheel.

This can identify:

- ABS ECU failure
- Wiring and connections
- Brake pedal sensor function
- Pressure sensor failure
- Wheel sensor signals
- Hydraulic pump failure
- Modulated brake force value
- Hydraulic system integrity – leakage

Cost benefit analysis criteria and preferred test method

The ABS system relies on the ability of each wheel sensor to provide an accurate value to the system ECU to allow changes in the applied brake forces to individual wheels to provide safer braking and vehicle control.
Therefore, the ability to check the functionality of the ABS system through the assessment of the wheel sensor signals and the ability of the ABS system to modulate brake force values are key test criteria.

Proposed test level: - Level 3

Test Methods

Possibility of identifying faulty ABS system:

- Current baseline: 0 - no base line conducted
- Level 1: 0.4
- Level 2a: 0.7
- Level 2b: 0.3
- Level 3: 1.0

Cost of tool(s):

- Current baseline: no base line conducted
- Level 1: VCI + basic communication SW [HW: 1000 – 1250€/SW 200 €]
  Principle is that data are coming from a standardized machine
  readable format from EU/VM free of charge.
- Level 2a: : VCI [HW: 1000 – 1250€/SW 400€]
- Level 2b: VCI [HW: 1000 – 1250€/SW 400€]
- Level 3: VCI [HW: 1000 – 1250€/SW 500€]
  Brake tester already available from other system testing

Note:
The costs shown reflect the VCI and software needed to provide the indicated levels of testing for the ABS system ONLY.
These costs would reduce directly in relationship to the testing of other ECSS systems (see below).

Additional tool functionality and cost amortisation:

Test tool, VCI and external test equipment (brake tester) can also be used to test:

- ESC (electronic stability control)
- EBS (Electronic braking system)
- SRS (Supplementary restraint system - no brake tester required)

Time of test

- Level 1: 30s
- Level 2a: +45s
- Level 2b: +45s
- Level 3: +45s – existing brake testing time already exists

13.2 Electronic Stability Control (ESC)

ECSS:ESC – electronic stability control

Description of faults according to 2010/48/EU:

Item: Annex II 7.12. Electronic Stability Control (ESC) if fitted/required

Method: Visual inspection

Reasons for failure:

A : Wheel speed sensors missing or damaged

B: Wirings damaged

C: Other components missing or damaged

D: Switch damaged or not functioning correctly

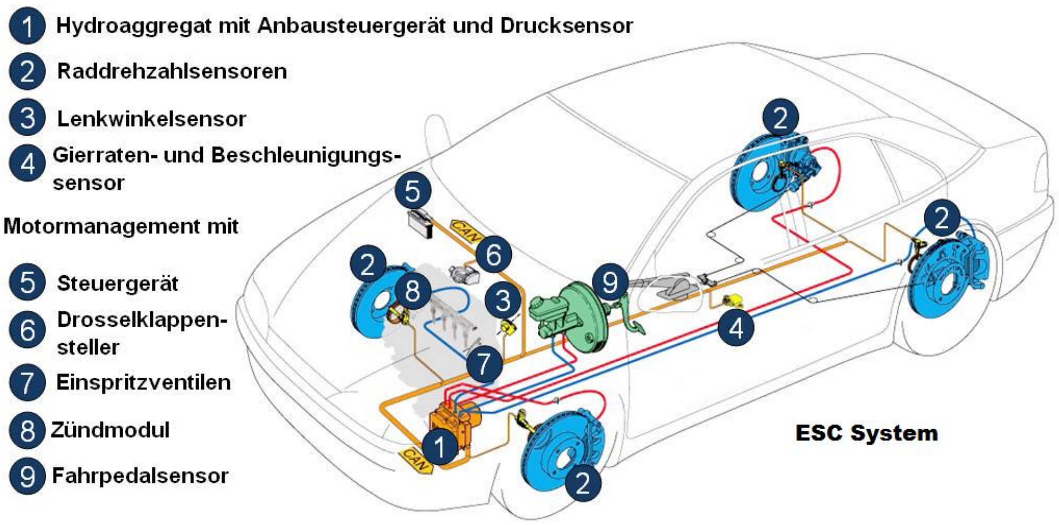
E: ESC MIL indicates any kind of failure of the system

DESCRIPTION

ESC is always on and enabled. A microcomputer monitors the signals from the ESC sensors and checks with high sample rate (typically 25 times a second), whether the driver's steering input corresponds to the actual direction in which the vehicle is moving. If the vehicle moves in a different direction ESC detects the critical situation and reacts immediately – independently of the driver. It uses the vehicle's braking system to stabilize the vehicle. With these selective braking interventions ESC generates the desired counteracting force, so that the car reacts as the driver intends. ESC not only initiates braking intervention, but can also reduce engine torque to slow the vehicle. So, within the limits of physics, the car is kept safely on the desired path.

FAILURES IDENTIFIED

A:System Architecture:



b: System component fault identification:

The scale of ‘0’ is low and ‘10’ is high is used below.

The figure against each level of testing indicates the probability to identify the fault at a specific test level (the levels are described after this section):

1. Brake pedal sensor:

Check if the pedal sensor is active.
Check if the pedal sensor functions correctly
Safety potential – 9
Level 1 - 0
Level 2a – 9
Level 2b - 0
Level 3 – 10

2. Hydraulic pump

Not operating correctly
Safety potential – 9
Level 1 - 0
Level 2a – 7
Level 2b - 6
Level 3 – 10

3. Hydraulic modulator valves

Not operating correctly
Safety potential – 9
Level 1 - 0
Level 2a – 7
Level 2b - 0
Level 3 – 10

4. Pressure sensor

Not operating correctly
Safety potential – 9
Level 1 - 0
Level 2a – 7
Level 2b - 0
Level 3 – 10

5. System integrity

System leakage
Safety potential – 6
Level 1 - 0
Level 2a – 2
Level 2b - 2
Level 3 – 10

6. Twisted connection of hydraulic tubes (e.g. left/right)

Check to verify pipes are correctly connected to the appropriate wheel location
Safety potential – 9
Level 1 - 0
Level 2a – 0
Level 2b - 0
Level 3 - 10

7. Wheel Speed Sensors

Stored DTC and dynamic check of wheel speed sensor signal relative to the other wheel sensors
Wiring – damaged or missing
Sensor - damaged or missing
Toothed Rim – damaged or contaminated
Check to verify sensors are correctly connected to the appropriate wheel location (e.g. left/right)
Safety potential – 9
Level 1 - 0
Level 2a – 9
Level 2b - 0
Level 3 - 10

8. Steering Angle Sensor

Sensor – damaged, missing or incorrect orientation/not calibrated
Wiring or connection - damaged or missing
Safety potential – 7
Level 1 - 0
Level 2a – 5
Level 2b - 0
Level 3 - 8

9. **Yaw Angle Sensor**

Sensor – damaged or missing
Wiring or connection - damaged

Safety potential – 7
Level 1 - 0
Level 2a – 5
Level 2b - 0
Level 3 - 0

10. ECU (ESC system)

Failed or missing
Wiring or connection damaged
ECU damaged, manipulated or spare part not matching
Safety potential – 9
Level 1 - 10
Level 2a - 9
Level 2b - 10
Level 3 - 10

11. ECU (ABS system)

Failed or missing
Wiring or connection damaged
ECU damaged, manipulated or spare part not matching
Safety potential – 9
Level 1 - 10
Level 2a – 7

Level 2b - 9
Level 3 – 10

12. ECU (Engine Management)
Failed or missing
Wiring or connection damaged
ECU damaged, manipulated or spare part not matching
Safety potential – 2
Level 1 - 10
Level 2a - 9
Level 2b - 0
Level 3 - 10

13. Throttle Actuator
Wiring or connection damaged
Actuator not operating correctly
Safety potential – 2
Level 1 - 0
Level 2a - 9
Level 2b - 7
Level 3 - 5

14. Ignition Module
Wiring or connection damaged
Module not operating correctly
Safety potential – 2
Level 1 - 0
Level 2a - 9
Level 2b - 0
Level 3 - 10

15. Accelerator Pedal Sensor
Wiring or connection damaged
Sensor not operating correctly
Safety potential – 2
Level 1 - 0
Level 2a - 9
Level 2b - 0
Level 3 – 5

16. Malfunction indicator light
Wiring or connection damaged
MIL not operating correctly
Safety potential – 2
Level 1 - 0
Level 2a - 0
Level 2b - 10
Level 3 – 0
CURRENT BASELINE – check of the components and MIL

Visual inspection of the ESC system’s components

MIL

Check if the MIL is connected and functioning, e.g. the MIL will turn on and then off.

MIL used ((inclusion of ISO 2575 symbol relative to ESC)

Level 1

Via OBD port, send communication signal to the ESC, ABS and engine management ECU’s.

Test method: “ping” of ESC, ABS and engine management ECU’s.

ESC ECU-component missing/not responding
ABS ECU-component missing/not responding
Engine Management ECU - component missing/not responding

This can identify:
ECU – missing or damaged
Wiring and connecters – missing or damaged

Level 2a

Diagnostic communication: reading PTI relevant information

Via the OBD port, communicate with the ESC, ABS and engine management ECU’s:

Reading parameters:
Status of MIL (on/off/…) read on the ECU’s versus the visual MIL
Read PTI relevant failure information, including stored DTCs and readiness codes (Sensors, valves, pump,…)
Identification of any general communication fault with ECU’s and/or sensors

This can identify:
ESC ECU failure
ABS ECU failure
Engine management ECU failure
Pressure sensor failure
Hydraulic pump not operating correctly
Hydraulic modulator valves not operating correctly
Incorrect wheel speed sensor signals
Incorrect steering wheel sensor signal
Incorrect yaw sensor signal
Incorrect accelerator pedal sensor value
Hydraulic system integrity – leaking
Throttle actuator not operating correctly
Ignition module not operating correctly
Accelerator position sensor not operating correctly

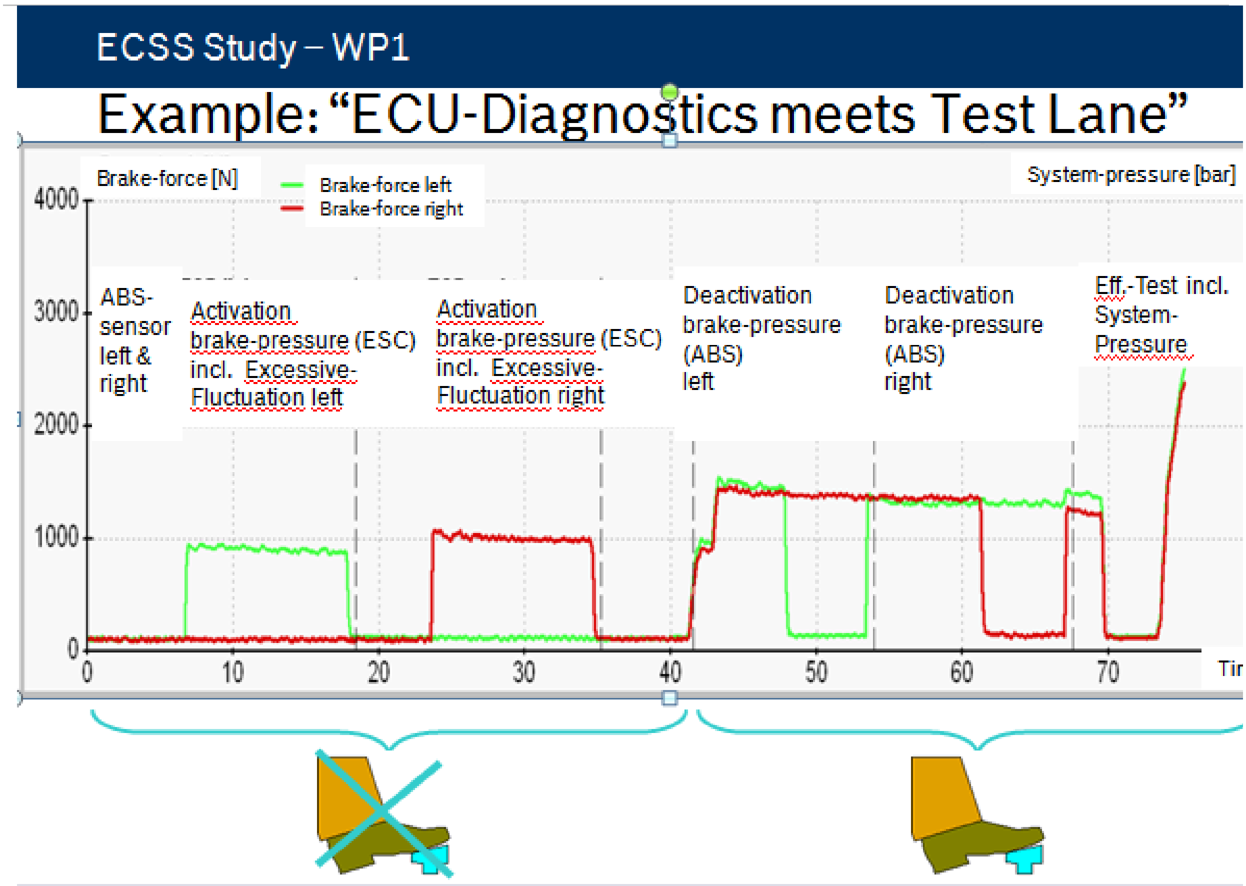
Level 2b

Diagnostic communication: ESC and ABS system activation

Hydraulic pump not operating (audible check)
Modulator valves not operating (audible check)
Trigger the MIL and visually check that the dashboard MIL illuminates correctly.

This can identify:
Hydraulic pump not operating correctly
Hydraulic modulator valves not working correctly
MIL not operating correctly
Throttle actuator not operating correctly
Hydraulic system integrity – leaking

Level 3



Diagnostic communication and ESC and ABS systems functionality test:

Via the OBD port, communicate with the ESC ECU:

Send control signals to read out steering angle, yaw sensor, accelerator, road speed inputs.
Use brake tester to verify system functionality through a check of the change in brake force values as the ESC/ABS system modulates the brake forces applied for

each corresponding wheel.

This can identify:
ESC ECU failure
ABS ECU failure
Hydraulic pump not working correctly
Hydraulic modulator valves not working correctly
Pressure sensor not working correctly
Twisted hydraulic pipes
Wheel speed sensor signals are correct
Steering angle sensor operates correctly
Twisted wheel senor signals
ESC system functioning correctly
Hydraulic system integrity – leaking
Accelerator position sensor not operating correctly

Cost benefit analysis criteria

The ESC system relies on the ability of steering angle, vehicle speed, yaw sensor and accelerator position sensors to provide information that allows the ESC system ECU to change the applied brake forces to individual wheels and control the engine torque to prevent a vehicle skid developing and to provide safer vehicle control. Therefore, the ability to check these various sensor signals and the ability of the ESC/ABS system to modulate brake force values and engine torque are key test criteria.

Cost of tool(s):

Current baseline: no base line conducted for system
Level 1: VCI + basic communication SW [HW: 1000 – 1250€/SW 500€]
(Principle based on technical data coming from a standardized machine readable format from VMs free of charge.)
Level 2a: VCI cost+VCI-SW [HW: 1000 – 1250€/SW 500€]
Level 2b: VCI cost+VCI-SW [HW: 1000 – 1250€/SW 500€]
Level 3: VCI cost+VCI-SW3+ brake tester incl. Interface to VCI [HW: 1000 – 1250€/SW 600€]

Note:
The costs shown reflect the VCI and software needed to provide the indicated levels of testing for the ESC system ONLY.
These costs would reduce directly in relationship to the testing of other ECSS systems (see below).

Additional tool functionality and cost amortisation:
Test tool, VCI and external test equipment (brake tester) can also be used to test:
ABS

EBS
SRS (no brake tester required)

Test methods:
Possibility of identifying faulty ESC system:

Current baseline:	0 - no base line conducted
Level 1:	0.3
Level 2a:	0.5
Level 2b:	0.2
Level 3:	0.7

Time of test

Level 1:	30 sec
Level 2a:	45 sec
Level 2b:	45 sec
Level 3:	45 sec or 2 x 40 sec (front & rear axle incl. ovality check)

13.3 Electronic Brake System (EBS)

ECSS: EBS – Electronic brake system

Description of faults according to 2010/48/EU:

Annex II - Item 1.7 – Electronic brake systems:
Warning device malfunctioning
Warning device shows system malfunctioning

DESCRIPTION

The modern brakes are associated with electronic assistance and hence, known as electronic brake system (EBS) as a whole. EBS is interactive with other functions such as Anti-lock brake system (ABS), electronic stability program (ESP), electronic brake force distribution (EBD), traction control system (TCS) etc.
With all these electronic assistance functions, modern automotive brakes are not limited to deceleration only, but they also play an important role in driver's assistance and safety. Electronic activation of the EBS braking components reduces build-up times in the brake cylinders, reducing response times and braking distances, whilst also providing automatic braking force distribution between the front and rear axles according to the load situation. The integrated ABS function ensures driving stability and steer ability throughout the braking procedure.

When the brake pedal is actuated, the EBS central braking unit (CBU) transforms the driver's request into electrical signals, controlling front-axle and rear-axle brakes, depending on the position of the pedal. The pressure at the brake cylinders is controlled directly by the CBU or via the ABS solenoid modulator valves. The pressure at the brake cylinders of the rear axle is controlled by the rear-axle modulator, which receives the nominal pressure value from the CBU. The rear-axle modulator has a separate ECU with integrated control algorithms for the rear-axle wheels. Brake pressure is calculated according to vehicle load and brake wear. EBS functions according to the deceleration control principle. Potential deviations between actual and desired deceleration are determined and adjusted.

FAILURES IDENTIFIED

The scale of '0' is low and '10' is high is used below.
The figure against each level of testing indicates the probability to identify the fault at a specific test level (the levels are described after this section):

1. Brake pedal sensor:

Check if the pedal sensor is active.
Check if the pedal sensor functions correctly
Safety potential – 9
Level 1 - 0
Level 2a – 9
Level 2b - 0
Level 3 - 10

2. Wheel speed sensor failure:

Check for stored wheel sensor DTCs
Dynamic check of wheel speed sensor signal relative to the other wheel sensors

Wiring – damaged or missing
Sensor - damaged or missing
Toothed Rim – damaged or contaminated
Twisted connection of wiring (e.g. left/right)
Safety potential – 9
Level 1 - 0
Level 2a – 9
Level 2b - 0
Level 3 – 10

3. Pump failure:

Check if the pump activates correctly
Safety potential – 9
Level 1 - 0
Level 2a – 6
Level 2b - 9
Level 3 – 10

4. Brake pressure sensor rear axle:

Check if the sensor operates correctly
Safety potential – 9
Level 1 - 0
Level 2a – 7
Level 2b - 0
Level 3 – 10

5. Brake pressure sensor front axle:

Check if the sensor operates correctly
Safety potential – 9
Level 1 - 0
Level 2a – 7
Level 2b - 0
Level 3 – 10

6. Longitudinal acceleration sensor:

Check if the sensor operates correctly
Safety potential – 9
Level 1 - 0
Level 2a – 7
Level 2b - 0
Level 3 – 10

7. Yaw angle sensor:

Check if the sensor operates correctly
Safety potential – 7
Level 1 - 0
Level 2a – 5
Level 2b - 0
Level 3 – 0

8. Steering angle sensor:

Check if the sensor operates correctly
Safety potential – 9
Level 1 - 0
Level 2a – 7
Level 2b - 0
Level 3 – 10

9. ECU failure:

Check communication with the EBS ECU.
Safety potential – 9
Level 1 - 9
Level 2a – 9
Level 2b - 9
Level 3 – 10

10. Hydraulic aggregate:

Hydraulic valves damaged
System leakage
Twisted connection of hydraulic tubes (e.g. left/right)
Safety potential – 9
Level 1 - 0
Level 2a – 0
Level 2b - 2
Level 3 – 10

CURRENT BASELINE

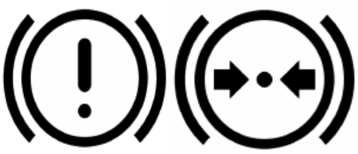
PRESENCE

Visual inspection of the component – N/A

MIL

Visual inspection of the MIL. It exists only as a general indication of a malfunction in the EBS system.

MIL used



Level 1

Via OBD port, send communication signal to the EBS ECU.
Test method: “ping” of EBS ECU.

This can identify:
ECU – failed, missing or damaged
Wiring and connectors – missing or damaged

Level 2a

Diagnostic communication – reading PTI relevant information

Via the OBD port, communicate with the EBS ECU:

Reading parameters:
Status of MIL (on/off/…) read on the ECU versus the visual MIL
Read PTI relevant failure information, including stored DTCs and readiness codes (Sensors, valves, pump,…)
Identification of any general communication fault with ECU and/or sensors

This can identify:
EBS ECU failure
All sensors failure (brake pedal sensor, wheel speed sensor, brake pressure rear axle sensor, brake pressure front axle sensor, longitudinal acceleration sensor, yaw angle sensor, steering angle sensor)
Wiring and connector – interruption of communication signals.
Hydraulic pump failure
Hydraulic valves damaged

Level 2b

Diagnostic communication – system component activation

Via the OBD port, communicate with the EBS ECU:

Trigger the MIL and visually check that the dashboard MIL illuminates correctly.
Activate the EBS system hydraulic pump and use an audible check to verify if the pump is running.
Activate the EBS system hydraulic valves and use an audible check to verify if the valves are running.

This can identify:
Objective test of the MIL functionality
EBS ECU failure
Hydraulic pump failure
Hydraulic valves damaged
Hydraulic system integrity – leakage

Level 3

Diagnostic communication and EBS system functionality test

Via the OBD port, communicate with the EBS ECU:

Send control signals for each wheel/axle.
Turn the steering wheel
Use brake tester to verify system functionality through a check of the change in brake force values as the EBS system modulates the brake forces applied

This can identify:
EBS ECU failure
Wiring and connections
Brake pedal sensor function
Pressure sensor failure
Wheel sensor signals
Hydraulic pump failure
Modulated brake force value

Hydraulic system integrity – leakage
Hydraulic valves damaged
Steering angle sensor
Twisted hydraulic pipes
Twisted sensors

Cost benefit analysis criteria and preferred test method

The EBS system relies on the ability of the brake pedal sensor and each wheel sensor to provide an accurate value to the system ECU to allow changes in the applied brake forces to individual wheels to provide safer braking and vehicle control.
Therefore, the ability to check the functionality of the EBS system through the assessment of the brake pedal sensor and the wheel sensor signals and the ability of the ABS system to modulate brake force values are key test criteria.

Cost of tool(s):

Current baseline: no base line conducted
Level 1: VCI + basic communication SW [HW: 1000 – 1250€/SW 200 €]
Principle is that data are coming from a standardized machine
readable format from EU/VM free of charge.
Level 2a: : VCI [HW: 1000 – 1250€/SW 400€]
Level 2b: VCI [HW: 1000 – 1250€/SW 400€]
Level 3: VCI [HW: 1000 – 1250€/SW 500€]
A four-wheel brake tester is required and different loads must be tested

Note:
The costs shown reflect the VCI and software needed to provide the indicated levels of testing for the EBS system ONLY.
These costs would reduce directly in relationship to the testing of other ECSS systems (see below).

Test methods:
Possibility of identifying faulty EBS system:

Current baseline:	0 - no base line conducted
Level 1:	0.1
Level 2a:	0.8
Level 2b:	0.3
Level 3:	1.0

Additional tool functionality and cost amortisation:

Test tool, VCI and external test equipment (four-wheel brake tester) can also be used to test:
ESC (electronic stability control)
EBS (Electronic braking system)
SRS (Supplementary restraint system - no brake tester required)

Time of test	
Level 1:	30s
Level 2a:	+45s
Level 2b:	+45s
Level 3:	+45s – existing brake testing time already exists

13.4 Electronic Power Steering (EPS)

ECSS: EPS – Electronic power steering

Description of faults according to 2010/48/EU:

Annex II – item 2.6- Electronic Power Steering (EPS)

A: EPS Malfunction Indicator Lamp (MIL) indicates any kind of failure of the system.
B: Inconsistency between the angle of the steering wheel and the angle of the wheels
C: power assistance not working

DESCRIPTION

Electrically powered steering uses an electric motor to drive either the power steering hydraulic pump or the steering linkage directly.

A "steering sensor" is located on the input shaft where it enters the gearbox housing. The steering sensor is actually two sensors in one: a "torque sensor" that converts steering torque input and its direction into voltage signals, and a "rotation sensor" that converts the rotation speed and direction into voltage signals. An "interface" circuit that shares the same housing converts the signals from the torque sensor and rotation sensor into signals the control electronics can process.

Inputs from the steering sensor are digested by a microprocessor control unit that also monitors input from the vehicle's speed sensor. The sensor inputs are then compared to determine how much power assistance is required according to a pre-programmed "force map" in the control unit's memory. The control unit then sends out the appropriate command to the "power unit" which then supplies the electric motor with current. The motor pushes the rack to the right or left depending on which way the voltage flows (reversing the current reverses the direction the motor spins). Increasing the current to the motor increases the amount of power assist.

The system has three operating modes: a "normal" control mode in which left or right power assist is provided in response to input from the steering torque and rotation sensor's inputs; a "return" control mode which is used to assist steering return after completing a turn; and a "damper" control mode that changes with vehicle speed to improve road feel and dampen kickback.

FAILURES IDENTIFIED

The scale of ‘0’ is low and ‘10’ is high is used below.

The figure against each level of testing indicates the probability to identify the fault at a specific test level (the levels are described after this section):

1. Steering angle sensor:

Check if the sensor is active.
Check if the sensor functions correctly
Safety potential – 9
Level 1 - 0
Level 2a – 9
Level 2b - 0
Level 3 - 10

2. Torque force sensor:

Check if the sensor functions correctly
Safety potential – 9
Level 1 - 0
Level 2a – 9
Level 2b - 0
Level 3 - 10

3. RPM sensor:

Check if the sensor functions correctly
Safety potential – 9
Level 1 - 0
Level 2a – 9
Level 2b - 0
Level 3 – 10

4. Speed sensor:

Check if the sensor operates correctly
Safety potential – 9
Level 1 - 0
Level 2a – 9
Level 2b - 0
Level 3 – 8

5. EPS ECU:

ECU – failed, missing or damaged
Wiring – damaged or missing
Safety potential – 9
Level 1 - 9
Level 2a – 8
Level 2b - 9
Level 3 – 10

6. Hydraulic pump:

Check if the pump operates correctly

Safety potential – 9
Level 1 - 0
Level 2a – 9
Level 2b - 9
Level 3 – 10

7. Hydraulic mechanical actuator:
Check if the actuator operates correctly (damage or jam because of corrosion)
Safety potential – 9
Level 1 - 0
Level 2a – 8
Level 2b - 9
Level 3 – 10

8. MIL:
Check if the MIL operates correctly
Safety potential – 9
Level 1 - 0
Level 2a – 8
Level 2b - 9
Level 3 – 10

9. Hydraulic oil:
Detection of spoiled oil
Safety potential – 9
Level 1 - 0
Level 2a – 0
Level 2b - 0
Level 3 – 10

10. Wiring and connector:
Check if wiring and connector operates correctly
Safety potential – 9
Level 1 - 0
Level 2a – 8
Level 2b - 10
Level 3 – 10

Pre-conditions for a proper working EPS are:

- Correct wheel-alignment (camber, toe, castor, run-out on turns)
- Correct adjusted steering wheel
- Correctly calibrated steering sensor(s)

In some member States the run-out on turns is evaluated using mechanical turning plates.

CURRENT BASELINE

PRESENCE	
	Visual inspection of the component and operation of the EPS switch
MIL	

Visual inspection of the MIL.

MIL used

FUNCTIONAL TEST

Evaluation of the runs-out on turn on turning plates

Level 1

Via OBD port, send communication signal to the EPS ECU.
Test method: "ping" of EPS ECU.

This can identify:
ECU – failed, missing or damaged
Wiring and connectors – missing or damaged

Level 2a

Diagnostic communication – reading PTI relevant information

Via the OBD port, communicate with the EPS ECU:

Reading parameters:
Status of MIL (on/off/…) read on the ECU versus the visual MIL
Read PTI relevant failure information, including stored DTCs and readiness codes (Sensors pump,…)
Identification of any general communication fault with ECU and/or sensors

This can identify:
EPS ECU failure
All sensors failure (steering angle sensor, torque force sensor, RPM sensor, speed sensor)
Wiring and connector – interruption of communication signals.
Hydraulic pump failure
Hydraulic actuator failure

Level 2b

Diagnostic communication – system component activation

Via the OBD port, communicate with the EPS ECU:

Trigger the MIL and visually check that the dashboard MIL illuminates correctly.

This can identify:
Objective test of the MIL functionality
EPS ECU failure
Wiring and connector – interruption of communication signals.

Level 3

Diagnostic communication and EBS system functionality test

Via the OBD port, communicate with the EBS ECU:

Turning steering wheel 45 degrees left and 45 degrees right in order to measure the run-out on turns.

This can identify:
EPS ECU failure
Wiring and connections

Hydraulic pump failure
Hydraulic actuator damaged
Steering angle sensor

Cost benefit analysis criteria and preferred test method

The EPS system relies on the ability of the steering wheel angle sensor and vehicle speed signals to provide an accurate value to the system ECU to allow changes in the applied steering torque to provide safer steering and vehicle control.
Therefore, the ability to check the functionality of the EPS system through the assessment of the steering wheel sensor signal and the ability of the EPS system to modulate steering force values are key test criteria.

Cost of tool(s):

Current baseline: no base line conducted
Level 1: VCI + basic communication SW [HW: 1000 – 1250€/SW 200 €]
Principle is that data are coming from a standardized machine
readable format from EU/VM free of charge.
Level 2a: : VCI [HW: 1000 – 1250€/SW 400€]
Level 2b: VCI [HW: 1000 – 1250€/SW 400€]
Level 3: VCI [HW: 1000 – 1250€/SW 500€]
Radius Turning Plates are required

Note:
The costs shown reflect the VCI and software needed to provide the indicated levels of testing for the EPS system ONLY.
These costs would reduce directly in relationship to the testing of other ECSS systems (see below).

Test methods:
Possibility of identifying faulty EPS system:

Current baseline: 0 - no base line conducted
Level 1: 0.3
Level 2a: 0.8
Level 2b: 0.5
Level 3: 1.0

Additional tool functionality and cost amortisation:

Test tool, VCI and external test equipment (radius turning plates) can also be used to test:
ABS (Anti-lock braking system)
ESC (electronic stability control)
EBS (Electronic braking system)

SRS (Supplementary restraint system - no brake tester required)

Time of test	
Level 1:	30s
Level 2a:	+45s
Level 2b:	+45s
Level 3:	+45s – existing radius turning plates test time already exists

13.5 Supplementary Restraint Systems (SRS)

ECSS: SRS - supplementary restraint systems

Description of faults according to 2010/48/EU:

Item 7.1.2 to 7.1.6 of Annex II, paragraph 4,
7.1.2 (e) Safety-belt retractor damaged or not functioning correctly.
7.1.3 Load limiter obviously missing or not suitable with the vehicle
7.1.4 Pre-tensioner obviously missing or not suitable with the vehicle
7.1.5 (a) Airbags obviously missing or not suitable with the vehicle.
7.1.5 (b) Airbag obviously non operative
7.1.6 SRS MIL indicates any kind of failure of the system

DESCRIPTION

SRS is an electromechanical set of components designed to cushion a person from injury. They include shock absorber systems used to reduce the deceleration of the vehicle occupants, as well as to provide them with additional protection. When activated, based on the input from several sensors and a computation by the SRS control unit, the SRS system will be partially or completely deployed.

The majority of SRS designs include pyrotechnical devices.

FAILURES IDENTIFIED

The scale of '0' is low and '10' is high is used below.

The figure against each level of testing indicates the probability to identify the fault at a specific test level (the levels are described after this section):

1. Airbag(s) missing

Direct communication with the SRS system ECU to establish that the airbag(s) is present and correctly coded into the system.
Safety potential – 9
Level 1 - 0
Level 2a – 9
Level 2b - 0
Level 3 – N/A

2. SRS ECU missing or inactive

Direct communication with the SRS ECU to establish that it is present and active.
Safety potential – 9
Level 1 - 10
Level 2a – 10
Level 2b - 10
Level 3 – N/A

3. Wiring and connection / interruption of communication/high resistance/open circuit

Direct communication with the SRS ECU to establish if any DTCs or pending codes are present or direct measurements of sensor values.
Safety potential – 9
Level 1 - 0
Level 2a – 9

Level 2b - 9
Level 3 – N/A

4. MIL not functioning correctly

Direct communication with the SRS ECU to establish that the MIL light is functioning correctly
Safety potential – 2
Level 1 - 0
Level 2a – 8
Level 2b - 10
Level 3 – N/A

5. Sensors (accelerometer, impact, door pressure, wheel speed, gyroscope, brake, seat occupancy etc.)

Direct communication with the SRS ECU to establish if any DTCs or pending codes are present or direct measurements of sensor values.
Safety potential – 9
Level 1 - 0
Level 2a – 8
Level 2b - 8
Level 3 – N/A

6. Pyrotechnical devices not present

Direct communication with the SRS ECU to establish if the pyrotechnic devices are present and correctly coded.
Safety potential – 9
Level 1 - 0
Level 2a – 9
Level 2b - 0
Level 3 – N/A

CURRENT BASELINE

PRESENCE

Visual inspection of the SRS system's components

MIL

Visual inspection of the MIL

MIL used: (inclusion of ISO 2575 symbol(s) relative to SRS)

Level 1

Via OBD port, send communication signal to the SRS ECU.
Test method: “ping” of SRS ECU.

This can identify:
ECU –failed, missing or damaged
Wiring and connecters – missing or damaged

Level 2a

Diagnostic communication: reading information

Reading PTI relevant failure information (no fault codes, pending codes, all components present…)

Reading parameters:
Status of MIL (on/off/…) read on the ECU versus the visual MIL
Read PTI relevant failure information, including stored DTCs and readiness codes (Sensors and actuators)
Identification of any general communication fault with ECU and/or sensors

This can identify:
ECU –failed, missing or damaged
MIL not functioning correctly
Airbag missing
SRS system sensor failures
SRS system sensor and pyrotechnical actuator(s) presence, wiring and connections
SRS system sensor and pyrotechnical actuator(s) values (resistances and status)

Level 2b

Diagnostic communication: SRS system activation

No activation of SRS system is foreseen.

Only generic test allowing checking that the MIL is operational.
Possibility of identifying fault: general communication, with ECU and/or sensors

This can identify:
ECU –failed, missing or damaged
Objective test of the correct operation of the MIL functionality
Wiring and connection to the SRS system ECU
SRS system sensor and pyrotechnical actuator(s) presence, wiring and connections
SRS system sensor and pyrotechnical actuator(s) values (resistances and status)

Level 3

Diagnostic communication and functionality testing of the SRS system

---

Not applicable.

Cost benefit analysis criteria and preferred test method:

In the event of a substantial vehicle crash, the SRS system relies on the ability of each sensor to provide an accurate value to the system ECU to provide trigger signals to be sent to the restraint components, which deploy to minimize potential injuries to the driver and vehicle occupants. Therefore, the ability to check the various system components and sensor connections verifies the ability of the SRS system to operate correctly when required. Direct dynamic testing is not possible.

Cost of tool(s):

Current baseline: No base line conducted for system
Level 1: VCI + basic communication SW [HW: 1000 – 1250€/SW 300€]
(Principle based on technical data coming from a standardized machine readable format from VMs free of charge.)
Level 2a: VCI + basic communication SW [HW: 1000 – 1250€/SW 300€]
Level 2b: VCI + basic communication SW [HW: 1000 – 1250€/SW 300€]
Level 3: Not applicable

Note:
The costs shown reflect the VCI and software needed to provide the indicated levels of testing for the SRS system ONLY.
These costs would reduce directly in relationship to the testing of other ECSS systems (see below).

Test methods:
Possibility of identifying faulty SRS system:

Current baseline: 0 - no base line conducted
Level 1: 0.4
Level 2a: 0.9
Level 2b: 1.0
Level 3: N/A

Additional tool functionality and cost amortisation:
Test tool, VCI can also be used to test:
ABS (brake tester also required)
EBS (brake tester also required)
ESC (brake tester also required)
Headlamp systems (headlamp tester required)

Time of test

Level 1: 15s
Level 2a: +30s

Level 2b: +15s
Level 3: N.A.

13.6 Advanced Emergency Brake System (AEBS)

ECSS: AEBS – Advanced emergency brake system

Description of faults according to 2010/48/EU:

No existing testing is conducted under 2010/48/EU

AEBS-LDWS- TF02-05 Proposal for AEBS regulation based on the European system (Daimler)[18]

Lamp check test: With the subject vehicle stationary and the ignition locking system in the "lock" or "off" position, activate the ignition locking system to the "on" or "run" position. The AEBS shall perform a check of lamp function as specified in paragraph 5.6.3. of this proposed regulation.

DESCRIPTION

An Advanced Emergency Braking System (AEBS) or Autonomous Emergency Braking (AEB) is an autonomous road vehicle safety system which employs sensors to monitor the proximity of vehicles in front and detects situations where the relative speed and distance between the host and target vehicles suggest that a collision is imminent. In such a situation, emergency braking can be automatically applied to avoid the collision or at least to mitigate its effects.

The sensor system consists of at least one sensor monitoring the area in front of the vehicle. Maximum sensor range is 200m to ensure early detection of objects at high speeds and to account for the system's response time. The sensor's main task is to detect objects moving in front of the vehicle. Sensors for the detection of objects are usually radar sensors. Laser sensors (LIDAR) are a less expensive, but are a rarely used alternative. To ensure the better classification of objects, radar sensors may be used in combination with cameras.

A human-machine-interface (HMI) integrates all actuators that exchange information with the driver, including acoustic signals (via speakers), warning lights or LEDs and haptic signals such as a brake jerk or accelerator pedal force feedback.

FAILURES IDENTIFIED

A: System Architecture:

:

[18] Reference: http://www.unece.org/fileadmin/DAM/trans/doc/2009/wp29grrf/AEBS-LDWS-TF-02-05e.pdf Accessed June 2014.

AEBS test require a check of not only the sensors' controller like radar/lidar/camera controller, but that all the architecture works properly (including also Engine/Transmission, ABS, EBS, EPS, Body/IP, Cruise Control and eventually PreCollision and Airbag).

In the following only the faults regarding "vision" system controller are shown.

b: System component fault identification:

The scale of '0' is low and '10' is high is used below.
The figure against each level of testing indicates the probability to identify the fault at a specific test level (the levels are described after this section):

1. Radar/LIDAR/camera:

Vision sensor damaged
Vision sensor "dirty"
Vision sensor not calibrated
Safety potential – 7
Level 1 - 5
Level 2a – 9
Level 2b - 0
Level 3 - 10

2. In-vehicle network communication:

In-vehicle communication is important to receive the data for obstacle position, speed and trajectory evaluation and to transmit data to the other ECUs for their correct operation.
Communication lost with all ECUs
Communication lost with body/IP
Communication lost with ABS/ESP
Communication lost with EPS
Communication lost with SRS system (pre-collision)
Wiring – damaged or missing
Safety potential – 8
Level 1 - 5
Level 2a – 9
Level 2b - 0
Level 3 – 10

3. ECU (ABS system)

Failed or missing
Wiring or connection damaged
ECU damaged, manipulated or spare part not matching
Safety potential – 9
Level 1 - 9
Level 2a – 9
Level 2b - 9
Level 3 – 10

4. Modulated brake force (Hydraulic modulator valves)
Not operating correctly
Safety potential – 9
Level 1 - 0
Level 2a – 7
Level 2b - 0
Level 3 – 10

5. Hydraulic pump
Not operating correctly
Safety potential – 9
Level 1 - 0
Level 2a – 7
Level 2b - 6
Level 3 – 10

6. Pressure sensor
Not operating correctly
Safety potential – 9
Level 1 - 0
Level 2a – 7
Level 2b - 0
Level 3 – 10

7. System integrity
System leakage
Safety potential – 6
Level 1 - 0
Level 2a – 2
Level 2b - 2
Level 3 – 10

CURRENT BASELINE

PRESENCE	
	Visual inspection of the component – N/A
MIL	
	Visual inspection of the MIL.
	MIL used:

Level 1

Via the OBD port, send communication signal to the AEBS ECUs.
Test method: “ping” of AEBS ECUs.

This can identify for the artificial vision aggregate:
ECU – failed, missing or damaged
Wiring and connectors – missing or damaged

Level 2a

Diagnostic communication – reading PTI relevant information

Via the OBD port, communicate with the AEBS ECUs:

Reading parameters:
Status of MIL (on/off/…) read of the ECU versus the observation of the MIL
Read PTI relevant failure information, including DTCs and readiness codes
Identification of any general communication fault with ECUs and/or sensors

This can identify:
Camera – not operating correctly
Radar/LIDAR emitter damaged or not operating correctly
Radar/LIDAR receiver damaged or not operating correctly
Radar/LIDAR not calibrated
AEBS ECUs failure, missing or damaged:
ECM
TCM
ABS/ESP
Body
SRS
EPS
ESC

Level 2b

Diagnostic communication – system component activation

Via the OBD port, communicate with the AEBS ECUs:

Trigger the MIL and visually check that the dashboard MIL illuminates correctly.
Activate the AEBS system warning system

This can identify:
HMI aggregate
Active lamp/ warning on dashboard
Active buzzer
Pre-collision aggregate
Seat belt activation

All other activations can be conducted during other ECCS testing (brake activation and assistance, engine/transmission reduced power, etc.)

Level 3

Diagnostic communication and AEBS system functionality test

Via the OBD port, communicate with the AEBS ECUs:

Driver alert using target
Increase the subject vehicle to the test speed in the test lane. Approach the target vehicle at the test track within the same lane (the target vehicle shall be moving

on the axis of the test course at a constant speed). The AEBS shall warn the driver

This can identify:
HMI aggregate
Active lamp/ warning on dashboard
Active buzzer
Camera damaged
Radar/LIDAR emitter damaged or not operating correctly
Radar/LIDAR receiver damaged or not operating correctly
Radar/LIDAR not calibrated or not operating

Braking system activation test
Continue approaching the target in the test lane. The AEBS system should activate the service brake and/or steering to avoid a collision.

This can identify:
AEBS ECUs failure, missing or damaged:
ABS/ESP
ESC
Body
EPS

Check artificial vision calibration
Using a wheel alignment system and target it's possible check the camera's calibration.

This can identify:
Camera/Radar/LIDAR is not calibrated correctly

Cost benefit analysis criteria and preferred test method

The AEBS system relies on the ability of the camera/LIDAR/Radar sensors to provide an accurate value to the AEBS ECU to allow changes in the steering and applied brake forces to individual wheels to provide safer braking and vehicle control.
Therefore, the ability to check the functionality of the AEBS system through the assessment of the input sensor signals and the ability of the AEBS system to control the vehicle steering and to modulate brake force values are key test criteria.

Proposed test level: - Level 3

Test Methods

Possibility of identifying faulty AEBS system:

Current baseline:	0 - no base line conducted
Level 1:	0.9
Level 2a:	0.7
Level 2b:	0.3
Level 3:	1.7

Cost of tool(s):

Current baseline: no base line conducted
Level 1: VCI + basic communication SW [HW: 1000 – 1250€/SW 200 €]
Principle is that data are coming from a standardized machine
readable format from EU/VM free of charge.
Level 2a: : VCI [HW: 1000 – 1250€/SW 400€]
Level 2b: VCI [HW: 1000 – 1250€/SW 400€]
Level 3: VCI [HW: 1000 – 1250€/SW 500€]
A 4 wheel brake tester, wheel alignment incl. Interface to VCI + target and relative moving cost + target and alignment cost

Note:
The costs shown reflect the VCI and software needed to provide the indicated levels of testing for the AEBS system ONLY.
These costs would reduce directly in relationship to the testing of other ECSS systems (see below).

Additional tool functionality and cost amortisation:

Test tool, VCI can also be used to test all other ECSS.

Time of test

Level 1: 30s
Level 2a: +40s
Level 2b: +40s
Level 3: +60s

13.7 Headlamps

ECSS: headlamps

(incl. Automatic headlight levelling system, Automatic headlight dip system, active/dynamic headlight direction control system (incl. automatic light))
Description of faults according to 2010/48/EU:
Annex II – Items 4.1 Headlamps and 4.5 Front and rear fog lamps

4.1 Headlamps:
4.1.1. Condition and operation:
Defective or missing light/light source.
Defective or missing projection system (reflector and lens).
Lamp not securely attached.

4.1.2. Alignment: Aim of a headlamp not within limits laid down in the requirements (a)
4.1.3. Switching:
Switch does not operate in accordance with the requirements (a) (Number of headlamps illuminated at the same time)
Function of control device impaired.

4.1.4. Compliance with requirements (a).
Lamp, emitted colour, position or intensity not in accordance with the requirements (a).
Products on lens or light source which obviously reduce light intensity or change emitted colour.
Light source and lamp not compatible

4.1.5. Levelling devices (where mandatory):
Device not operating.
Manual device cannot be operated from driver’s seat.

4.1.6. Headlamp cleaning device (where mandatory): Device not operating.

4.5. Front and rear fog lamps:
4.5.1. Condition and operation
Defective light source.
Defective lens.
Lamp not securely attached.

4.5.2. Alignment: Front fog lamp out of horizontal alignment when the light pattern has cut-off line

4.5.3. Switching: Switch does not operate in accordance with the requirements (a).

4.5.4. Compliance with requirements (a):
Lamp, emitted colour, position or intensity not in accordance with the requirements (a)
System does not operate in accordance with the requirements (a)

The following systems are not covered by Directive 2010/48/EU:
AUTOMATIC HEADLIGHT DIP SYSTEM
ACTIVE/DYNAMIC HEADLIGHT DIRECTION CONTROL SYSTEM (INCL. AUTOMATIC LIGHT)
LED headlight systems
Matrix headlight systems

DESCRIPTION

Depending on the load, optionally road possible pitch angle, dynamic driving situations, the system regulates the headlamp´s vertical and/or horizontal aim (e.g. in accordance with ECE-R 121).
The system automatically activates and deactivates the full beam according to driving situation and lighting conditions (adaptive cut off line).
During cornering and depending on the steering angle and speed, the light beam is directed in the direction of travel and/or an additional headlight is activated. (e.g. in accordance with ECE-R 48; ECE-R 98; ECE-R 112; R-119 ECE-R 123)
Depending on the ambient brightness, the system automatically switches on and off the driving light.
Depending on the traffic situation, the system automatically switches on and off, or regulates the direction of the high beam assistant (vertical cut off line; dynamic spot light, matrix beam)

FAILURES IDENTIFIED

1. ECU failure

Check communication with the headlight ECU.
Safety potential – 9
Level 1 - 8
Level 2a -8
Level 2b - 9
Level 3 - 10

2. Height levelling sensors

Check communication with the load levelling sensor
Safety potential – 5
Level 1 - 0
Level 2a - 8
Level 2b - 9
Level 3 - 10

3. Yaw rate sensor

Sensor – damaged or missing
Wiring or connection - damaged
Safety potential – 5
Level 1 - 0
Level 2a - 8
Level 2b - 0
Level 3 - 10

4. Steering angle sensor

Sensor – damaged, missing or incorrect orientation/not calibrated
Wiring or connection - damaged or missing
Safety potential – 5
Level 1 - 0
Level 2a - 8
Level 2b - 0
Level 3 - 10

5. Speed sensor

Sensor – damaged, missing or not operating correctly
Wiring or connection - damaged or missing
Safety potential – 5
Level 1 - 0
Level 2a - 8
Level 2b - 0
Level 3 - 10

6. Light intensity sensor

Sensor – damaged, missing or incorrect orientation/not calibrated
Wiring or connection - damaged or missing
Safety potential – 8
Level 1 - 0
Level 2a - 8
Level 2b - 0
Level 3 - 10

7. Windscreen camera

Camera – damaged, missing or not operating correctly
Wiring or connection - damaged or missing
Safety potential – 8
Level 1 - 0
Level 2a - 6
Level 2b - 0
Level 3 - 10

8. Switches not operating correctly

Switch – damaged, missing or not operating correctly
Wiring or connection - damaged or missing
Safety potential – 9
Level 1 - 0
Level 2a - 0
Level 2b - 0
Level 3 - 10

9. Wiring and connection – interruption of communication signal

Wiring or connection - damaged or missing
Safety potential – 9

Level 1 - 5
Level 2a - 8
Level 2b - 9
Level 3 - 10

10. Headlights not operating correctly or not the correct headlights/ lamps are operating

Headlights – damaged, missing or not operating correctly
Wiring or connection - damaged or missing
Safety potential – 9
Level 1 - 0
Level 2a - 0
Level 2b - 7
Level 3 - 10

11. Headlamps directional control incorrect

Headlights – damaged or not operating correctly
Wiring or connection - damaged or missing
Safety potential – 9
Level 1 - 0
Level 2a - 0
Level 2b - 7
Level 3 - 10

CURRENT BASELINE

PRESENCE	
	Visual inspection of the components
	(external) measurement of headlamp aim
	identification (e.g. approval marks) for lights and lamps
MIL	
	not standardized MILs
	if MIL available, it is usually passive (not activated after ignition- or engine-on)

Level 1

Communication with system ECU for existence via OBD port.
Test method: “ping” of EPS ECU.

This can identify:
ECU – failed, missing or damaged
Wiring and connectors – missing or damaged

Level 2a

Diagnostic communication: reading information	
	Reading PTI relevant failure information, including readiness (sensors, actuators, lights)
	Reading parameters: Status of MIL (on/off/…) read on the ECU versus the visual MIL This can identify: ECU – failed, missing or damaged

Wiring and connectors – missing or damaged
Height levelling sensor – not operating correctly
Yaw rate sensor – not operating correctly
Steering angle sensor – not operating correctly
Speed sensor – incorrect input signal
Light intensity sensor – not operating correctly
Windscreen camera – not operating correctly

Level 2b

Diagnostic communication: activation

	activate separate lights
	Trigger MIL: via electronic activation, allows checking if the dashboard indicator illuminates.
	trigger height leveling to most upward position, most downward position and back to normal position
	trigger bending lights to most left position, most right position and back to normal position

This can identify:
ECU – failed, missing or damaged
Wiring and connectors – missing or damaged
Height leveling sensor
Headlamps do not move correctly
Headlight not operating correctly or not the correct headlights/ lamps are operating

Level 3

Diagnostic communication and other equipment:

	combination of triggering a system (e.g. decreased light level) and measurement of the outcomes using a headlamp tester; comparison against a predictable behaviour
	for multi-LED-systems: combination of triggering a system (e.g. decreased light levels) comparison of the illuminated LEDs against a predictable behaviour
	read sensors during a short test drive (yaw rate, leveling sensors), checked against wheel speed- and steering sensors
	for Automatic headlight dip system: simulation of oncoming light to have high beam switched off or masked
	for Automatic high beam (high beam assist) systems: check the correct setting of the camera and the headlight system

This can identify:
ECU – failed, missing or damaged
Wiring and connectors – missing or damaged
Height leveling sensor – not operating correctly
Headlamp operation – not operating correctly
Auxiliary driving lamps – not operating correctly
Yaw rate sensor – not operating correctly
Steering angle sensor – not operating correctly

Speed sensor – incorrect signal
Light intensity sensor – not operating correctly
Windscreen camera – not operating correctly
Switches - not operating correctly

Cost benefit analysis criteria

Cost of tool(s):

Current baseline: no base line conducted for system – other tool XXX already available for other system. Beam setter 450 – 800€
Level 1: VCI + basic communication SW [HW: 1000 – 1250€] Principle is that data are coming from a standardized machine readable format from EU free of charge. SW 200€
Level 2a: : VCI [HW: 1000 – 1250€] SW 400€
Level 2b:
Level 3: VCI [HW: 1000 – 1250€] SW 500€

Test method

Current baseline:	0 - no base line conducted
Level 1:	0.2
Level 2a:	0.7
Level 2b:	0.5
Level 3:	0.8

Time of test

Level 1: 10s
Level 2a: 20s
Level 2b: 30s
Level 3: 40s

13.8 Tyre Pressure Monitoring System (TPMS)

ECSS: TPMS – Tyre Pressure Monitoring system
Description of faults according to 2010/48/EU:

Not covered

DESCRIPTION
Indirect TPMS – is not considered

Indirect TPMS
Indirect TPMS systems do not use physical pressure sensors but measure air pressures by monitoring individual wheel rotational speeds and other signals available outside of the tyre itself. First generation iTPMS systems utilize the effect that an under-inflated tyre has a slightly smaller diameter (and hence lower tangential velocity) than a correctly inflated one. These differences are measurable through the wheel speed sensors of ABS/ESC systems. Second generation iTPMS can also detect simultaneous under-inflation in up to all four tyres using spectrum analysis of individual wheels, which can be realized in software using advanced signal processing techniques. The spectrum analysis is based on the principle that certain eigenforms and frequencies of the tyre/wheel assembly are highly sensitive to the inflation pressure. These oscillations can hence be monitored through advanced signal processing of the wheel speed signals. Current iTPMS consist of software modules being integrated into the ABS/ESC units.

iTPMS cannot measure or display absolute pressure values, they are relative by nature and have to be reset by the driver once the tyres are checked and all pressures adjusted correctly. The reset is normally done either by a physical button or in a menu of the on-board computer. iTPMS are, compared to dTPMS, more sensitive to the influences of different tyres and external influences like road surfaces and driving speed or style. The reset procedure, followed by an automatic learning phase of typically 20 to 60 minutes of driving under which the iTPMS learns and stores the reference parameters before it becomes fully active, cancels out many, but not all of these. As iTPMS do not involve any additional hardware, spare parts, electronic or toxic waste as well as service whatsoever (beyond the regular reset), they are regarded as easy to handle and very customer friendly [2].
ABS is considered as a stand-alone system in the case of this study.

According to Nira, based on their request to TÜV SÜD to do a pre-test according to similar requirements of the EU legislation, the iTPMS system passed that pre-test.[3] However, the full test procedure as required by the EU regulation, completed by the regulatory body assigned to make the homologation, has not yet been done. Manufacturers like Dunlop Tech also claim their products to fulfil the regulations [4].
iTPMS are widely regarded as inaccurate due to the nature of which they obtain their pressure readings. As such, most TPMS units now on the market are of the 'Direct' type.

Direct TPMS
Direct TPMS employ pressure sensors on each tyre, either internal or external. The sensors physically measure the tyre pressure in each tyre and report it to the vehicle's instrument cluster or a corresponding monitor. Some units also measure and alert temperatures of the tyre as well. These systems can identify under-inflation in any combination, be it one tyre or all,

simultaneously. Although the systems vary in transmitting options, many TPMS products (both OEM and aftermarket solutions) can display real time tyre pressures at each location monitored whether the vehicle is moving or parked. There are many different solutions but all of them have to face the problems of limited battery lifetime and exposure to tough environments. If the sensors are mounted on the outside of the wheel, which is the case for some aftermarket systems, they are in danger of mechanical damage, aggressive fluids and other substances as well as theft. If they are mounted on the inside of the rim, they are no longer easily accessible for service like battery change and additionally, the RF communication has to overcome the damping effects of the tyre which additionally increases the need for energy.

A direct TPMS sensor consists of following main functions requiring only a few external components — e.g., battery, housing, PCB — to get the sensor module that is mounted to the valve stem inside the tyre:
- pressure sensor;
- analog-digital converter;
- microcontroller;
- system controller;
- oscillator;
- radio frequency transmitter;
- low frequency receiver, and
- voltage regulator (battery management).

Most originally fitted dTPMS have the sensors mounted on the inside of the rims and the batteries are not exchangeable. With a battery change then meaning that the whole sensor will have to be replaced and the exchange being possible only with the tyres dismounted, the lifetime of the battery becomes a crucial parameter. To save energy and prolong battery life, many dTPMS sensors hence do not transmit information when not rotating (which also keeps the spare tyre from being monitored) or apply a complex and expensive two-way communication which enables an active wake-up of the sensor by the vehicle. For OEM auto dTPMS units to work properly, they need to recognize the sensor positions and have to ignore the signals from other vehicles' sensors. There are hence numerous tools and procedures to make the dTPMS "learn" or "re-learn" this information, some of them can be carried out by the driver, others need to be done by the workshops or even require special electronic tools. The cost and variety of spare parts, procedures and tools has led to much trouble and confusion both for customers and workshops.

Aftermarket dTPMS units not only transmit while vehicles are moving or parked, but also provide users with numerous advanced monitoring options including data logging, remote monitoring options and more. They are available for all types of vehicles, from motorcycles to heavy equipment, and can monitor up to 64 tyres at a time, which is important for the commercial vehicle markets. Many aftermarket dTPMS units do not require specialized tools to program or reset, making them much simpler to use.

FAILURES IDENTIFIED

The direct TPMS system is monitoring the tyre pressure system consisting of::

Electronic components:

1. TPMS ECU

Check if the TPMS ECU is fitted.

Check if the TPMS is active/operating correctly
Check if the wheel sensor signals are active
Safety potential – 6
Level 1 - 3
Level 2a – 9
Level 2b - 9
Level 3 - 10

2. Pressure transducer

Check if the transducer is damaged, not operating correctly or not correctly calibrated (if fitted)
Built-in transceiver – damaged or not operating correctly (if fitted)
Safety potential – 6
Level 1 - 0
Level 2a –7
Level 2b - 9
Level 3 - 10

3. Other components

Connections or wiring – damaged or missing
Safety potential – 6
Level 1 - 0
Level 2a –7
Level 2b - 9
Level 3 - 10

CURRENT BASELINE

PRESENCE	
	Visual inspection of the systems components
MIL	
	Visual inspection of the MIL
	MIL used (inclusion of ISO 2575 symbol relative to TPMS)

TPMS - Low pressure warning icon

TPMS – System failure icon

Functional test

Currently not done

Level 1

Identification of the ECU (Hardware and Software Version)

Test method: “ping” of system ECU.

Level 2a

Diagnostic communication: reading information

Reading PTI relevant failure information

Reading parameters:
Status of MIL (on/off/…) comparing the status of the ECU vs the MIL – visual inspection
Reading the PTI relevant DTCs – stored or pending trouble codes

Level 2b

Diagnostic communication: ECSS system activation

TPMS system is on as soon as the ignition is on:
Verify each wheel sensor signal and value (if possible)
If fitted, activate the RF antenna and check RF signal

Level 3

Diagnostic communication and functionality testing of the ECSS system:

Identify the ECU and software version
Activate each wheel sensor (if fitted)
Read sensor signals (sensor ID, RF pressure, temperature and battery status) and compare to ambient values.

Cost benefit analysis criteria

Test Methods

Current baseline: no base line conducted -
Level 1: 0.2
Level 2a: 0.6
Level 2b: 0.7
Level 3: 1.2
Possibility of identifying fault:

TPMS is consider to be relevant for emission reductions as well as accident reduction

Cost of tool(s):

Current baseline: no base line conducted for system – other tool like diagnostic

computer are already available to read DTC and real pressure data
Level 1:
Level 2a:
Level 2b:
Level 3:

Time of test

Level 1: 30s
Level 2a: 45s
Level 2b: 45s
Level 3: 45s

14Annex 2: List of vehicle failures which may not light MIL

ECSS		Failures	Test method	Test level	Test outcome
Brakes	**Generic**	hydraulic pipes interchanged	trigger ESC pressure for each wheel separately on brake tester	3	while left brake calliper is triggered, brake force results to the right tyre/wheel
		counterfeit brake pads on front axle	reference braking values, containing:		(while left tyre/wheel is without any) or vice versa
			lowest brake force “front” at measured brake system pressure	3	
			lowest brake force “rear” at measured brake system pressure	3	
			judgement of brake force distribution (at normalized brake pressure)	3	At measured brake system pressure, the lowest brake force front is not reached brake force distribution inadequate
	ABS	Faulty ECU	Ping' ECU to establish if communication is possible	1	ECU is fitted and 'alive' (also applies if levels 2a, 2b and 3 test are performed)
	Anti-lock brakes	air gap between wheel speed sensor and tooth rim too large	read out of wheel speed for each wheel on RBT	3	affected wheel speed sensor shows irregular data
		faulty toothed wheel (damaged or gaps filled in)	read out of wheel speed for each wheel on RBT	3	affected wheel speed sensor shows irregular data
		modulator valves not operating correctly	read out of applied brake force to each wheel when ABS system triggered	3	Inconsistent modulation of brake force values
		hydraulic pump not operating correctly	read the pressure value to ensure that the ABS system can operate correctly	3	Brake pressure insufficient when the system is operational
		hydraulic pressure sensor not operating correctly	read the pressure value to ensure correct control of the ABS system function	3	Brake pressure and/or pressure modulation not operating correctly
		brake pedal sensor signal	depress brake pedal and read values	3	Incorrect ABS system function when the brake pedal is pressed
	EBA	Brake pedal sensor	Pedal sensor fitted and connected	2a	Brake pedal sensor provides a signal and no DTC's are stored
	Emergency brake assist	Brake pedal sensor signal	Pedal sensor value	2b	Brake pedal sensor value corresponds to correct signal values
		hydraulic pressure sensor not operating correctly	read the speed and value of the pressure rise when the brake pedal is rapidly, but not violently or fully applied	2b	Pressure sensor values correspond to the expected values
		system not functioning	Send vehicle speed signal to the EBA/ABS ECU to ensure system is operational and then rapidly, but not violently or fully, depress the brake pedal	3	Check if maxiumum brake force is automatically applied
	ESC				
	Electronic stability control	interchanged or malfunctioning wheel speed sensors	read-out of all related sensor data	2a	}
		malfunctioning or wrongly mounted yawrate, acceleration or steering wheel-sensors	read-out of electric power steering current	2a	} data of the sensors and actuators not cross-system consistent
		non-functioning or wrong functioning of electric power steering	cross-system consistency check data of sensor data during a short test drive	2a	}
		hydraulic pump not operating correctly	read the pressure value to ensure that the ABS system can operate correctly	3	Brake pressure insufficient when the system is operational
		hydraulic pressure sensor not operating correctly	read the pressure value to ensure correct control of the ABS system function	3	Brake pressure and/or pressure modulation not operating correctly
		brake pedal sensor signal	depress brake pedal progessively and fully	3	Incorrect ABS system function when the brake pedal is pressed
		steering wheel sensor missing, damaged or not calibrated correctly	Turn steering wheel fully lock to lock	2b	No values available, values incorrect or not calibrated correctly
	EBS	Brake pedal sensor	depress brake pedal progessively and fully	3	Incorrect ABS system function when the brake pedal is pressed
	Electronic braking system	faulty toothed wheel (damaged or gaps filled in)	read out of wheel speed for each wheel on RBT	3	affected wheel speed sensor shows irregular data
		Brake pressure sensor - front axle	read out pressure sensor value	2b	Pressure sensor values correspond to the expected values & correlate to the brake pedal input value
		Brake pressure sensor - rear axle(s)	read out pressure sensor value	2b	Pressure sensor values correspond to the expected values
		Hydraulic pump not operating correctly	read the pressure value to ensure that the ABS system can operate correctly	3	Brake pressure insufficient when the system is operational
		steering wheel sensor missing, damaged or not calibrated correctly	Turn steering wheel fully lock to lock	2b	No values available, or values incorrect
	AEBS				
	Automatic emergency braking system	TBC			
SRS	Airbag(s)	Airbag missing or not configured to vehicle correctly	read out of crash counter and additionally verify if all airbags are fitted and configured into the vehicle correctly	2a	Check that airbag(s) are fitted and configured correctly to the vehicle
	Seat belt pre-tensioner	check that pre-tensioner is fitted	read out of the resistance value and check if the pre-tensioner is configured vehicle correctly	2b	Check that pre-tensioner(s) are fitted and configured correctly
		steering wheel sensor missing, damaged or not calibrated correctly	Turn steering wheel fully lock to lock	2b	No values available, values incorrect or not calibrated correctly
EPS	Electronic power steering	hydraulic mechanical actuator	Turn steering wheel fully lock to lock	3	system provides the correct power assistance
Dynamic Headlight and levelling	automatic levelling	moving range insufficient	trigger vertical movement far up, far down and back	3	headlamp does not move to the end stops
			read out of level sensor data while moving the vehicle vertically (manually or by sitting into the car, lifting of the vehicle or driving into the roller brake tester)	2a	affected level (speed) sensor shows no change in signal
	dynamic headlight control	linkage of the headlight broken, damaged or otherwise malfunctioning	verify that the mechanical action corresponds to the electronic control signal commands	3	headlight directional control not responding correctly to control commands
TPMS	Tyre pressure monitoring systems	TPMS ECU is fitted and active	Ping' ECU to establish if communication is possible	1	ECU is fitted and 'alive' (also applies if levels 2a, 2b and 3 test are performed)
		Check if the wheel sensor signals are active and correspond to the correct wheel position and tyre fitment	TBC		

Note: Failures highlighted with shading were selected for laboratory testing.

15Annex 3: Available tools for laboratory testing

15.1 Universal diagnostic tools

Company	Tools	ABS			AEBS			EBS			EPS			ESC			Lights			SRS			TPMS		
		level 1	levels 2a & 2b	level 3	level 1	levels 2a & 2b	level 3	level 1	levels 2a & 2b	level 3	level 1	levels 2a & 2b	level 3	level 1	levels 2a & 2b	level 3	level 1	levels 2a & 2b	level 3	level 1	levels 2a & 2b	level 3	level 1	levels 2a & 2b	level 3
Actia	**2 softwares:** -multidiag -actitronix **Equipment:** -pc - xg mobile -VCO + OBD plug cable	ok	ok	ok				not available yet	not available yet	not available yet	ok	ok	ok	ok	ok for 2a 2b:?	?				ok	ok 2b: at least MIL	MIL	ok	ok 2b: using ext equip	using ext equip
AREX	PC-based plate brake tester with 4 brake plates to measure the results of the ABS test	ok	ok	ok																					
Autocom	Good coverage	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	concerns	concerns	concerns
AVL DiTest	Good coverage	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok
Bosch	**1st step:** Standard-KTS-System **2nd step:** field-testing with interactive solution SD-Diagnostics/Braketester	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok
Boxenteam	Scan tool and turning plates for EPS Scan tool for TPMS Plate brake tester for Brakes-related systems	plate brake tester			plate brake tester			plate brake tester			ok	ok	ok	plate brake tester									ok	ok	ok
Brain Bee		ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok
Capelec	Electronic Headlight tester																Electronic Headlight tester								
FSD	PTI-Adapter 21 PLUS, software PTI21	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok
Hella Gutmann Solutions	Diagnostic tester MM66 Valve exciter (TPMS) Beamsetter (Lights)	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok
Maha	**ABS/ESC Level 3:** Roller brake tester MBT 2250 for passenger cars incl. PC-cabinet and application software EUROSYSTEM VCI – Tool "PTI-TOOL" connected to EUROSYSTEM **Lights:** Digital Headlight Tester '"LITE 3"			ok												ok			ok						
Tecnomotor	TPM - 02 (TPMS diagnostic/reprogramming tool) Socio 500 -300 (diagnostic units) Scan tool but specialised on TPMS - good coverage	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok
TEN Automotive	Plate brake tester	plate brake tester			plate brake tester			plate brake tester						plate brake tester											
Texa	Axone4 (Display unit) Navigator Nano (VCI) Good coverage	ok	ok	ok				ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok
Vteq	Brake Tester - Vteq Brake Tester Brak3080 (software can be modified accordingly)	Roller Brake Tester			Roller Brake Tester			Roller Brake Tester						Roller Brake Tester											

15.2 Specialised tools

Company	Tools	ABS			AEBS			EBS			EPS			ESC			Lights			SRS			TPMS		
		level 1	levels 2a & 2b	level 3	level 1	levels 2a & 2b	level 3	level 1	levels 2a & 2b	level 3	level 1	levels 2a & 2b	level 3	level 1	levels 2a & 2b	level 3	level 1	levels 2a & 2b	level 3	level 1	levels 2a & 2b	level 3	level 1	levels 2a & 2b	level 3
Actia	**2 softwares:** -multidiag -actitronix **Equipment:** -pc - xg mobile -VCO + OBD plug cable	ok	ok	ok				not available yet	not available yet	not available yet	ok	ok	ok	ok	ok for 2a 2b:?	?				ok	ok 2b: at least MIL	MIL	ok	ok 2b: using ext equip	using ext equip
AREX	PC-based plate brake tester with 4 brake plates to measure the results of the ABS test	ok	ok	ok																					
Autocom	Good coverage	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	concerns	concerns	concerns
AVL DiTest	Good coverage	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok
Bosch	**1st step:** Standard-KTS-System **2nd step:** field-testing with interactive solution SD-Diagnostics/Braketester	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok
Boxenteam	Scan tool and turning plates for EPS **Scan tool for TPMS** Plate brake tester for Brakes-related systems	plate brake tester			plate brake tester			plate brake tester			ok	ok	ok	plate brake tester									ok	ok	ok
Brain Bee		ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok
Capelec	Electronic Headlight tester																Electronic Headlight tester								
FSD		ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok
Hella Gutmann Solutions	Diagnostic tester MM66 **Valve exciter (TPMS)** Beamsetter (Lights)	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok
Maha	**ABS/ESC Level 3:** Roller brake tester MBT 2250 for passenger cars incl. PC-cabinet and application software EUROSYSTEM VCI – Tool "PTI-TOOL" connected to EUROSYSTEM **Lights:** Digital Headlight Tester '"LITE 3"			ok												ok			ok						
Tecnomotor	TPM - 02 (TPMS diagnostic/reprogramming tool) Socio 500 -300 (diagnostic units) **Scan tool but specialised on TPMS - good coverage**	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok
TEN Automotive	Plate brake tester	plate brake tester			plate brake tester			plate brake tester						plate brake tester											
Texa	Axone4 (Display unit) Navigator Nano (VCI) Good coverage	ok	ok	ok				ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok	ok
Vteq	Brake Tester - Vteq Brake Tester Brak3080 (software can be modified accordingly)	Roller Brake Tester			Roller Brake Tester			Roller Brake Tester						Roller Brake Tester											

16Annex 4: Cost Benefit Analysis for selection of concept method

16.1 Anti-lock Braking System (ABS)

No.		1			
System type		Braking			
ECSS		ABS - Anti-lock braking system			
European vehicle number fitted with this system		?			
Assessment level		1	2a	2b	3
Tool		VCI + basic SW	VCI + SW2a	VCI + SW2b	VCI + SW3 + brake tester incl. Interface to VCI
Test drive out of the inspection station necessary (Y,N)		n	n	n	n
Costs					
Cost level of tool and SW (0-10)		8	9	9	10
Level of costs on external information (0-10)		0	0	0	0
Level of cost for additional test equipment (0-10)		0	0	0	3
cost (0 - 10) - Note: lowest cost 0, highest cost 10 [mean of cost]		3	3	3	4
Duration of inspection step without conditioning in sec.		30	45	45	45
automatic test procedure (timesave in sec.)		25	30	30	30
time (sec.) [Duration of inspection step without conditioning - automatic test procedure]		5	15	15	15
time (0-10) - [10*time/max. time]		3.3	10.0	10.0	10.0
intermediate result - [(Cost + 3*time)/4]		3.2	8.3	8.3	8.6
Benefit					
Subsystems	safety potential (1-10)	potential to identify the fault (0-10)	potential to identify the fault (0-10)	potential to identify the fault (0-10)	potential to identify the fault (0-10)
Brake pedal sensor	9	0	9	0	10
Wheel speed sensor	9	0	9	0	10
Hydraulic pump	9	0	6	9	10
Pressure sensor	9	0	7	0	10
System hydraulic integrity	9	0	0	2	10
ABS ECU	9	9	9	9	10
Modulated brake force	9	0	7	0	10
count of subsystems	7				
benefit (0-10) - Note: lowest 0, highest 10 [Σ(safety potential * potential to identify the fault)/count of subsystems]		1.2	6.0	2.6	9.0
Benefit / cost ratio					
benefit - cost ratio [benefit/cost]		0.4	0.7	0.3	1.0

16.2 Electronic Stability Control (ESC)

No.		3			
System type		Braking			
ECSS		ESC - Electronic Stability Control			
European vehicle number fitted with this system		?			
Assessment level		1	2a	2b	3
Tool		VCI + basic SW	VCI + SW2a	VCI + SW2b	VCI + SW3 + brake tester incl. Interface to VCI
Test drive out of the inspection station necessery (Y,N)		n	n	n	n
Costs					
Cost level of tool and SW (0-10)		8	9	9	10
Level of costs on external information (0-10)		0	0	0	0
Level of cost for additional test equipment (0-10)		0	0	0	3
cost (0 - 10) - Note: lowest cost 0, highest cost 10 [mean of cost]		3	3	3	4
Duration of inspection step without conditioning in sec.		30	45	45	45
automatic test procedure (timesave in sec.)		20	30	30	30
time (sec.) [Duration of inspection step without conditioning - automatic test procedure]		10	15	15	15
time (0-10) - [10*time/max. time]		6.7	10.0	10.0	10.0
intermediate result - [(Cost + 3*time)/4]		5.7	8.3	8.3	8.6
Benefit					
Subsystems	safety potential (1-10)	potential to identify the fault (0-10)	potential to identify the fault (0-10)	potential to identify the fault (0-10)	potential to identify the fault (0-10)
Brake pedal sensor	9	0	9	0	10
Hydraulic pump	9	0	7	6	10
Hydraulic modulator valves	9	0	7	0	10
Pressure sensor	9	0	7	0	10
System integrity	6	0	2	2	10
Twisted connection of hydraulic tubes (e.g. left/right)	9	0	0	0	10
Wheel Speed Sensors	9	0	9	0	10
Steering Angle Sensor	7	0	5	0	8
Yaw Angle Sensor	7	0	5	0	0
ESC ECU	9	10	9	10	10
ABS ECU	9	10	7	9	10
Engine ECU	2	10	9	0	10
Throttle Actuator	2	0	9	7	5
Ignition Module	2	0	9	0	10
Accelerator Pedal Sensor	2	0	9	0	5
Malfunction indicator light	2	0	0	10	0
count of subsystems	15				
benefit (0-10) - Note: lowest 0, highest 10 [Σ(safety potential * potential to identify the fault)/count of subsystems]		1.3	3.8	1.8	5.4
Benefit / cost ratio					
benefit - cost ratio [benefit/cost]		**0.2**	**0.5**	**0.2**	**0.6**

16.3 Electronic Braking System (EBS)

No.		2			
System type		Braking			
ECSS		EBS- Electronic Braking System			
European vehicle number fitted with this system		?			
Assessment level		1	2a	2b	3
Tool		VCI + basic SW	VCI + SW2a	VCI + SW2b	VCI + SW3 + brake tester incl. Interface to VCI
Test drive out of the inspection station necessary (Y,N)		n	n	n	n
Costs					
Cost level of tool and SW (0-10)		8	9	9	10
Level of costs on external information (0-10)		0	0	0	0
Level of cost for additional test equipment (0-10)		0	0	0	3
cost (0 - 10) - Note: lowest cost 0, highest cost 10 [mean of cost]		3	3	3	4
Duration of inspection step without conditioning in sec.		30	45	45	45
automatic test procedure (timesave in sec.)		20	30	30	30
time (sec.) [Duration of inspection step without conditioning - automatic test procedure]		10	15	15	15
time (0-10) - [10*time/max. time]		6.7	10.0	10.0	10.0
intermediate result - [(Cost + 3*time)/4]		5.7	8.3	8.3	8.6
Benefit					
Subsystems	safety potential (1-10)	potential to identify the fault (0-10)	potential to identify the fault (0-10)	potential to identify the fault (0-10)	potential to identify the fault (0-10)
Brake pedal sensor	9	0	9	0	10
Wheel speed sensor	9	0	9	0	10
Hydraulic Pump	9	0	6	9	10
Brake pressure sensor rear	9	0	7	0	10
Brake pressure sensor front	9	0	7	0	10
Longitudinal acceleration sensor	9	0	7	0	10
Yaw angle sensor	7	0	5	0	0
Steering angle sensor	9	0	7	0	10
EBS ECU	9	9	9	9	10
Hydraulic agregat	9	0	0	2	10
count of subsystems	10				
benefit (0-10) - Note: lowest 0, highest 10 [Σ(safety potential * potential to identify the fault)/count of subsystems]		0.8	6.6	2.7	9.0
Benefit / cost ratio					
benefit - cost ratio [benefit/cost]		0.1	0.8	0.3	1.0

16.4 Electronic Power Steering (EPS)

No.		4			
System type		**Steering**			
ECSS		EPS - Electronic Power Steering			
European vehicle number fitted with this system		?			
Assessment level		**1**	**2a**	**2b**	**3**
Tool		VCI + basic SW	VCI + SW2a	VCI + SW2b	VCI + SW3 + Radius Turning Plates
Test drive out of the inspection station necessery (Y,N)		n	n	n	n
Costs					
Cost level of tool and SW (0-10)		8	9	9	10
Level of costs on external information (0-10)		0	0	0	0
Level of cost for additional test equipment (0-10)		0	0	0	1
cost (0 - 10) - Note: lowest cost 0, highest cost 10 [mean of cost]		3	3	3	4
Duration of inspection step without conditioning in sec.		30	45	45	45
automatic test procedure (timesave in sec.)		25	30	30	30
time (sec.) [Duration of inspection step without conditioning - automatic test procedure]		5	15	15	15
time (0-10) - [10*time/max. time]		3.3	10.0	10.0	10.0
intermediate result - [(Cost + 3*time)/4]		3.2	8.3	8.3	8.4
Benefit					
Subsystems	**safety potential (1-10)**	**potential to identify the fault (0-10)**	**potential to identify the fault (0-10)**	**potential to identify the fault (0-10)**	**potential to identify the fault (0-10)**
Steering angle sensor	**9**	0	9	0	10
Torque force sensor	**9**	0	9	0	10
RPM sensor	**9**	0	9	0	10
Speed sensor	**9**	0	9	0	8
EPS ECU	**9**	9	8	9	10
Hydraulic pump	**9**	0	9	9	10
Hydraulic mechanical actuator	**9**	0	8	9	10
MIL	**9**	0	8	9	10
Hydraulic Oil	**9**	0	0	0	10
Wiring and connector	**9**	0	8	10	10
count of subsystems	**10**				
benefit (0-10) - Note: lowest 0, highest 10 [Σ(safety potential * potential to identify the fault)/count of subsystems]		0.8	6.9	4.1	8.8
Benefit / cost ratio					
benefit - cost ratio [benefit/cost]		**0.3**	**0.8**	**0.5**	**1.0**

16.5 Supplementary Restraint System (SRS)

No.		5			
System type		**Restraint**			
ECSS		SRS - Supplementary Restraint Systems			
European vehicle number fitted with this system		?			
Assessment level		1	2a	2b	3
Tool		VCI + basic SW	VCI + SW2a	VCI + SW2b	VCI + SW3
Test drive out of the inspection station necessery (Y,N)		n	n	n	n
Costs					
Cost level of tool and SW (0-10)		6	7	7	na
Level of costs on external information (0-10)		0	0	0	
Level of cost for additional test equipment (0-10)		0	0	0	
cost (0 - 10) - Note: lowest cost 0, highest cost 10 [mean of cost]		2	2	2	
Duration of inspection step without conditioning in sec.		15	30	15	na
automatic test procedure (timesave in sec.)		10	20	10	na
time (sec.) [Duration of inspection step without conditioning - automatic test procedure]		5	10	5	
time (0-10) - [10*time/max. time]		5.0	10.0	5.0	
intermediate result - [(Cost + 3*time)/4]		4.3	8.1	4.3	
Benefit					
Subsystems	**safety potential (1-10)**	**potential to identify the fault (0-10)**	**potential to identify the fault (0-10)**	**potential to identify the fault (0-10)**	**potential to identify the fault (0-10)**
Airbag(s)	**9**	0	9	0	na
SRS ECU	**9**	10	10	10	na
Wiring and connection	**9**	0	9	9	na
MIL	**2**	0	8	10	na
Sensors	**9**	0	8	8	na
Pyrotechnical devices	**9**	0	9	0	na
count of subsystems	**6**				
benefit (0-10) - Note: lowest 0, highest 10 [Σ(safety potential * potential to identify the fault)/count of subsystems]		1.5	7.0	4.4	
Benefit / cost ratio					
benefit - cost ratio [benefit/cost]		**0.4**	**0.9**	**1.0**	

16.6 Automatic Emergency Braking System (AEBS)

No.		6			
System type		**Braking**			
ECSS		AEBS - Automatic Emergency Braking Systems			
European vehicle number fitted with this system		?			
Assessment level		1	2a	2b	3
Tool		VCI + basic SW	VCI + SW2a	VCI + SW2b	VCI + SW3 + brake tester incl. Interface to VCI
Test drive out of the inspection station necessery (Y,N)		n	n	n	n
Costs					
Cost level of tool and SW (0-10)		8	9	9	10
Level of costs on external information (0-10)		0	0	0	0
Level of cost for additional test equipment (0-10)		0	0	0	3
cost (0 - 10) - Note: lowest cost 0, highest cost 10 [mean of cost]		3	3	3	4
Duration of inspection step without conditioning in sec.		30	40	40	60
automatic test procedure (timesave in sec.)		25	20	20	50
time (sec.) [Duration of inspection step without conditioning - automatic test procedure]		5	20	20	10
time (0-10) - [10*time/max. time]		2.5	10.0	10.0	5.0
intermediate result - [(Cost + 3*time)/4]		2.5	8.3	8.3	4.8
Benefit					
Subsystems	**safety potential (1-10)**	**potential to identify the fault (0-10)**	**potential to identify the fault (0-10)**	**potential to identify the fault (0-10)**	**potential to identify the fault (0-10)**
Radar/LIDAR/camera	**7**	5	9	0	10
In-vehicle network communication	**8**	5	9	0	10
ABS ECU	**9**	9	9	9	10
Modulated brake force	**9**	0	7	0	10
Hydraulic pump	**9**	0	7	6	10
Pressure sensor	**9**	0	7	0	10
System hydraulic integrity	**6**	0	2	2	10
count of subsystems	**7**				
benefit (0-10) - Note: lowest 0, highest 10 [Σ(safety potential * potential to identify the fault)/count of subsystems]		2.2	6.0	2.1	8.1
Benefit / cost ratio					
benefit - cost ratio [benefit/cost]		**0.9**	**0.7**	**0.3**	**1.7**

16.7 Headlights

No.		7			
System type		Headlights			
ECSS		Headlight control systems			
European vehicle number fitted with this system		?			
Assessment level		1	2a	2b	3
Tool		VCI + basic SW	VCI + SW2a	VCI + SW2b	VCI + SW3 + Headlight tester incl. interface
Test drive out of the inspection station necessery (Y,N)		n	n	n	n
Costs					
Cost level of tool and SW (0-10)		8	9	9	10
Level of costs on external information (0-10)		0	0	0	2
Level of cost for additional test equipment (0-10)		0	0	0	3
cost (0 - 10) - Note: lowest cost 0, highest cost 10 [mean of cost]		3	3	3	5
Duration of inspection step without conditioning in sec.		10	20	30	40
automatic test procedure (timesave in sec.)		0	10	20	30
time (sec.) [Duration of inspection step without conditioning - automatic test procedure]		10	10	10	15
time (0-10) - [10*time/max. time]		6.7	6.7	6.7	10.0
intermediate result - [(Cost + 3*time)/4]		5.7	5.8	5.8	8.8
Benefit					
Subsystems	safety potential (1-10)	potential to identify the fault (0-10)	potential to identify the fault (0-10)	potential to identify the fault (0-10)	potential to identify the fault (0-10)
Headlight ECU	9	8	8	9	10
Height levelling sensors	5	0	8	9	10
Yaw rate sensor	5	0	8	0	10
Steering angle sensor	5	0	8	0	10
Speed sensor	5	0	8	0	10
Light intensity sensor	8	0	8	0	10
Windscreen camera	8	0	6	0	10
Switches	9	0	0	0	10
Wiring and connections	9	5	8	9	10
Headlight operation	9	0	0	7	10
Headlamp direction control	9	0	0	7	10
count of subsystems	11				
benefit (0-10) - Note: lowest 0, highest 10 [Σ(safety potential * potential to identify the fault)/count of subsystems]		1.1	3.8	3.0	7.4
Benefit / cost ratio					
benefit - cost ratio [benefit/cost]		0.2	0.7	0.5	0.8

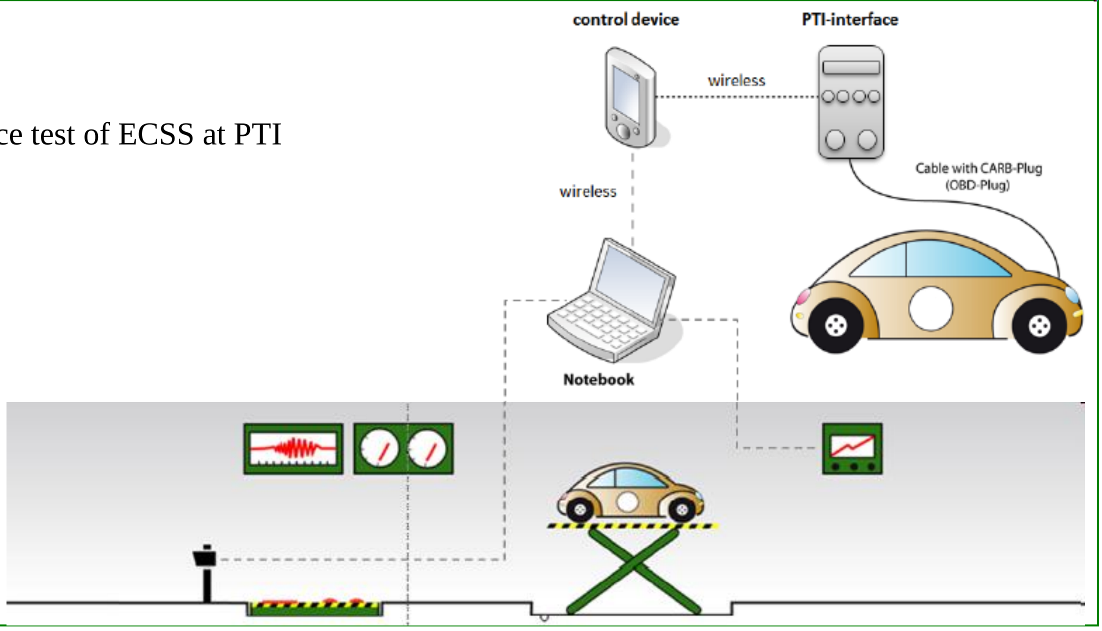
16.8 Tyre Pressure Monitoring System (TPMS)

No.		8			
System type		Tyres			
ECSS		TPMS - Tyre Pressure Monitoring System			
European vehicle number fitted with this system		?			
Assessment level		1	2a	2b	3
Tool		VCI + basic SW	VCI + SW2a	VCI + SW2b	VCI + SW3
Test drive out of the inspection station necessery (Y,N)		n	n	n	n
Costs					
Cost level of tool and SW (0-10)		5	6	6	6
Level of costs on external information (0-10)		0	0	0	0
Level of cost for additional test equipment (0-10)		0	0	0	2
cost (0 - 10) - Note: lowest cost 0, highest cost 10		2	2	2	3
Duration of inspection step without conditioning in sec.		30	45	45	45
automatic test procedure (timesave in sec.)		20	20	20	30
time (sec.) [Duration of inspection step without conditioning - automatic test procedure]		10	25	25	15
time (0-10) - [10*time/max. time]		4.0	10.0	10.0	6.0
intermediate result - [(Cost + 3*time)/4]		3.4	8.0	8.0	5.2
Benefit					
Subsystems	safety potential (1-10)	potential to identify the fault (0-10)	potential to identify the fault (0-10)	potential to identify the fault (0-10)	potential to identify the fault (0-10)
TPMS ECU	6	3	9	9	10
Pressure transducer	6	0	7	9	10
Other components	6	0	7	9	10
count of subsystems	3				
benefit (0-10) - Note: lowest 0, highest 10 [Σ(safety potential * potential to identify the fault)/count of subsystems]		0.6	4.6	5.4	6.0
Benefit / cost ratio					
benefit - cost ratio [benefit/cost]		**0.2**	**0.6**	**0.7**	**1.2**

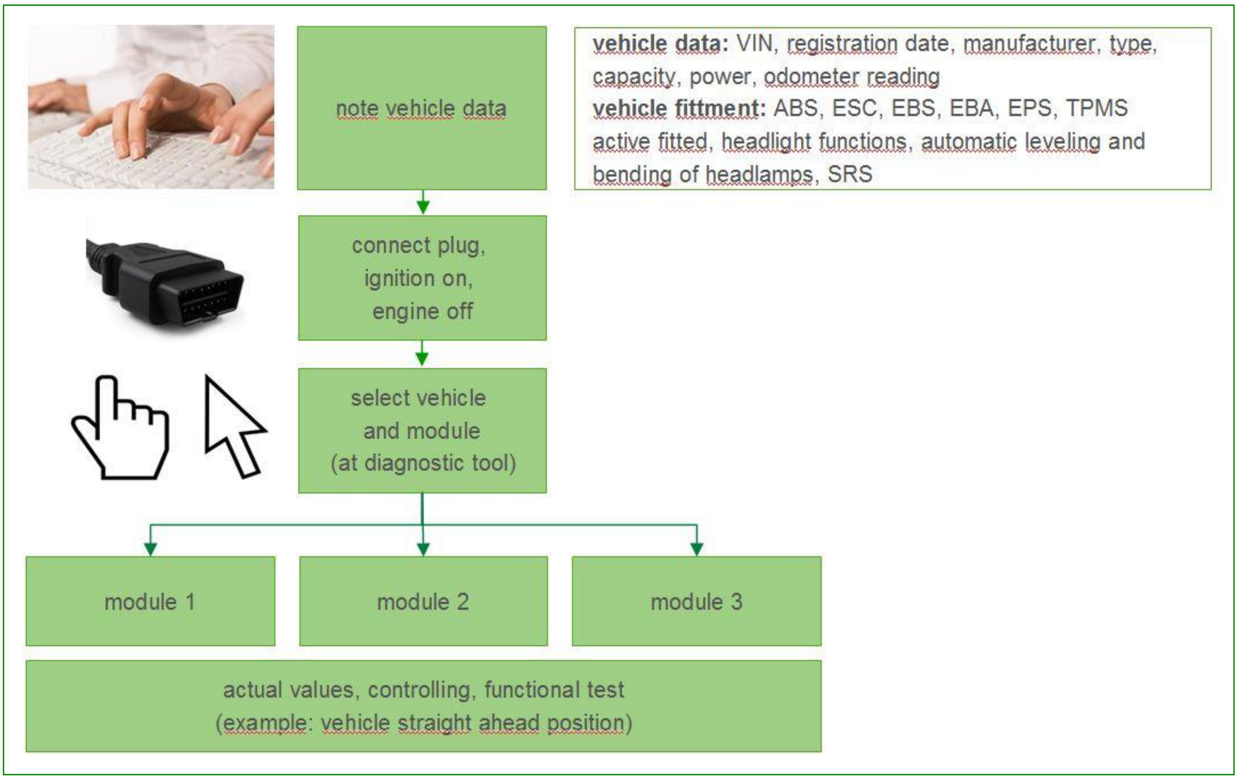
17 Annex 5: Field Testing: Elaborated Method and Data Collection

17.1 Performance test

Performance test of ECSS at PTI
„field test“



17.2 Field testing – first steps



In the excel spreadsheet “general data” of the file “Original”, which was developed for the field test these steps are structured as follow:

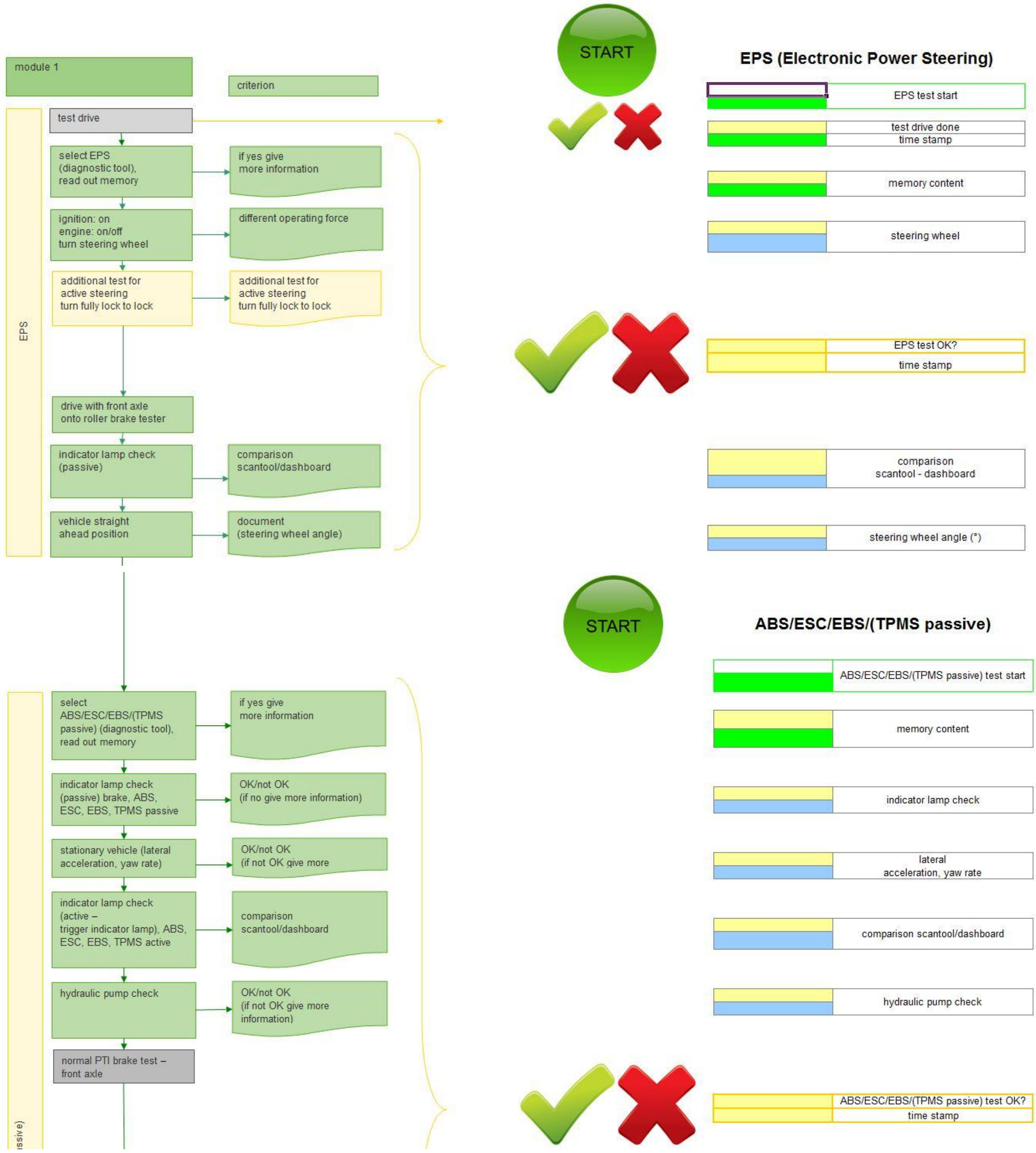
Organisation:	TUEV Rheinland	
Test inspector:	Achim	
Tools:	**Tool**	**TPMS tool (activ TPMS)**

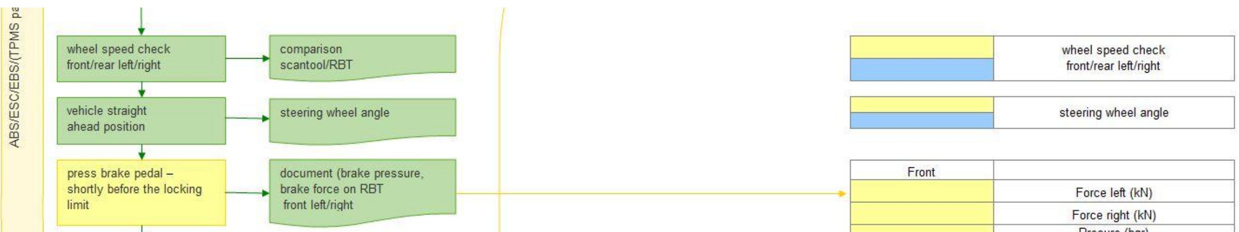
Position					
1	Vehicle : Registration date >2001				
2	Record vehicle data	**Vehicle**	**Data**		
3		VIN:			
4		Licence plate number:			
5		Registration date:			
6		Manufacturer:			
7		Type:			
8		Capacity (ccm):			
9		Power (kW):			
10		Odometer reading (km):		**Indicator lamp**	
11	Record vehicle fittment	ABS fitted		ABS	
12		ESC fitted		ESC	
13		EBS fitted		EBS	
14		EBA fitted		EBA	
15		TPMS active fitted		TPMS active	
16		EPS fitted		EPS	
17		Headlight functions fitted		Headlight functions	
18		Automatic leveling and bending of headlamps fitted		Automatic leveling and bending of headlamps	
19		SRS fitted		SRS	

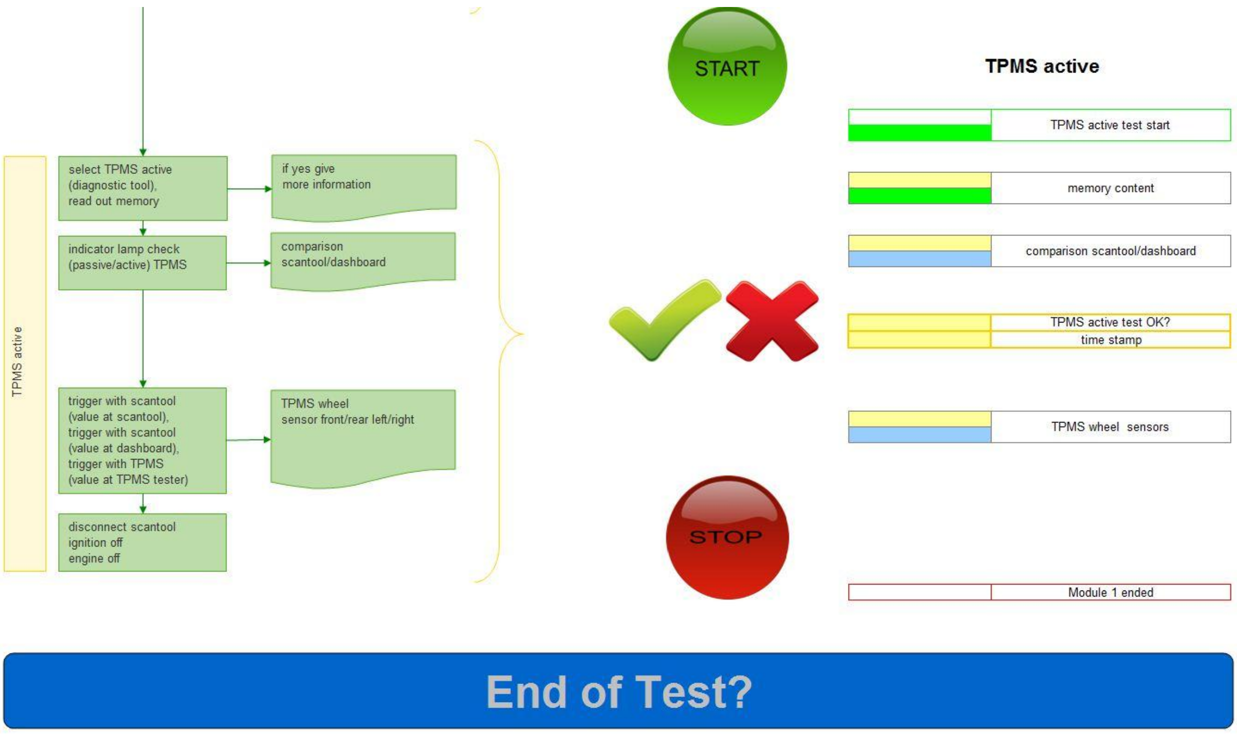
	Results on PTI test		
		Failures	Average failure rate [%]
20	Brake system		
21	Steering		
22	Visibility		
23	Lights		
24	Axles, Tyres		
25	Chassis		
26	Additional equipment		
27	Environment		
28	Additional checks		
29	Identification		

17.3 Field testing – module 1

The second excel spreadsheet in the file "Original" consists of module 1.

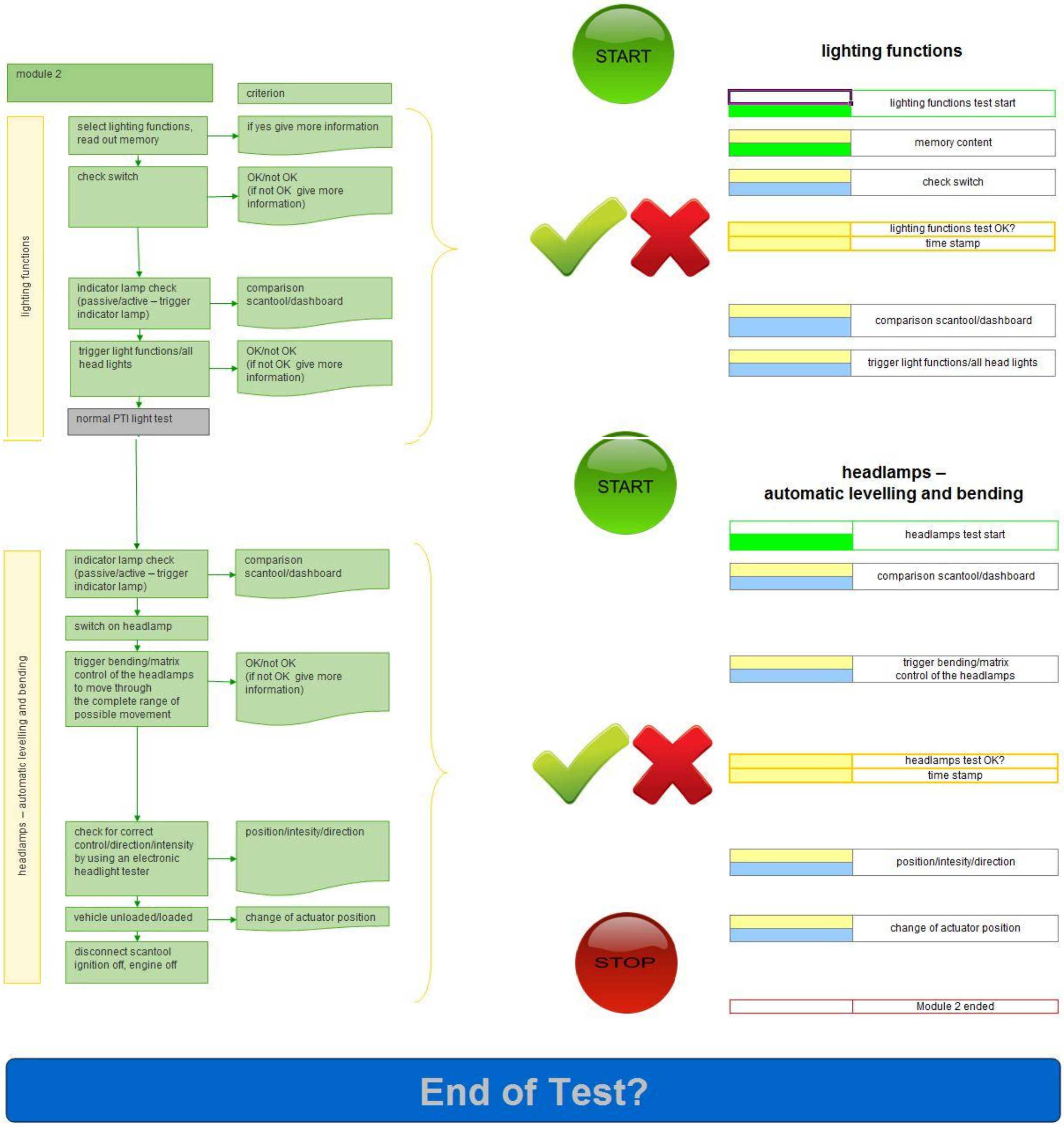





TPMS active
select TPMS active (diagnostic tool), read out memory
if yes give more information
indicator lamp check (passive/active) TPMS
comparison scantool/dashboard
trigger with scantool (value at scantool), trigger with scantool (value at dashboard), trigger with TPMS (value at TPMS tester)
TPMS wheel sensor front/rear left/right
disconnect scantool ignition off engine off
START
STOP
TPMS active
TPMS active test start
memory content
comparison scantool/dashboard
TPMS active test OK?
time stamp
TPMS wheel sensors
Module 1 ended
End of Test?

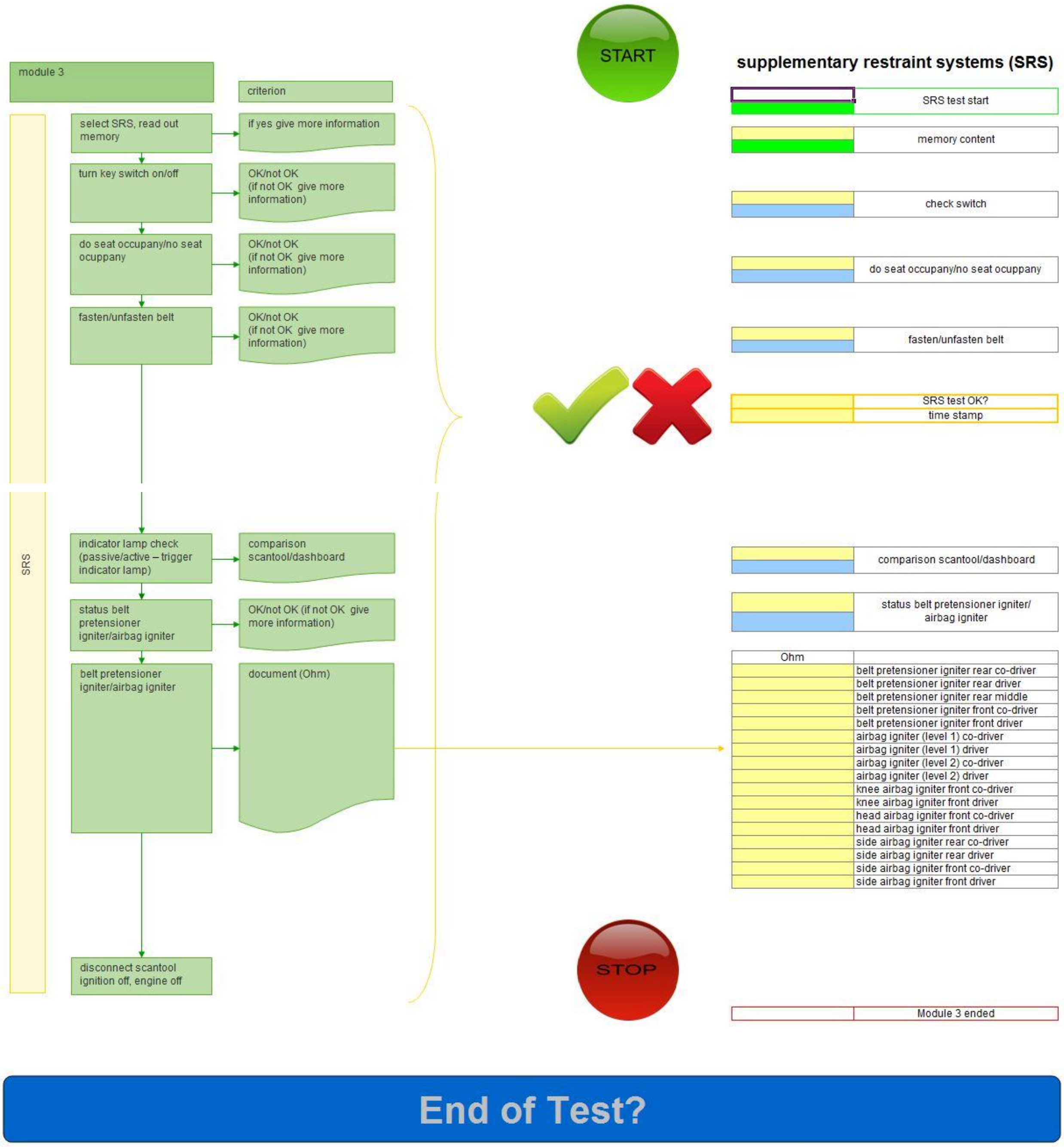
17.4 Field testing – module 2

The third excel spreadsheet in the file "Original" consists of module 2.



17.5 Field testing – module 3

The third excel spreadsheet in the file "Original" consists of module 3.



18 Annex 6: Field testing: Results and analysis

Table 28: Manufacturers of tested vehicles

Manufacturer	Sum all vehicles
VW	208
Mercedes/Mercedes Benz	157
Ford	112
Toyota	84
Opel	82
Audi	76
Volvo	65
BMW	63
Peugeot	43
Citroen	40
Skoda	43
Daimler Chrysler	42
Renault	36
Mazda	23
Nissan	22
Seat	18
Kia	14
Fiat	16
Saab	10
Chevrolet	10
Hyundai	7
Subaru	7
Mitsubishi	6
Honda	4
Dacia	4
Landrover	4
Suzuki	3
Mini	2
Lexus	2
Vaz Lada	1
MCC Smart	3
Porsche	1
Alfa Romeo	1
Jeep	1
Number of tests with declared name of manufacturer	**1210**
Blank lines/not filled in	**1**
Not captured	**2**
Sum	**1213**

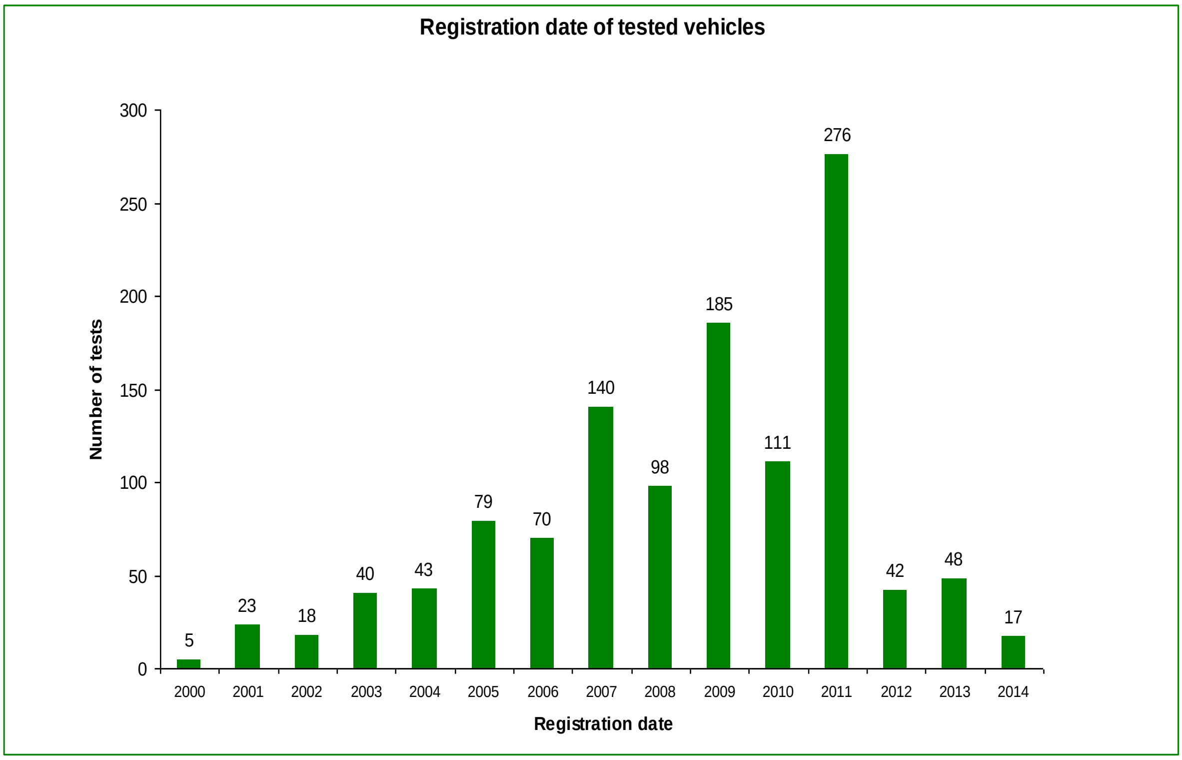


Figure 14: Distribution of vehicle age

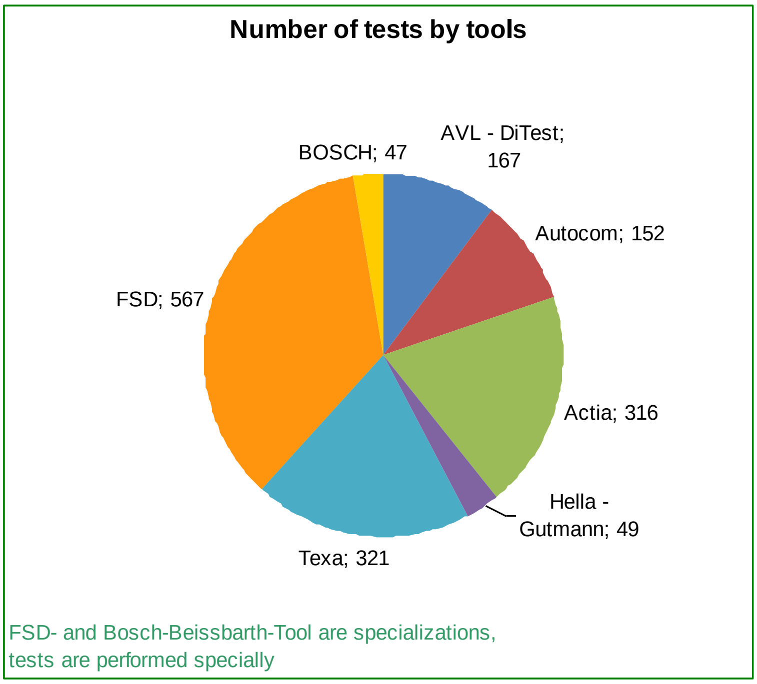


Figure 15: Distribution of the test tools

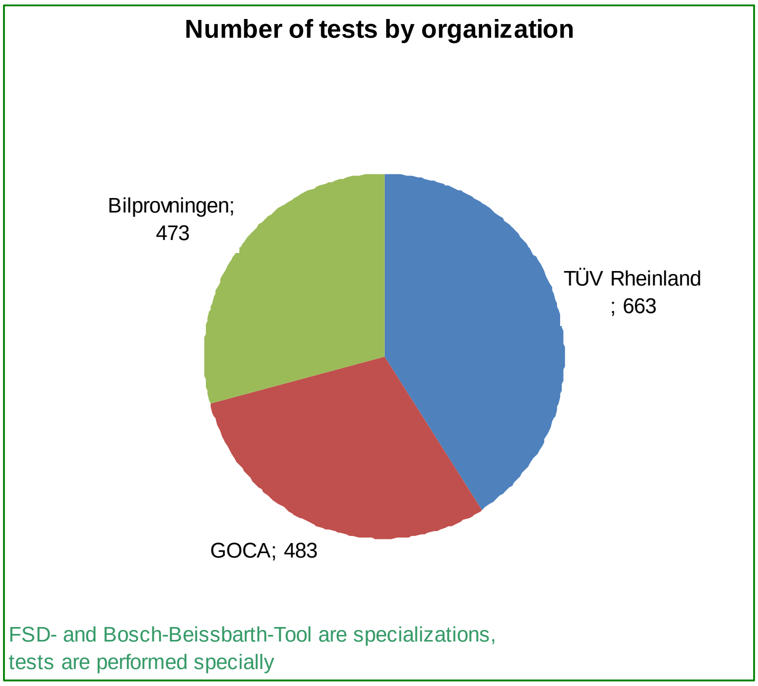


Figure 16: Distribution of organisations conducting the field tests

Table 29: Analysis of tool-vehicle coverage

Type of scan tool	Type of ECSS	Type of module	all tests [# of tests]	valid tests [# of tests]	percentage of invalid tests % [%]	percentage of valid tests [%]	availability on tool [# of tests]	non-availability on tool	tool-vehicle coverage [%]	remarks
ACTIA	EPS	1	133	82	38	62	76	6	93	
	ABS/ESC/TPMS passive	1	133	104	22	78	89	15	86	
	Brakes only	-	-	-	-	-	-	-	-	
	TPMS active	1	133	69	48	52	0	69	0	
	Lighting	2	133	69	48	52	56	13	81	
	Headlamps	2	133	68	49	51	51	17	75	
	SRS	3	133	90	32	68	44	46	49	
AVL-DiTest	EPS	1	121	110	9	91	44	66	40	
	ABS/ESC/TPMS passive	1	121	106	12	88	59	47	56	
	Brakes only	-	-	-	-	-	-	-	-	
	TPMS active	1	121	65	46	54	1	64	2	
	Lighting	2	121	0	100	0	0	0	0	unclear if AVL tool was used at all
	Headlamps	2	121	0	100	0	0	0	0	unclear if AVL tool was used at all
	SRS	3	121	102	16	84	63	39	62	
Autocom	EPS	1	152	0	100	0	0	0	0	unclear if Autocom tool was in use at all
	ABS/ESC/TPMS passive	1	152	0	100	0	0	0	0	unclear if Autocom tool was in use at all
	Brakes only	-	-	-	-	-	-	-	-	
	TPMS active	1	152	0	100	0	0	0	0	unclear if Autocom tool was in use at all
	Lighting	2	152	0	100	0	0	0	0	unclear if Autocom tool was in use at all
	Headlamps	2	152	0	100	0	0	0	0	unclear if Autocom tool was in use at all
	SRS	3	152	152	0	100	152	0	100	
BOSCH Beissbarth	EPS	-	-	-	-	-	-	-	-	
	ABS/ESC/TPMS passive	1	47	47	0	100	47	0	100	
	Brakes only	-	-	-	-	-	-	-	-	
	TPMS active	-	-	-	-	-	-	-	-	
	Lighting	-	-	-	-	-	-	-	-	
	Headlamps	-	-	-	-	-	-	-	-	
	SRS	-	-	-	-	-	-	-	-	
FSD	EPS	-	-	-	-	-	-	-	-	
	ABS/ESC/TPMS passive	-	-	-	-	-	-	-	-	
	Brakes only	-	503	473	6	94	473	30	100	
	TPMS active	-	-	-	-	-	-	-	-	
	Lighting	*	503	503	0	100	94	0	19	unclear if FSD tool was used for light check during every test
	Headlamps	-	-	-	-	-	-	-	-	
	SRS	-	-	-	-	-	-	-	-	
Hella-Gutmann	EPS	1	145	2	99	1	2	0	100	unclear if Hella Gutmann tool was used twice only
	ABS/ESC/TPMS passive	1	145	2	99	1	2	0	100	unclear if Hella Gutmann tool was used twice only
	Brakes only	-	-	-	-	-	-	-	-	
	TPMS active	1	145	1	99	1	1	0	100	unclear if Hella Gutmann tool was used once only
	Lighting	2	145	99	32	68	40	59	40	
	Headlamps	2	145	47	68	32	4	43	9	
	SRS	3	145	0	100	0	0	0	0	unclear if Hella Gutmann tool was used at all
Texa	EPS	1	112	79	29	71	78	1	99	
	ABS/ESC/TPMS passive	1	112	110	2	98	109	1	99	
	Brakes only	-	-	-	-	-	-	-	-	
	TPMS active	1	112	50	55	45	5	45	10	
	Lighting	2	112	60	46	54	14	46	23	
	Headlamps	2	112	59	47	53	12	47	20	
	SRS	3	112	105	6	94	103	2	98	
Tecnomotor	TPMS active	1	0	0	0	0	0	0	0	obviously the Tecnomotor tool was not used at all
All module 1-3 tests added (incl. BOSCH Beissbarth):			1213							
All module 1-3 tests (excl. BOSCH):			1166							
Remarks:										
*	triggering of light functions only									
Based on database "Evaluation_V16_20140523_revBASt"										

Table 30: Brake efficiency criteria (reference braking forces)

Vehicle information			Front axle				Rear axle				Evaluation (by criteria)			
Manufacturer	Type	Number of vehicles	Ratio force to pressure front min (dN/bar)	Number of vehicles with min value front	Ratio force to pressure front max (dN/bar)	Number of vehicles with max value front	Ratio force to pressure rear min (dN/bar)	Number of vehicles with min value rear	Ratio force to pressure rear max (dN/bar)	Number of vehicles with max value rear	Insufficient brake efficiency (front)	Insufficient brake efficiency (rear)	Insufficient brake efficiency (front) in %	Insufficient brake efficiency (rear) in %
VW	1K	45	8	1	18	1	4	17	7	1	0	0	0,00	0,00
Ford	JA8	35	7	1	22	2	3	1	5	9	10	1	28,57	2,86
Daimler	169	29	7	1	23	1	2	10	6	1	0	0	0,00	0,00
Daimler	204	22	11	1	28	1	5	5	11	1	0	0	0,00	0,00
Daimler	245	20	7	1	18	2	2	1	5	2	0	0	0,00	0,00
Ford	DA3	19	9	1	18	1	4	5	7	1	0	0	0,00	0,00
VW	3 C	17	11	1	23	1	4	1	9	1	0	0	0,00	0,00
VW	1KM	16	9	1	18	1	4	2	7	1	0	0	0,00	0,00
Daimler	204 K	15	14	1	24	1	5	1	10	1	0	0	0,00	0,00
VW	1KP	14	10	1	18	1	4	3	5	11	0	0	0,00	0,00
Skoda	1Z	14	10	1	14	4	4	2	7	3	0	0	0,00	0,00
Daimler	451	12	6	1	14	1	4	5	6	1	0	0	0,00	0,00
Audi	8P	12	11	2	29	1	4	1	14	1	0	0	0,00	0,00
Audi	B8	12	15	3	27	1	6	1	10	1	0	0	0,00	0,00
VW	5N	11	10	2	19	1	4	1	7	3	1	1	9,09	9,09
Citroen	7	1	15	1	-	-	5	1	-	-	-	-	-	-
VW	6R	10	9	2	15	1	3	7	4	3	0	1	0,00	10,00
Audi	8E	9	12	2	24	1	4	2	7	2	-	-	-	-
Daimler	212	8	15	1	27	1	6	1	15	1	0	0	0,00	0,00
Skoda	5J	8	8	1	15	1	3	3	6	1	0	0	0,00	0,00
Peugeot	W*****	8	9	1	17	3	3	1	7	1	0	0	0,00	0,00
Toyota	XP9F(a)	8	10	1	21	1	4	6	6	1	0	0	0,00	0,00
Daimler	212 K	7	20	1	27	1	8	2	51	1	0	0	0,00	0,00
Renault	JZ	7	14	1	17	4	4	4	5	3	0	0	0,00	0,00
Opel	S-D	7	12	2	18	1	4	6	5	1	0	0	0,00	0,00
BMW	187	6	11	1	17	1	6	2	8	3	0	0	0,00	0,00
Audi	8R	6	13	1	20	1	6	2	9	2	-	-	-	-
Opel	P-J	6	15	1	21	1	5	5	7	1	0	0	0,00	0,00
VW	1F	6	12	2	18	1	4	1	6	1	0	1	0,00	20,00
Opel	A-H/Monocab	5	17	1	24	1	4	1	7	2	0	2	0,00	40,00
VW	1T	4	8	1	17	1	5	2	6	2	0	0	0,00	0,00
Ford	DXA	4	16	2	18	1	5	1	6	3	0	0	0,00	0,00
Fiat	312	3	10	1	16	1	4	2	6	1	0	0	0,00	0,00
BMW	1K4	3	15	1	18	1	7	1	11	1	0	0	0,00	0,00
VW	2K	3	13	2	15	1	6	3	-	-	0	0	0,00	0,00
Audi	4F	3	12	1	18	1	7	2	8	1	0	0	0,00	0,00
Seat	5P	3	12	2	16	1	5	2	7	1	0	0	0,00	0,00

Vehicle information			Front axle				Rear axle				Evaluation (by criteria)			
Manufacturer	Type	Number of vehicles	Ratio force to pressure front min (dN/bar)	Number of vehicles with min value front	Ratio force to pressure front max (dN/bar)	Number of vehicles with max value front	Ratio force to pressure rear min (dN/bar)	Number of vehicles with min value rear	Ratio force to pressure rear max (dN/bar)	Number of vehicles with max value rear	Insufficient brake efficiency (front)	Insufficient brake efficiency (rear)	Insufficient brake efficiency (front) in %	Insufficient brake efficiency (rear) in %
Daimler	639/2	3	21	1	23	2	6	3	-	-	0	0	0,00	0,00
Seat	6J	3	13	1	18	1	4	1	6	1	0	0	0,00	0,00
Ford	DM2	3	8	1	11	1	5	1	11	1	0	0	0,00	0,00
Ford	DYB	3	15	1	21	1	5	2	7	1	0	0	0,00	0,00
Nissan	J10	3	14	1	17	1	4	1	5	2	0	0	0,00	0,00
Ford	WA6	3	16	1	20	1	5	2	6	1	0	0	0,00	0,00
Renault	Z	3	12	1	19	1	4	2	5	1	0	0	0,00	0,00
Fiat	199	2	7	1	19	1	2	1	4	1	0	0	0,00	0,00
Opel	OG-A	2	16	1	24	1	6	1	10	1	0	0	0,00	0,00
Skoda	3T	2	14	2	-	-	6	2	-	-	1	1	50,00	50,00
Peugeot	4*****	2	17	1	22	1	4	2	-	-	0	0	0,00	0,00
Ford	BA7	2	15	1	21	1	6	1	7	1	0	0	0,00	0,00
BMW	Mini	2	9	1	14	1	3	1	4	1	0	0	0,00	0,00
Toyota	T27	2	9	2	-	-	4	1	5	1	0	0	0,00	0,00
VW	13	1	15	1	-	-	5	1	-	-	0	0	0,00	0,00
Daimler	172	1	23	1	-	-	6	1	-	-	0	0	0,00	0,00
Daimler	207	1	20	1	-	-	8	1	-	-	0	0	0,00	0,00
Daimler	246	1	13	1	-	-	4	1	-	-	0	0	0,00	0,00
Daimler	251	1	20	1	-	-	9	1	-	-	0	0	0,00	0,00
BMW	1K2	1	17	1	-	-	6	1	-	-	0	0	0,00	0,00
Seat	1P	1	12	1	-	-	4	1	-	-	0	0	0,00	0,00
Daimler	212 AMG	1	21	1	-	-	9	1	-	-	-	-	-	-
VW	3D	1	19	1	-	-	6	1	-	-	-	-	-	-
BMW	3K	1	17	1	-	-	7	1	-	-	0	0	0,00	0,00
Audi	4H	1	21	1	-	-	8	1	-	-	-	-	-	-
BMW	5K	1	19	1	-	-	8	1	-	-	-	-	-	-
BMW	5L	1	16	1	-	-	9	1	-	-	-	-	-	-
Mazda	BL	1	200	1	-	-	102	1	-	-	0	0	0,00	0,00
Hyundai	FDH	1	11	1	-	-	3	1	-	-	1	1	100,00	100,00
Citroen	N	1	19	1	-	-	7	1	-	-	-	-	-	-
Opel	P-J/SW	1	15	1	-	-	7	1	-	-	-	-	-	-
BMW	X1	1	17	1	-	-	8	1	-	-	0	0	0,00	0,00
Audi	-	1	21	1	-	-	7	1	-	-	0	0	0,00	0,00
BMW	X5	1	9	1	-	-	5	1	-	-	0	0	0,00	0,00

19 Annex 7: List of specific technical information required from VMs for implementation of inspection methods developed within project

19.1 Overview and description of the information packages

In PTI, vehicles are inspected in terms of the installation, condition, function and the efficacy of their components and systems to ensure continued roadworthiness and environmental compliance. For vehicles with electronically controlled safety systems (ECSS), these tests require specific vehicle manufacturer data / technical information concerning the assessment of these ECSS:

19.1.1 Basic diagnostic information

- Vehicle-specific description of the location of the vehicle identification number (VIN) or unequivocal vehicle identification information.
- Vehicle-specific description of the location and the access to the electronic vehicle interface.
- Vehicle-specific specification of pin assignment used, bus types and protocols of each ECSS.
  (e.g. pin assignment: 6 (H),14 (L); bus type: HIGHSPEEDCAN; protocol: UDSonCAN)
- Vehicle-specific specification of the general communication parameters of each ECSS.
  (e.g. baud rate: 500000)
- For all ECU's involved in the use cases: specification of ECU-specific communication parameters
  (e.g. CAN physical request identifier: 0x712)

19.1.2 Fitment test information

- Vehicle-specific information about the installed systems, originally fitted at the time of manufacture and which are part of the roadworthiness test requirements under the 2014/45 (EU) Directive.
- Vehicle-specific information regarding the valid vehicle configurations (combinations of variants / versions / codings of the different ECUs)
- Specification of (on-board or off-board) test methods suitable to identify, whether the system/function is still installed, is in a valid configuration and has not been manipulated, including:
  - Detailed description of the test algorithm and the coverage of the test method
  - Specification of diagnostic sequences and diagnostic services used

  - Proof of the reliability, correctness and usability of the test method
- (e.g. method for ESC fitment test, method for Airbag fitment test, …)

19.1.3 Predefined system condition test methods

- Vehicle-specific specification of (on-board or off-board) test methods suitable to verify the correct functioning of all components of the complete functional chain, including sensors, ECUs, actuators and connection via bus system or other signalling lines[19], including:
  - Detailed description of the test algorithm (including threshold values) and the coverage of the test method
  - Specification of diagnostic sequences and diagnostic services used
  - Proof of the reliability, correctness and usability of the test method
- (e.g. method for condition testing of wheel speed sensor, method for condition testing of the ESC system,…)

19.1.4 Predefined system function/ efficacy test methods

- Vehicle-specific specification of (on-board or off-board) test methods suitable to verify the correct functioning of complete system/function[20], including:
  - Proof of the reliability, correctness and usability of the test method
  - Detailed description of the test algorithm (including threshold values) and the coverage of the test method
  - Specification of diagnostic sequences and diagnostic services used
- (e.g. method for function testing of wheel speed sensor, method for efficacy test of ESC brake force modulation,…)

The data/technical information shall be provided in a pre-defined, machine readable format, with standardised data content and structure that requires the minimum subsequent processing to support PTI testing of a vehicle's ECSS (e.g. ODX for technical information, OTX for test sequences both with special PTI author guidelines) via a single point of access.
The vehicle manufacturers data/technical information shall be provided for offline-usage, on a VIN-based access (for that purpose, VIN shall not be considered as a privacy information),, or other unequivocal identification method

[19] In case of a defect the result of the test method has to include the identification of the defective components.
[20] In case of a defect the result of the test method has to include the identification of the defective components.

19.2 Specific technical information

Table 31: Information for reference brake value method.

Item	Method	Data/Information	Reasons for failure
1. BRAKING EQUIPMENT			
1.2 Service braking performance and efficiency			
1.2.2 Efficiency	*Efficacy Test using electronic vehicle interface* *(e.g. Measurement of brake forces on a brake tester, readout of related brake pressure using electronic vehicle interface; comparison with the reference values (pressure and brake force) per axle and thresholds for brake force distribution)* Test with a brake tester or, if one cannot be used for technical reasons, by a road test using a deceleration recording instrument to establish the braking ratio which relates to the maximum authorized mass or, in the case of semi-trailers, to the sum of the authorised axle loads. Vehicles or a trailer with a maximum permissible mass	Vehicle-specific: ▪ Reference brake force values at input pressure for each braked axle ▪ Thresholds for reference brake force distribution ▪ Reference brake force values at input brake pedal force for each braked axle (where value of pressure is not available, or pressure sensor state is “NOK”) ▪ Information whether brake pressure sensor is installed ▪ Basic diagnostic information (1.1) ▪ Predefined system function/ efficacy test methods (1.4) Including (e.g.) : - Readout value of brake pressure sensor - Readout correction value for brake pressure sensor - …	(a) Does not achieve the minimum correlated value between input pressure and brake force generated at the wheels

Item	Method	Data/Information	Reasons for failure
	exceeding 3.5 tonnes has to be inspected following the standards given by ISO 21069 or equivalent methods. Road tests should be carried out under dry conditions on a flat, straight road.		

Table 32: ABS-specific information.

Item	Method	Data/Information	Reasons for failure
1. BRAKING EQUIPMENT			
1.6. Anti-lock braking system (ABS)	Visual inspection and inspection of warning device and ~~/ or~~ *fitment test using electronic vehicle interface, and condition test using electronic interface, and function / efficacy test* using electronic vehicle interface *(e.g. Using a brake tester, while pressing the brake pedal, modulate the brake pressure using electronic vehicle interface.* *Using a brake tester evaluate the*	▪ Basic diagnostic information (1.1) ▪ Fitment test information (1.2) (c) ▪ Predefined system condition test methods (1.3) (a) (b) (c) (d) (e) (g) Including (e.g.): - Readout state of MIL - Readout PTI relevant condition information - Mapping of PTI relevant condition information to negative system and component condition - Activation of MIL - Readout value of wheel speed sensor axle1 left - Readout value of wheel speed sensor axle1 right - …	(a) Warning device malfunctioning. Wheel speed sensors missing, damaged, not functioning correctly or incorrect value (b) Wirings damaged. (c) Electronic control units missing, manipulated, not

Item	Method	Data/Information	Reasons for failure
	wheel speed sensor signals using electronic vehicle interface and verify that they are the same for the same rotational wheel speed. *Actuate the hydraulic pump using electronic vehicle interface, compare the pressure generated to threshold values.)*	▪ Predefined system function / efficacy test methods (1.4) (a) (b) (c) (d) (f) (g) Including (e.g.): - Readout value of wheel speed sensor axle1 left - Readout value of wheel speed sensor axle1 right - Readout value of wheel speed sensor axle2 left - Readout value of wheel speed sensor axle2 right - Readout correction value for each sensor - Activation of brake modulation axle1 left - Activation of brake modulation axle1 right - Activation of brake modulation axle2 left - Activation of brake modulation axle2 right - Activation of the hydraulic pump and a readout of the brake system pressure generated. - …	functioning correctly or incorrect configuration (d) Actuators for brake force modulation not functioning correctly (e) Warning devices not functioning correctly or manipulated (f) System function not sufficient (g) Other components missing, damaged or not functioning correctly.

Table 33: EBS-specific information.

Item	Method	Data/Information	Reasons for failure
1. BRAKING EQUIPMENT			
1.7. Electronic brake system (EBS)	Visual inspection and inspection of warning device and ~~/ or~~ *fitment test using electronic vehicle interface, and condition test using electronic interface, and function / efficacy test using electronic vehicle interface* (e.g. *On a level surface and with the vehicle stationary, read acceleration- and yaw rate value using electronic vehicle interface and compare to thresholds.* *On a brake tester, while pressing the brake pedal, modulate the brake pressure using electronic vehicle interface.* *Actuate the hydraulic pump using electronic vehicle interface, compare the pressure generated to threshold values.* *On a brake tester evaluate wheel speed sensor signals using*	▪ Basic diagnostic information (1.1) ▪ Fitment test information (1.2) (b) ▪ Predefined system condition test methods (1.3) (a) (b) (c) (d) (f) Including (e.g.): - Readout state of MIL - Readout PTI relevant condition information - Mapping of PTI relevant condition information to negative system and component condition - Activation of MIL - Readout value of wheel speed sensor axle1 left - … ▪ Predefined system function / efficacy test methods (1.4) (a) (b) (c) (e) (f) Including (e.g.): - Readout value of wheel speed sensor axle1 left - Readout value of wheel speed sensor axle1 right - Readout value of wheel speed sensor axle2 left - Readout value of wheel speed sensor axle2 right - Readout value of steering angle sensor - Readout value of acceleration sensor - Readout value of yaw rate sensor - Readout correction value for each sensor - Activation of brake modulation axle1 left - Activation of brake modulation axle1 right - Activation of brake modulation axle2 left	(a) Incorrect brake signal function or incorrect value Wirings damaged. Warning device malfunctioning. (b) Electronic control units missing, manipulated, not functioning correctly or incorrect configuration (c) Actuators for brake force modulation not functioning correctly (d) Warning devices not functioning correctly or manipulated (e) System function not sufficient,

Item	Method	Data/Information	Reasons for failure
	electronic vehicle interface and verify that they are the same for the same rotational wheel speed. *On a brake tester with the vehicle in the straight ahead position, read out the value of the steering wheel sensor using electronic vehicle interface and compare to threshold values.)*	- Activation of brake modulation axle2 right - Activation of the hydraulic pump and a readout of the brake system pressure generated. - …	e.g. other components missing, damaged or not functioning correctly, warning device shows system malfunction.

Table 34: EPS-specific information.

Item	Method	Data/Information	Reasons for failure
2. STEERING			
2.6. Electronic Power Steering (EPS)	Visual inspection and consistency check between the angle of the steering wheel and the angle of the wheels when switching on/off the engine, and ~~/ or~~*fitment test using electronic vehicle interface, and condition test using electronic interface, and function / efficacy test* using electronic vehicle interface (e.g. *On a roller brake tester with the vehicle in the straight*	▪ Basic diagnostic information (1.1) ▪ Fitment test information (1.2) [(a) (d) (h)] ▪ Predefined system condition test methods (1.3) [(a) (b) (c) (d) (f) (h) (i)] Including (e.g.): - Readout state of MIL - Readout PTI relevant condition information - Mapping of PTI relevant condition information to negative system and component condition - Activation of MIL - Readout value of wheel speed sensor axle1 left - Readout value of wheel speed sensor axle1 right - …	(a) Wheel speed sensors missing, damaged, not functioning correctly or incorrect value (b) Steering wheel angle sensors not functioning correctly or incorrect value (c) Steering torque sensors not functioning correctly or incorrect value

Item	Method	Data/Information	Reasons for failure
	ahead position, read out value of steering wheel sensor using electronic vehicle interface and compare to thresholds values. *Where possible, make a short test drive (~50 m, 90° bend, >15 km/h), and check cross consistency of wheel speed sensors, yaw speed sensor, steering angle sensor, current and direction of EPS using electronic vehicle interface.* *Compare steering effort required with and without engine on. For active steering systems, also compare the difference of road wheel steering angle generated with and without engine on when the steering wheel is turned.)*	▪ Predefined system function / efficacy test methods (1.4) (a) (b) (c) (d) (e) (g) (h) (i) Including (e.g.): - Readout value of wheel speed sensor axle1 left - Readout value of wheel speed sensor axle1 right - Readout value of wheel speed sensor axle2 left - Readout value of wheel speed sensor axle2 right - Readout value of steering angle sensor - Readout value of acceleration sensor - Readout value of yaw rate sensor - Readout correction value of each sensor - …	(d) Electronic control units missing, manipulated, not functioning correctly or incorrect configuration (e) Actuators for power assistance modulation not functioning correctly (f) Warning devices not functioning correctly or manipulated (g) System function not sufficient (h) Other components missing, damaged or not functioning correctly. EPS malfunction indicator lamp (MIL) indicates any kind of failure of the system. (i) Inconsistency between the angle of the steering wheel and the angle of the wheels, steering affected

Table 35: Lighting-specific information - Headlamp Alignment.

Item	Method	Data/Information	Reasons for failure
4. LAMPS, REFLECTORS AND ELECTRICAL EQUIPMENT			
4.1 Headlamps			
4.1.2. Alignment	*Visual inspection and fitment test using electronic vehicle interface, and condition test using electronic interface, and function / efficacy test using electronic vehicle interface.* (e.g. *Trigger bending/matrix control of the headlamps to move through the complete range of possible illumination (mechanical and/or electronic) using electronic vehicle interface, check for correct control/direction/intensity by using an electronic headlamp tester to verify the correlation between input signals and the corresponding system function*. *On a level surface with the vehicle stationary, read the value of the vehicle level sensor using electronic vehicle interface and compare to values when moving the vehicle by, for*	▪ Basic diagnostic information (1.1) ▪ Fitment test information (1.2) 1) (c) ▪ Predefined system condition test methods (1.3) (a) (b) (c) (d) (e) (g) Including (e.g.): - Readout state of MIL 2) - Readout PTI relevant condition information - Mapping of PTI relevant condition information to negative system and component condition - Activation of MIL 2) - … ▪ Predefined system function / efficacy test methods (1.4) (a) (c) (d) (e) (f) (g) Including (e.g.): - Activation of Headlamps - Activation of dynamic cornering lights 2) - Activation of AFS functions 2) - …	(a) Function or aim of a headlamp not within limits laid down in the requirements[1]. (b) System indicates failure via the electronic vehicle interface. (c) Electronic control units missing, manipulated, not functioning correctly or incorrect configuration (d) Actuators for alignment modulation not functioning correctly (e) Warning devices not functioning correctly or manipulated (f) System function not

	example, sitting in/on the rear of the vehicle). Determine the ~~fitment and~~ complete functionality of the horizontal and directional aim of each headlamp using a headlamp aiming device and electronic vehicle interface		sufficient (g) Other components missing, damaged or not functioning correctly.

1) For optional headlamp functions where applicable.

Table 36: Lighting-specific information - Headlamps Switching.

Item	Method	Data/Information	Reasons for failure
4. LAMPS, REFLECTORS AND ELECTRICAL EQUIPMENT			
4.1 Headlamps			
4.1.3. Switching	Visual inspection and fitment test *using electronic vehicle interface by* operation and ~~or~~ *condition test* using electronic vehicle interface and *function / efficacy test* using electronic vehicle interface *(e.g. Trigger lighting switch functions (sequentially where appropriate) using electronic vehicle interface and verify the results.)*	▪ Basic diagnostic information (1.1) ▪ Fitment test information (1.2) 1) (c) (d) (e) (h) ▪ Predefined system condition test methods (1.3) (a) (b) (c) (d) (e) (f) (h) Including (e.g.): - Readout state of MIL 2) - Readout PTI relevant condition information - Mapping of PTI relevant condition information to negative system and component condition - Activation of MIL 2) - Readout values of sensor which are used for switching 2) - … ▪ Predefined system function / efficacy test methods (1.4) 2) (a) (b) (d) (e) (f) (g) (h)	(a) Switch does not operate in accordance with the requirements. (b) Function of control device impaired. (c) System indicates failure via the electronic vehicle interface. (d) Electronic control units missing, manipulated, not functioning

Item	Method	Data/Information	Reasons for failure
		Including (e.g.): - Readout values of sensor which are used for switching [2] - …	correctly or invalid configuration (e) Sensors for switching missing, damaged, not functioning correctly or incorrect value (f) Warning devices not functioning correctly or manipulated. (g) System function not sufficient (h) Other components missing, damaged or not functioning correctly.

1) For optional headlamp functions
2) Where applicable

Table 37: Lighting-specific information – Headlamps Levelling devices.

Item	Method	Data/Information	Reasons for failure
4. LAMPS, REFLECTORS AND ELECTRICAL EQUIPMENT			
4.1 Headlamps			
4.1.5. Levelling devices (where mandatory)	Visual inspection and fitment *test using electronic vehicle interface*, ~~or~~ *condition test using electronic interface, and function/efficacy test* using electronic vehicle interface *(e.g. Trigger levelling control of the headlamps to move through the complete range of possible movement (mechanical and/or electronic) using electronic vehicle interface, check for correct control/direction/intensity by using an electronic headlight tester to verify the correlation between input signals and the corresponding system function*. *On a level surface and with the vehicle stationary, read the value of level sensor using electronic vehicle interface, compare to values when moving the vehicle vertically*	▪ Basic diagnostic information (1.1) ▪ Fitment test information (1.2) [1) (d) (e) (h)] ▪ Predefined system condition test methods (1.3) [1) (a) (c) (d) (e) (f) (h)] Including (e.g.): - Readout state of MIL [1) 2)] - Readout PTI relevant condition information [1)] - Mapping of PTI relevant condition information to negative system and component condition - Activation of MIL [1) 2)] - Readout values of sensor which are used for levelling [1)] - … ▪ Predefined system function / efficacy test methods (1.4) [1) (a) (d) (e) (g) (h)] Including (e.g.): - Readout values of sensor which are used for levelling [1)] - …	(a) Device not operating. (b) System indicates failure via the electronic vehicle interface. (c) Electronic control units missing, manipulated, not functioning correctly or incorrect configuration (d) Sensors for levelling missing, damaged, not functioning correctly or incorrect value (e) Warning devices not functioning correctly or manipulated (f) System function not sufficient (g) Other components missing, damaged

Item	Method	Data/Information	Reasons for failure
	by, for example, sitting in/on the rear of the vehicle.)		or not functioning correctly.

1) For automatic levelling 2)Where applicable

Table 38: Lighting-specific information – Front and rear position lamps, side marker lamps, end outline marker lamps and daytime running lamps.

Item	Method	Data/Information	Reasons for failure
4. LAMPS, REFLECTORS AND ELECTRICAL EQUIPMENT			
4.2 Front and rear position lamps, side marker lamps, end outline marker lamps and daytime running lamps			
4.2.1. Condition and operation	Visual inspection ~~and by operation~~ *and function / efficacy test using electronic vehicle interface* *(e.g. Trigger lighting functions (sequentially where appropriate) using electronic vehicle interface and verify the results.* *Trigger all lighting functions at the same time using electronic vehicle interface, check for correct illumination)*	▪ Basic diagnostic information (1.1) ▪ Predefined system function/ efficacy test methods (1.4) Including (e.g.): - Activation of each lamp - …	(a) Defective light source or lamp not functioning correctly.

Table 39: Lighting-specific information – Stop lamps.

Item	Method	Data/Information	Reasons for failure
4. LAMPS, REFLECTORS AND ELECTRICAL EQUIPMENT			
4.3 Stop lamps			
4.3.1. Condition and operation	Visual inspection ~~and by operation~~ *and function / efficacy test using electronic vehicle interface* *(e.g. Trigger lighting functions (sequentially where appropriate) using electronic vehicle interface and verify the results.* *Trigger all lighting functions at the same time using electronic vehicle interface, check for correct illumination).*	▪ Basic diagnostic information (1.1) ▪ Predefined system function/ efficacy test methods (1.4) Including (e.g.): - Activation of each lamp - …	(a) Defective light source or lamp not functioning correctly.
4.3.2. Switching	Visual inspection and fitment test using electronic vehicle interface and *condition test using electronic interface, and function / efficacy test* using the electronic vehicle interface. *(e.g. Trigger lighting functions (sequentially where appropriate) using electronic vehicle interface and verify the results.* *Trigger all lighting functions at the same time using electronic vehicle interface, check for correct illumination).*	▪ Basic diagnostic information (1.1) ▪ Fitment test information (1.2) (a) (b) (f) ▪ Predefined system condition test methods (1.3) (a) (b) (c) (d) (f) Including (e.g.): - Readout state of MIL [1)] - Readout PTI relevant condition information - Mapping of PTI relevant condition information to negative system and component condition - Activation of MIL [1)] - Readout values of sensor which are used for switching - …	(a) Emergency brake light functions fail to operate, or do not operate correctly. (b) Electronic control units missing, manipulated, not functioning correctly or incorrect configuration (c) sensors for switching missing, damaged, not

Item	Method	Data/Information	Reasons for failure
		▪ Predefined system function / efficacy test methods (1.4) [(a) (b) (c) (e) (f)] Including (e.g.): - Readout values of sensor which are used for switching - …	functioning correctly or incorrect value (d) Warning devices not functioning correctly or manipulated (e) System function not sufficient (f) Other components missing, damaged or not functioning correctly.

1) Where applicable

Table 40: Lighting-specific information – Direction indicator and hazard warning lamps.

Item	Method	Data/Information	Reasons for failure
4. LAMPS, REFLECTORS AND ELECTRICAL EQUIPMENT			
4.4 Direction indicator and hazard warning lamps			
4.4.1. Condition and operation	Visual inspection and ~~by operation~~ *function / efficacy test using electronic vehicle interface* *(e.g. Trigger lighting functions (sequentially where appropriate) using electronic vehicle interface and verify the results.* *Trigger all lighting functions at the same time using electronic vehicle interface, check for correct illumination).*	▪ Basic diagnostic information (1.1) ▪ Predefined system function/ efficacy test methods (1.4) Including (e.g.): - Activation of each lamp - …	(a) Defective light source , or not functioning correctly

Table 41: Lighting-specific information – Front and rear fog lamps.

Item	Method	Data/Information	Reasons for failure
4. LAMPS, REFLECTORS AND ELECTRICAL EQUIPMENT			
4.5 Front and rear fog lamps			
4.5.1. Condition and operation	Visual inspection and ~~by operation~~ *function / efficacy test using electronic vehicle interface.* *(e.g. Trigger lighting functions (sequentially where appropriate) using electronic vehicle interface and verify the results.* *Trigger all lighting functions at the same time using electronic vehicle interface, check for correct illumination).*	▪ Basic diagnostic information (1.1) ▪ Predefined system function/ efficacy test methods (1.4) Including (e.g.): - Activation of each lamp - …	(a) Defective light source , or not functioning correctly

Table 42: Lighting-specific information – Reversing lamps.

Item	Method	Data/Information	Reasons for failure
4. LAMPS, REFLECTORS AND ELECTRICAL EQUIPMENT			
4.6 Reversing lamps			
4.6.1. Condition and operation	Visual inspection and ~~by operation~~ *function / efficacy test using electronic vehicle interface* *(e.g. Trigger lighting functions (sequentially where appropriate) using electronic vehicle interface and verify the results.* *Trigger all lighting functions at the same time using electronic vehicle interface, check for correct illumination).*	▪ information (1.1) ▪ Predefined system function/ efficacy test methods (1.4) Including (e.g.): - Activation of each lamp - …	(a) Defective light source or lamp not functioning correctly

Table 43: Lighting-specific information – Rear registration plate lamp.

Item	Method	Data/Information	Reasons for failure
4. LAMPS, REFLECTORS AND ELECTRICAL EQUIPMENT			
4.7 Rear registration plate lamp			
4.7.1. Condition and operation	Visual inspection and ~~by operation~~ *function / efficacy test using electronic vehicle interface* *(e.g. Trigger lighting functions (sequentially where appropriate) using electronic vehicle interface and verify the results.* *Trigger all lighting functions at the same time using electronic vehicle interface, check for correct illumination).*	▪ Basic diagnostic information (1.1) ▪ Predefined system function/ efficacy test methods (1.4) Including (e.g.): - Activation of each lamp - …	(a) Defective light source or lamp not functioning correctly

Table 44: TPMS-specific information.

Item	Method	Data/Information	Reasons for failure
5. AXLES, WHEELS, TYRES AND SUSPENSION			
5.2 Wheels and tyres			
5.2.3. Tyres	Visual inspection of the entire tyre by either rotating the road wheel with it off the ground and the vehicle over a pit or on a hoist, or by rolling the vehicle backwards and forwards over a pit. *Inspection of TPMS warning device and fitment test using electronic vehicle interface, and condition test using electronic interface, function / efficacy test using electronic vehicle interface.* *(e.g. Read out TPMS sensor values using electronic vehicle interface and verify that the displayed pressure is appropriate.)*	▪ Basic diagnostic information (1.1) ▪ Fitment test information (1.2) (a) (c) (e) ▪ Predefined system condition test methods (1.3) (a) (b) (c) (d) (e) Including (e.g.): - Readout state of MIL - Readout PTI relevant condition information - Mapping of PTI relevant condition information to negative system and component condition - Activation of MIL - Readout value of TPMS wheel sensor axle1 left [1)] - Readout correction value for each sensor [1)] - … ▪ Predefined system function / efficacy test methods (1.4) (a) (b) (c) (d) (e) Including (e.g.): - Readout value of TPMS wheel sensor axle1 left [1)] - Readout value of TPMS wheel sensor axle1 right [1)] - Readout value of TPMS wheel sensor axle2 left [1)]	(a) Tyre pressure monitoring system malfunctioning or tyre obviously underinflated. Obviously inoperative (b) Wirings damaged. (c) Electronic control units missing, manipulated, not functioning correctly or incorrect configuration (d) Tyre pressure sensors not functioning correctly or incorrect value (e) Other components missing, manipulated, not functioning

Item	Method	Data/Information	Reasons for failure
		- Readout value of TPMS wheel sensor axle2 right [1)] - Readout correction value for each sensor [1)] - …	correctly

1) Where applicable

Table 45: SRS-specific information - safety belt load limiter.

Item	Method	Data/Information	Reasons for failure
7. OTHER EQUIPMENT			
7.1 Safety-belts/buckles and restraint systems			
7.1.3. Safety belt load limiter	Visual inspection and ~~/ or~~ *fitment test using electronic vehicle interface, and condition test* using electronic vehicle interface	▪ Basic diagnostic information (1.1) ▪ Fitment test information (1.2) [(a) (b) (c) (e)] ▪ Predefined system condition test methods (1.3) [(a) (b) (c) (d) (e)] Including (e.g.): - Readout PTI relevant condition information - Mapping of PTI relevant condition information to negative system and component condition - …	(a) Load limiter obviously missing or not suitable with the vehicle. (b) System indicates failure via the electronic vehicle interface. (c) Electronic control units missing, manipulated, not functioning correctly or incorrect configuration. (d) Wirings damaged. (e) Other components missing, manipulated, not

			functioning correctly

Table 46: SRS-specific information - safety belt pre-tensioners.

Item	Method	Data/Information	Reasons for failure
7. OTHER EQUIPMENT			
7.1 Safety-belts/buckles and restraint systems			
7.1.4. Safety belt Pre-tensioners	Visual inspection and ~~/or~~ *fitment test using electronic vehicle interface, and condition test* using electronic vehicle interface	▪ Basic diagnostic information (1.1) ▪ Fitment test information (1.2) (a) (b) (c) (e) ▪ Predefined system condition test methods (1.3) (a) (b) (c) (d) (e) Including (e.g.): - Readout PTI relevant condition information - Mapping of PTI relevant condition information to negative system and component condition - …	(a) Pre-tensioner obviously missing or not suitable with the vehicle. System indicates failure via the electronic vehicle interface. (b) Electronic control units missing, manipulated, not functioning correctly or incorrect configuration (c) Wirings damaged. (d) Other components missing, manipulated, not functioning correctly

Table 47: SRS-specific information – Airbag.

Item	Method	Data/Information	Reasons for failure
7. OTHER EQUIPMENT			
7.1 Safety-belts/buckles and restraint systems			
7.1.5. Airbag	Visual inspection and ~~/ or~~ *fitment test using electronic vehicle interface, and condition test* using electronic vehicle interface	▪ Basic diagnostic information (1.1) ▪ Fitment test information (1.2, including de-activation possibilities and installed occupancy sensor) (a) (b) (d) (f) ▪ Predefined system condition test methods (1.3) (a) (b) (c) (d) (e) (f) Including (e.g.): - Readout state of MIL - Readout crash counter - Readout PTI relevant condition information - Mapping of PTI relevant condition information to negative system and component condition - Activation of MIL - …	(a) Airbags obviously missing or not suitable with the vehicle. (b) System indicates failure via the electronic vehicle interface. (c) Airbag obviously not able to function correctly. (d) Electronic control units missing, manipulated, not functioning correctly or incorrect configuration. (e) Wirings damaged. (f) Other components missing, manipulated, not

			functioning correctly

Table 48: SRS-specific information - SRS Systems.

Item	Method	Data/Information	Reasons for failure
7. OTHER EQUIPMENT			
7.1 Safety-belts/buckles and restraint systems			
7.1.6. SRS Systems	Visual inspection and ~~/ or~~ *fitment test using electronic vehicle interface, and condition test* using electronic vehicle interface	▪ Basic diagnostic information (1.1) ▪ Fitment test information (1.2) (b) (c) (e) ▪ Predefined system condition test methods (1.3) (a) (b) (c) (d) (e) Including (e.g.): - Readout state of MIL - Readout PTI relevant condition information - Mapping of PTI relevant condition information to negative system and component condition - Activation of MIL - …	(a) SRS MIL indicates any kind of failure of the system. (b) System indicates failure via the electronic vehicle interface. (c) Electronic control units missing, manipulated, not functioning correctly or incorrect configuration. (d) Wirings damaged. (e) Other components missing, manipulated, not functioning correctly

Table 49: ESC-specific Information.

Item	Method	Data/Information	Reasons for failure
7. OTHER EQUIPMENT			
7.12. Electronic Stability Control (ESC) if fitted/required	Visual inspection and ~~/ or~~ *inspection of warning device, fitment test using electronic vehicle interface, and condition test using electronic interface, and function / efficacy test* using electronic vehicle interface (e.g. *On a level surface with the vehicle stationary, read acceleration and yaw rate values using electronic vehicle interface, compare to threshold values.* *On a roller brake tester, while pressing the brake pedal, modulate the brake pressure using electronic vehicle interface.*	▪ Basic diagnostic information (1.1) ▪ Fitment test information (1.2) [(b) (c) (f)] ▪ Predefined system condition test methods (1.3) [(a) (b) (c) (d) (e) (f) (g) (h) (i) (k)] Including (e.g.): - Readout state of MIL - Readout PTI relevant condition information - Mapping of PTI relevant condition information to negative system and component condition - Activation of MIL - Readout value of wheel speed sensor axle1 left - … ▪ Predefined system function / efficacy test methods (1.4) [(a) (b) (c) (d) (f) (g) (i) (j) (k)] Including (e.g.): - Readout value of wheel speed sensor axle1 left - Readout value of wheel speed sensor axle1 right - Readout value of wheel speed sensor axle2 left - Readout value of wheel speed sensor axle2 right - Readout value of steering angle sensor	(a) Wheel speed sensors missing, damaged, not functioning correctly or incorrect value (b) Steering wheel angle sensors not functioning correctly or incorrect value (c) Brake pressure sensor not functioning correctly or incorrect value (d) Driving dynamics sensors not functioning correctly or incorrect value (e) Wirings

Item	Method	Data/Information	Reasons for failure
	Actuate the hydraulic pump using electronic vehicle interface, compare to threshold values. *On a roller brake tester evaluate the wheel speed sensor signals using electronic vehicle interface and verify that they are the same for the same rotational wheel speed.* *On a roller brake tester with the vehicle in the straight ahead position read out the values of the steering wheel sensor using electronic vehicle interface, and compare to threshold values.)*	- Readout value of acceleration sensor - Readout value of yaw rate sensor - Readout correction value for each sensor - Activation of brake modulation axle1 left - Activation of brake modulation axle1 right - Activation of brake modulation axle2 left - Activation of brake modulation axle2 right - Activation of the hydraulic pump and a readout of the brake system pressure generated. - …	damaged. (f) Electronic control units missing, manipulated, not functioning correctly or incorrect configuration (g) Actuators for brake force modulation not functioning correctly (h) Warning devices not functioning correctly or manipulated (i) Switching elements missing, damaged, not functioning correctly or manipulated (j) System function not sufficient (k) Other components missing,

Item	Method	Data/Information	Reasons for failure
			manipulated, not functioning correctly.

20 Annex 8: Estimate of change in inspection time for inclusion of ECSS methods into today's PTI testing

As input for the Cost Benefit analysis, an estimation of the change in inspection time needed for inclusion of the proposed ECSS methods into today's PTI testing (i.e. those trailed in field testing) was made based on experience gained during field testing. This estimate was made by summing the times required for each step of the inspection method and subtracting any time savings for the today's PTI test. Details of this work are shown in the Table below.

No	Action	Remarks	Time added hr:min:sec	Time saved hr:min:sec
1	**Start ECSS tests**			
1	Turn key switch passenger airbag off		00:00:04	
2	put ignition on and check indicater lamps		00:00:00	
	from EPS, ABS, ESC, TPMS, Lights and SRS (MIL)			
3	connect VCI with the car	For some countries already done today for emissions check	00:00:13	
3a	identify ECSS controllers	at ~4 controllers, high speed CAN; slower if more or other than expected controllers (VIN data!) are installed	00:00:10	
4	Ask VCI to read out memories, put on screen and in PTI System	Activity in parallel	00:00:00	
	All necessary Memory from EPS, ABS, ESC, TPMS, Lights and SRS			
	Same time read some parameters			
	Lateral acceleration (ABS)			
	Yaw rate (ABS)			
	Trigger values (Tpms)			
	Status igniters (SRS)			
	Value igniters (SRS)			
	switch passenger airbag (SRS)			
5	VCI tool activation of indicator lamp test (Lights, SRS, EPS, ABS, ESC)	grouped ~5 lamps at the same time, 2sec on	00:00:04	
2	**Start TEST EPS AND BRAKES**			
6	Turn wheels	no additional time, already in PTI	0:00:00	
7	activate EPS test and first part ABS test	additional time for test drive; additional benefits for inspector (recognition of "strange" noises, ...)	0:00:10	
	activation of hydraulic pump (brakes)	no additional time, pump must be triggered for ESC valve (line 30/36) anyway		
8	drive front axle into roller brake tester and	no additional time, already in PTI and info in send automaticaly	0:00:00	
	get info about steering angle (EPS, ABS, ESC)	end test EPS	0:00:00	
	get info about wheel speed sensors (ABS, ESC)		0:00:00	
9	brake front axle	no additional time, already in PTI and info in send automaticaly	0:00:00	
	get info about brake force and brake pressure		0:00:00	
10	Trigger ESC valves front Left and right and check	just for triggering each wheel brake once, rest of procedure already part of PTI	0:00:09	
11	Trigger ABS valves front Left and right and check	just for triggering each wheel brake once, rest of procedure already part of PTI	0:00:09	
12	drive rear axle into roller brake tester and		0:00:00	
	get info about wheel speed sensors (ABS, ESC)		0:00:00	
13	brake rear axle	no additional time, already in PTI and info in send automaticaly	0:00:00	
	get info about brake force and brake pressure		0:00:00	
14	Trigger ESC valves rear Left and right and check	just for triggering each wheel brake once, rest of procedure already part of PTI	0:00:09	
15	Trigger ABS valves rear Left and right and check	just for triggering each wheel brake once, rest of procedure already part of PTI, end test ABS ESC	0:00:09	
	Add 2 sec for reference brake force test components	time saving because ~60% of cars must be loaded to reach 58% (mandatory for cars >01/2012 -> CBA); time to load 1:30, unload 1:30 under perfect condition; plus 2x saved re-start of rollers (2x6 sec)	0:00:02	0:01:55
3	**Start LIGHT TEST**			
16	Trigger light functions and do PTI check	time needed ~12 lights a 2,2s; time consumption = only additional time to today´s PTI (~1,5s/light); time saving because of no need for 2nd person inside car or for additional ways or for locking brake pedal	00:00:09	00:00:10
17	Trigger bending and do PTI check (L&R)		00:00:05	
18	change actuator position onloaded/loaded vehicle		00:00:02	
4	**Start SRS TEST**			
19	do seat occupancy	additional time only for occupy co-drivers-seat; can be included into PTI routine (when inspector is next to co-drivers-seat anyway, e.g. to check VIN, seltbelt, factory plate, ...)	00:00:10	
20	fasten and unfasten seat belt	no additional time, already in PTI	00:00:00	
		Total time	**0:01:45**	**0:02:05**
		Grand total	**0:00:20**	saved