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New approaches for automated vehicles certification

Part I - Current and upcoming methods for safety assessment

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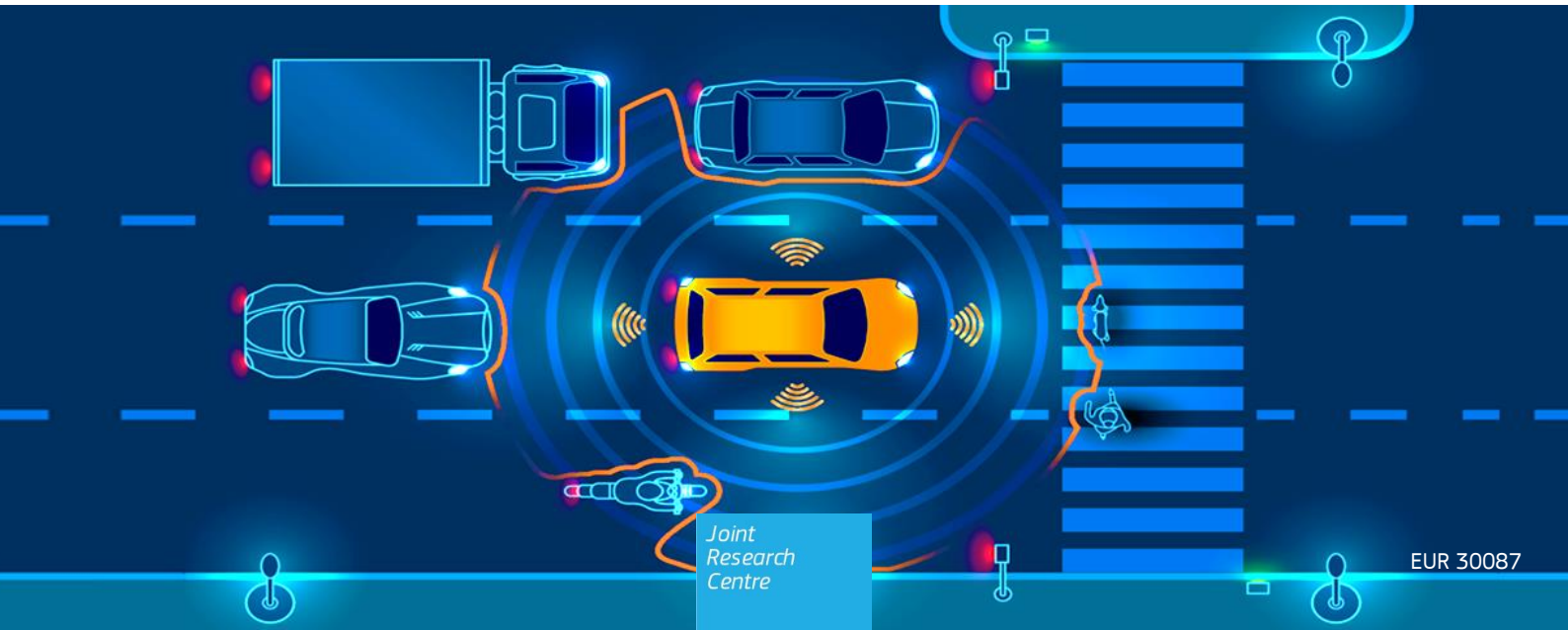

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Abstract

Autonomous vehicles (AVs) technology is still under development and appropriate legislative safeguards must be established to regulate the placing on the market of such vehicles and ensuring proper road-users safety. Given the pace of technological development in that field, a very fast response is needed to ensure that automated vehicles are safe and that this safety is properly assessed/demonstrated by manufacturers or/and public authorities.

Many different approaches for assessing the safety of AVs are being considered in the European Union and worldwide by governments, industry and other stakeholders. The present report summarises the outcomes of a literature review and analysis of different approaches considered for AVs safety assessment that were discussed during the 1st Technical Workshop on New Approaches for Automated Vehicle Certification, co-chaired by the European Commission's Joint Research Centre (JRC) and Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs (DG GROW) on November 22nd 2018 in Brussels. The workshop gathered together a group of experts on AV active safety verification, to discuss the state of play in the field, which are the different merits/limits of the different methodologies and the way forward.

Preliminary analysis and considerations suggested the complementarity of the considered approaches, both in terms of readiness and perspective. Further research and stakeholders' collaboration will be needed to elaborate on a possible harmonised approach.

1 Introduction

Autonomous vehicles (AVs) technology is evolving with an unprecedented fast pace and suitable type approval legislation updates are needed to ensure safe vehicles on-road prior to market deployment. The increasing complexity of AV systems, necessary to allow the vehicle performing driving tasks autonomously, demands for deeper understanding of safety-critical aspects. In addition, further research on innovative safety assessment methods is required, since verification through physical testing alone will not be enough to face the huge variety of driving tasks and scenarios to be assessed.

As announced in the Communication on connected and automated mobility adopted on 17 May 2018 (European Commission, 2018), the European Commission would work with Member States in 2018 on guidelines to ensure a harmonised approach for national ad-hoc vehicle safety assessments of automated vehicles. Moreover, it would initiate work with Member States and stakeholders on a new approach for vehicle safety certification for automated vehicles.

The work has already started on the Guidelines for the type approval of automated vehicles (SAE levels 3 and 4) under a European Union (EU) exemption procedure[1] with a proposal from European Commission services made on 18 October 2018, which was opened for public comments until 16 November 2018. The guidelines were adopted by Member States on 12 February 2019 (European Commission, 2019).

At the same time, the Europe on the move Communication proposed a revision of the Vehicle General Safety Regulation (European Union, 2018), empowering the Commission to lay out technical requirements and specific test criteria for the type-approval of automated vehicles for what concerns safety requirements. On 25 March 2019, the European Parliament, Council and Commission reached a provisional political agreement on the revised General Safety Regulation. As a result, new safety technologies will become mandatory in European vehicles by 2022.

Due to the intrinsic characteristics of such new technologies (enabling the vehicle to take over driver's tasks), defining unique and unambiguous type approval procedure for ensuring AVs safety is not a trivial task, and it will not be possible to only consider some simple physical testing as in the traditional way. At the moment, many different approaches for assessing the safety of AVs are being considered in the EU and worldwide by governments, industry and other stakeholders. Therefore, there is the need for evaluating alternative and complementary methodologies to ensure that these vehicles are safe and provide ways to assess vehicle safety. This work will be relevant in the short term for assessments carried out under the EU exemption procedure as well as for the future EU legal vehicles safety framework. Moreover, it is intended to support the discussion that needs to take place at international level in the framework of the United Nations and with our main international partners (e.g. China, Japan, Korea, Russia, USA).

The present report summarises the outcomes of a literature review and analysis of different approaches considered for AVs safety assessment that were discussed during the 1st Technical Workshop on New Approaches for Automated Vehicle Certification, co-chaired by the JRC and DG GROW on November 22nd 2018 in Brussels. The workshop gathered a group of experts on AV active safety verification, to discuss the state of play in the field, which are the different merits/limits of the different methodologies and the way forward. The contents of the present report were shared in the form of a concept paper prior to the meeting. The workshop agenda is attached in the Annex.

[1]Technologies not foreseen by current vehicle rules, such as automated driving systems may be approved under a special exemption procedure in accordance with Article 20 of Directive 2007/46/EC on the approval of motor vehicles.

2 Methodologies

2.1 Responsibility-Sensitive Safety (RSS)

The Mobileye approach (Mobileye, 2018) for AVs safety foresees the application of a predetermined set of rules to ensure safe operation and unequivocally evaluate and determine responsibility when AVs are involved in collisions with human-driven cars. The proposed solution sets clear rules for fault in advance, based on a mathematical model: when the rules are predetermined, then the responsibility can be defined conclusively based on facts. Accidents with automated vehicles could still happen (e.g. because of other road users), but the set of rules would at least guarantee that this accident is not caused by the automated vehicle.

Mobileye designed the Responsibility-Sensitive Safety (RSS) to ensure that the automated system would not issue a command that would lead to the AV causing an accident. According to Mobileye, such approach would allow avoiding the data-intensive validation process on-road or in a simulated environment: AV safety is simply validated by proving that the system evaluates all commands against the predetermined set of mathematical rules.

According to Mobileye, RSS system can validate three orders of magnitude improvement to one traffic fatality for every one billion hours of driving vs. the human-driven vehicle rate of one traffic fatality for every one million hours of driving (i.e. a US traffic fatality rate of approximately 40 per year compared to approximately 40,000 in 2016).

As specified by Mobileye, the AV shall operate based on the following definitions:

- Safe State, when there is no risk that the AV will cause an accident despite possible unsafe actions from other vehicles
- Default Emergency Policy, that defines the boundaries for most aggressive evasive action that an AV can take to maintain or regain a Safe State
- Cautious Command, representing the complete set of commands that maintains a Safe State

RSS base principle is that the AV is never allowed to make a command outside the set of Cautious Commands, ensuring that the planning module itself will never cause an accident.

2.2 International horizontal regulation of automated vehicles

France is establishing a legislative framework (French Republic, 2018) to allow testing of autonomous cars on public roads and the circulation of autonomous vehicles by 2022 (Autovista Group, 2018). At present, driverless vehicles tests on public roads are restricted to precise time and location in order to avoid interference with ordinary road users.

In May 2017 the Ministry for the Environment, Energy and Sea released a working document with preliminary framework considerations on an International horizontal regulation of automated vehicles (French Republic, 2017), aimed at contributing to the discussion ongoing at United Nations Economic Commission for Europe (UNECE) Working Party 29 (WP29) Intelligent Transport Systems and Automated Driving (ITS/AD) Informal Group.

The document proposes the "horizontal" regulation to be based on a systemic approach (vehicle, infrastructure, driving conditions, connection); diversity of “task sharing” between driver and system (from SAE level 2 to level 4); use-cases and their operation domain (Delache and Bazzucchi, 2017).

Sound regulation architecture can be defined starting from the following building concepts:

1. the identification of vehicles' sub-systems (driver, Human-Machine Interfaces - HMI, automation system, driving organs)
2. automation use-cases, defined by the combination of four main parameters (Operational Design Domain - ODD, elementary functions, triggering conditions, driving task sharing)
3. Regulation domains, decomposed based on previously defined concepts and functions and independently from technologies or systems

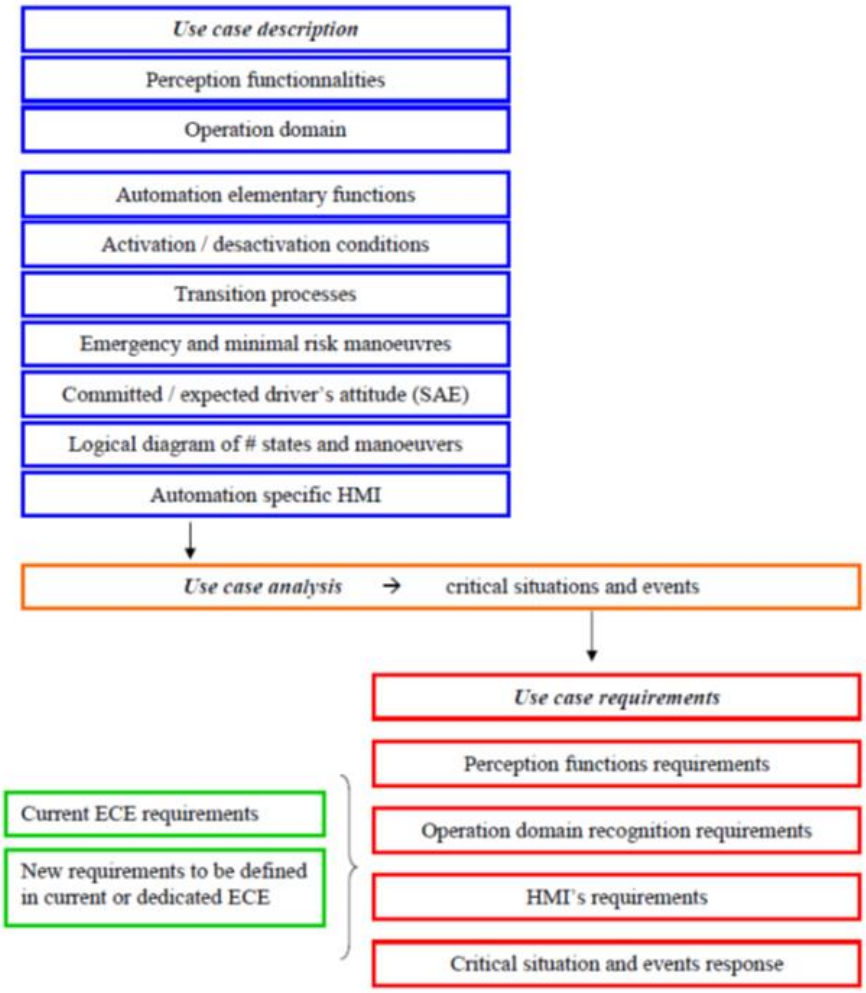
The regulation philosophy is based on use-cases description, including their precise and applicable set of use-conditions (different use-conditions imply different use-cases) and driver attitude/commitment.

The regulation might include specific requirements on HMI main functionalities and message priority management, in order to ensure their efficiency in addressing safety.

Critical situations/events beyond normal use conditions have to be identified for which the automated vehicle's behaviour is expected to be specific. A multi-layer approach is proposed, which sets different requirements depending on the involved level of criticality (levels ranging from 1 to 5). According to such principle, different minimal risk manoeuvers (MRM) performance levels would be defined. Moreover, connectivity related issues could be taken into account in the analysis of critical situations/events as they represent an additional contribution to the vehicle's sensing capabilities.

The resulting regulation's architecture (Figure 1) includes a horizontal layer plus vertical regulations. The horizontal layer builds on use-case description, use-case analysis and use-case requirements.

Figure 1. Proposed schematic architecture.



Source: French Republic, 2017.

The document also includes considerations on possible validation approaches and tools to match the different "regulation building blocks" proposed. First considerations are made on level of verification (Self-declared, Evidence-based, Certified by third party, Tested by public authority) and validation tools (Documentation screening or analysis, Simulations, Tests) according to the type of requirements and level of criticality (Table 1).

Table 1. Possible validation procedures and tools

Level of criticity	*Type of requirement*	*Level of verification*	*Validation input / tools*
Criticity level 0	No regulation (= know how)		
Criticity level 1	Situation and event aknowledgment	Self-declaration or Evidence based	Documentation Simulations
Criticity level 2	Response availability	Self-declaration or Evidence based or Certified	Documentation Simulation
Criticity level 3	Response functionnal description	Self-declaration or Certified	Documentation
Criticity level 4	Response required functionnalities	Self-declaration Evidence based or Certified	Documentation Simulations
Criticity level 5	Response required performance	Evidence based or Certified or Tested	Simulation Tests

Source: French Republic, 2017.

2.3 PEGASUS Method for Assessment of Highly Automated Driving Function (HAD-F)

The project for the establishment of generally accepted quality criteria, tools and methods as well as scenarios and situations for the release of highly-automated driving functions (PEGASUS) is promoted by the German Federal Ministry for Economic Affairs and Energy (BMWi). Its objective is to develop and demonstrate methods, criteria, tools and guidelines to safeguard highly automated driving functions (Level 3), in order to facilitate the rapid implementation of automated driving into practice (PEGASUS, 2019).

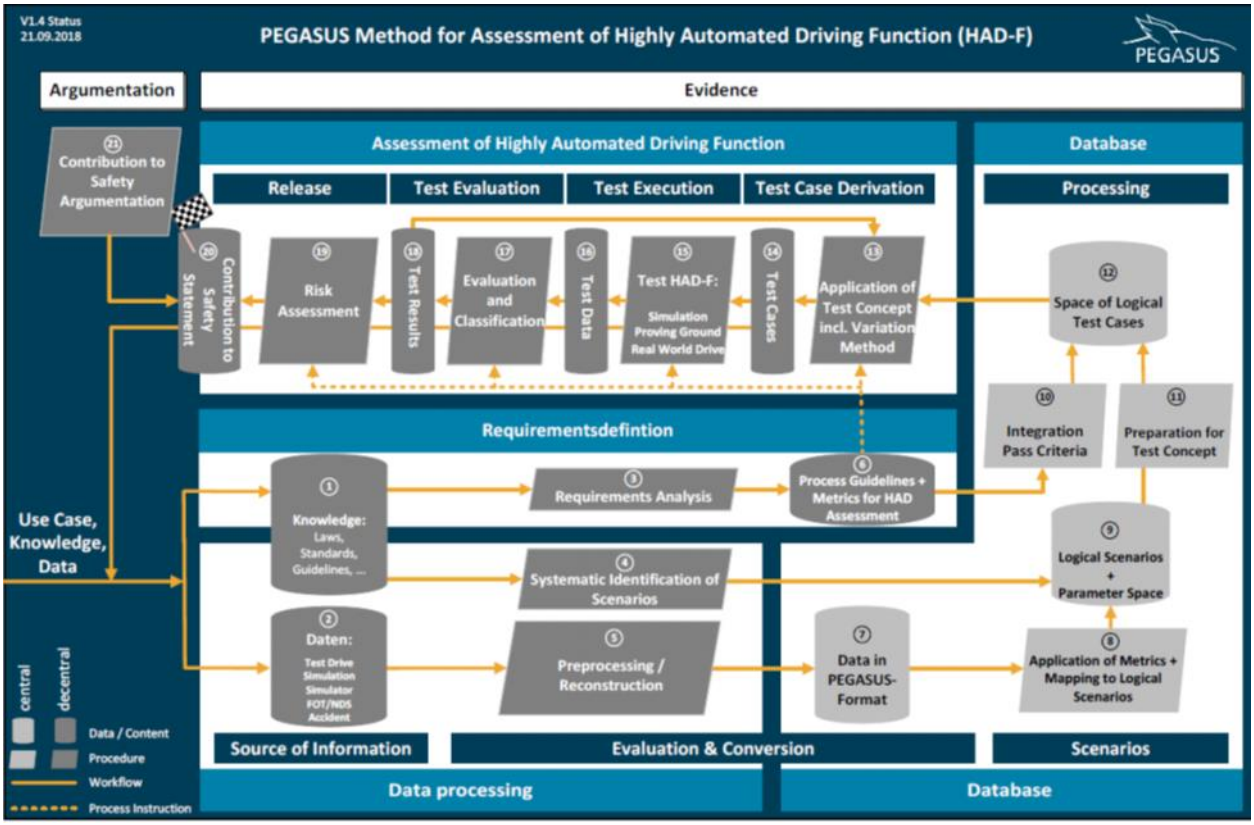
The project was launched in 2016 with the aim of developing, until 2019, a standardised procedure for the testing and approval of automated driving functions and gathers together automotive companies, suppliers, small and medium-sized companies as well as research facilities. The main goals also include the development of a continuous and flexible tool chain to safeguard the automated driving; the integration of the tests in the development processes; the definition of a cross-manufacturer method for the safeguarding of highly automated driving functions.

Within the project PEGASUS, a scenario-based approach is considered to reduce the approval effort for highly automated driving. The basic assumption is that critical scenarios are quite rare and randomly distributed in real traffic, while no critical events happen during most of highway driven range. Moreover, since testing of the ordinary scenarios does not bring relevant contribution to the approval process, the identification of critical scenarios to be tested would significantly reduce the long driving test distances needed for a statistical approval (Amersbach and Winner, 2017).

PEGASUS general methodology is sketched in Figure 2 (read counter-clockwise from the bottom left "Use Case, Knowledge, Data" to the upper left "Safety Argumentation"). The right hand side describes procedural aspects, how the evidence for the safety argumentation is generated. The process flow consists of four basic elements: A. Definition of requirements, B. Data Processing, C. Information storage and processing in a database, D. Evaluation of the highly automated driving function.

Based on current knowledge (1) (legal or standardisation documents), safety requirements (3) are analysed and identified for highly automated vehicles. PEGASUS Project develops such fundamental safety requirements as a recommendation only. Within a second step, the knowledge (1) is also used for systematic scenario identification (4) and integrated into the scenario database (9). Current data (2) from different sources are converted or reconstructed into a uniform PEGASUS data format (5). This data (7) are assigned to logical scenarios in the database (8). The goal of this analytical data-driven concept is to evaluate whether the systematic identification covers the real scenarios or if additional scenarios and parameter spaces are needed.

Figure 2. PEGASUS method.



Source: PEGASUS, 2019.

The space of logical test cases (12), provided by the database is used by the test concept (13) to vary and to generate concrete test cases (14). This includes a determination of concrete scenarios, an assignment of test environments (simulation-based approaches, proving ground, real world) as well as a transfer of the existing test criteria. The test concept uses the information from the database and the test results within an iterative search for challenging cases. The test cases (14) are executed with simulation-based test methods, at the proving ground or in real world tests, or combinations thereof. Based on the primary evaluation criteria (3) the test results are evaluated (17) and used to determine (19) the risk with a unified approach proposed from (3) (Mazzega, 2018).

Driving task decomposition was also presented within the PEGASUS project for test case generation (Amersbach and Winner, 2017), aiming at reducing the approval effort even more. A six-layer decomposition of for HAD function is presented to analyse failures that lead to traffic accidents (failure chain): (Layer 0) Information access; (Layer 1) Information reception; (Layer 2) Information processing; (Layer 3) Situational understanding; (Layer 4) Behavioural decision; (Layer 5) Action. Thanks to the combination of the scenario-based approach with the functional decomposition of the HAD function to be approved, particular test cases can be specified based on a Fault Tree Analysis (FTA). As a result, some of the identified test cases can be eliminated or aggregated, reducing the needed testing effort. Further to that, the decomposition approach can be used to reduce the approval effort for variants or updated functions.

2.4 Vehicle Safety Security Framework (VSSF)

The Dutch Vehicle Authority (RDW), proposed a methodology (Pater, 2018) that starts from the assumption that the European Type Approval System is not sustainable for testing upcoming generation of vehicles with more than 100 million lines of software and connections to the outside world. Therefore, in order to bridge the gap between regulation and innovation a new way of testing, certifying and monitoring is needed, which will eventually include virtual testing of the car and a driver license for the software. In preparation of the new type approval regulation, RDW identified three main fields of action:

— Learning Audit / Learning Experience - VSSF

— Vehicle Driving License – vDL

— Experimentation Law (January 2019)

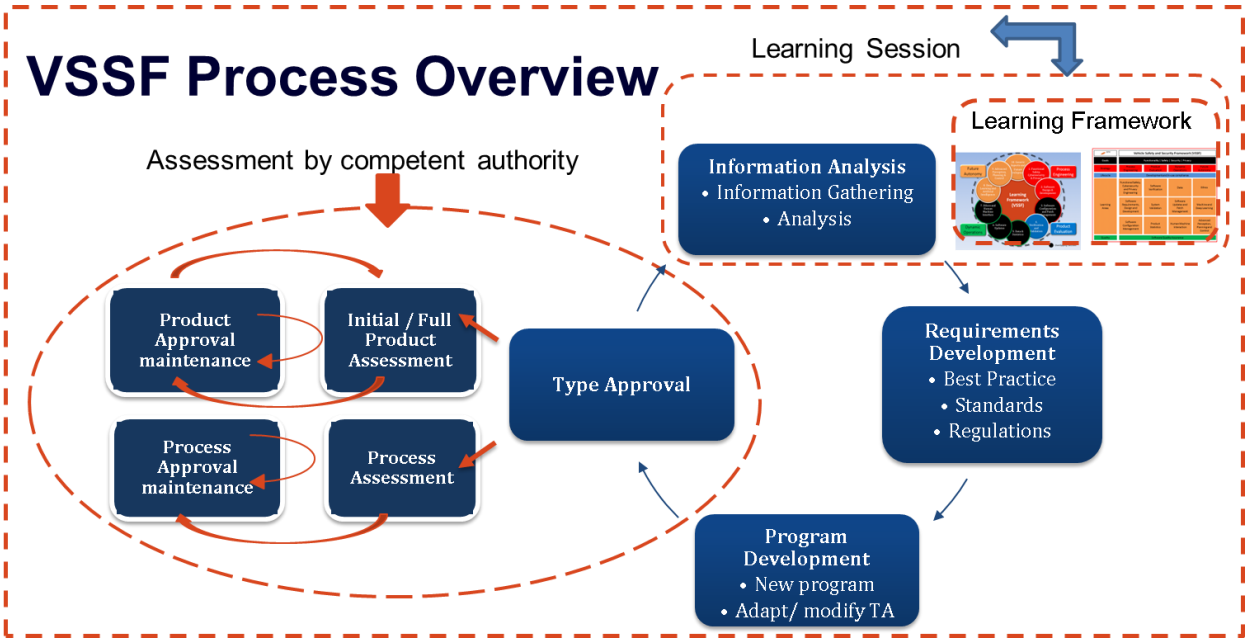
As initial step towards standardising the process of approving vehicles with highly automated systems, RDW established the "The Vehicle Safety and Security Framework" (VSSF, Table 2) in order to build the necessary expertise through learning experiences. According to the VSSF process (Figure 3), information is gathered through learning sessions and then analysed within the learning framework. Requirements are developed starting from that, which are then fed into best practices, standards and guidelines. Based on those requirements, a new/updated program is developed for product type approval.

Table 2. RDW Learning Framework.

RDW	Vehicle Safety and Security Framework (VSSF)			
Goals	Functionality | Safety | Security | Privacy			
Strategy	Process Engineering	Product Evaluation	Dynamic Operations	Future Autonomy
Lifecycle	Development and In-use compliance			
Learning Areas	Functional Safety, Cybersecurity and Privacy Engineering	Software Verification	Data	Ethics
	Software Requirements, Design and Development	System Validation	Software Updates and/or Patch Management	Machine and Deep Learning
	Software Configuration Management	Product Statistics	Human Machine Interaction	Advanced Perception, Planning and Control
Quality	Software Quality Assurance			

Source: Pater, 2018.

Figure 3. VSSF process.



Source: Pater, 2018.

Further to that, RDW designated Green Dino to develop a licence for Artificial Intelligence (AI)-drivers. As a result, a collaboration of stakeholders was initiated under the 'Digital Driving License Project', in order to define an international standard for licensing of intelligent vehicle operating systems, human and AI. The proposed process of testing includes: virtual environment, scale modelling, proving ground, driving exam, driving license and in-use compliance. First pilot driving license in the Netherlands planned within 2019. International collaboration for the release of a new ISO standard by 2022 is also proposed.

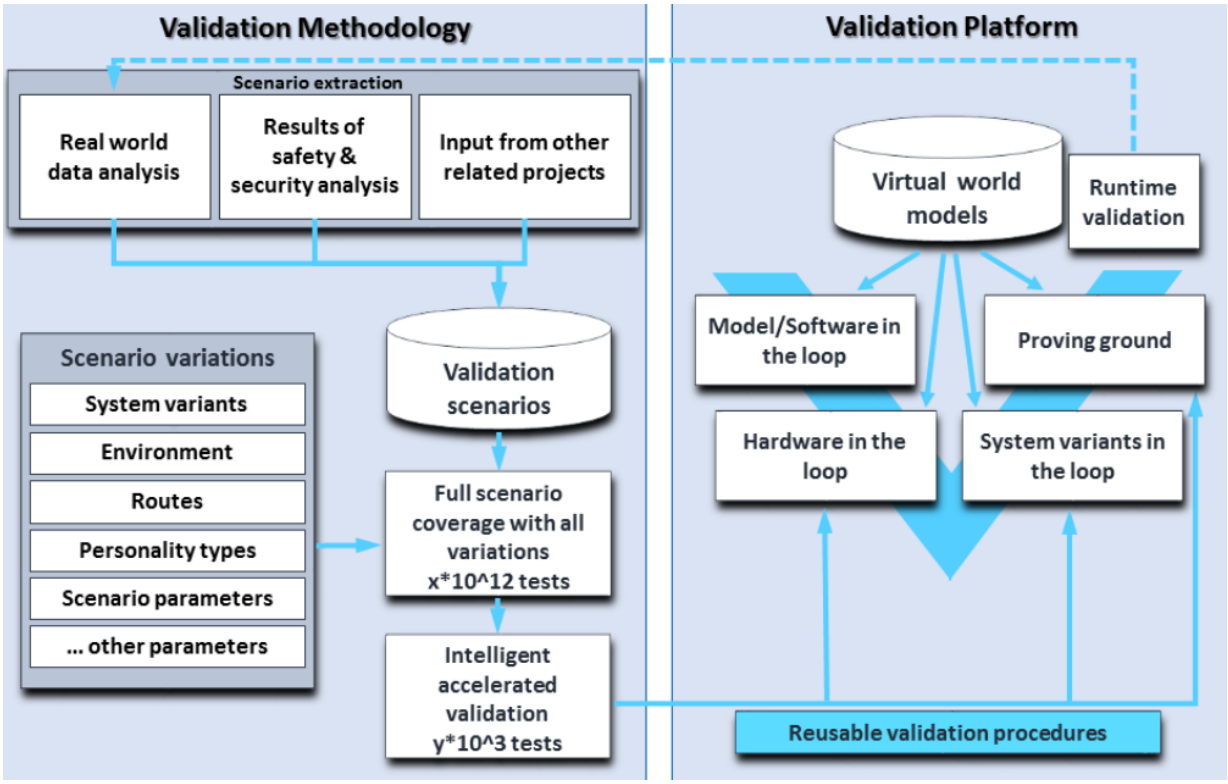
2.5 ENABLE-S3 Project - European Initiative to Enable Validation for Highly Automated Safe and Secure Systems

ENABLE-S3 is an industry-driven project and aspires to substitute today's cost-intensive verification & validation efforts by more advanced and efficient methods to pave the way for the commercialisation of highly automated cyber physical systems (ACPS). From one side pure simulation alone cannot cover all physical details and from the other real-world tests are too expensive, too time consuming and potentially dangerous. Thus, ENABLE-S3 aims at developing an innovative solution combining both approaches in an optimised manner (ENABLE–S3, 2019).

ENABLE-S3 is use-case driven, representing relevant environments and scenarios from six industry sectors (automotive, aerospace, rail, maritime, health, and farming). Each of the models, methods and tools integrated into the validation platform can be applied to at least one use case, under the guidance of the Verification and Validation (V&V) methodology, where they are validated and their usability demonstrated.

The project aims at developing new technologies to ensure correct, reliable and safe (e.g. according to regulatory requirements) behaviour of highly automated and autonomous systems (situation understanding, decision-making, planning and control). ENABLE-S3 approach focuses on virtualisation using modelling and simulation. The main objective is to ensure automated systems reliability and minimising the risk of design/implementation faults by the provision of a comprehensive modular verification and validation framework covering the validation methodology on the one hand side and the validation platform to conduct the tests on the other side (Figure 4).

Figure 4. ENABLE-S3 validation framework.



Source: ENABLE-S3, 2019.

The technical approach covers the following aspects:

- Extraction of test scenarios (e.g. from vehicle road data)
- Scenario-based verification & validation in virtual, semi-virtual, and real testing environments
- Environment and sensor models as well as sensor stimuli for Model/Software in the Loop (MiL/SiL), Hardware in the Loop (HiL) and Vehicle in the Loop (ViL)
- Integrated safety and security analysis approaches
- Reduction of required tests for highly varying environmental conditions
- Draft-standards for test scenario descriptions

For the automotive sector, six use-cases are considered (ENABLE-S3, 2018):

- Use case 1 – Highway pilot
- Use case 2 – Intersection crossing using autonomous vehicles
- Use case 3 – Use case context-aware in-car reasoning system
- Use case 4 – Traffic jam pilot with Vehicle to Everything (V2X) communication
- Use case 5 – Traffic jam chauffeur with in-vehicle sensors
- Use case 6 – Use case valet parking

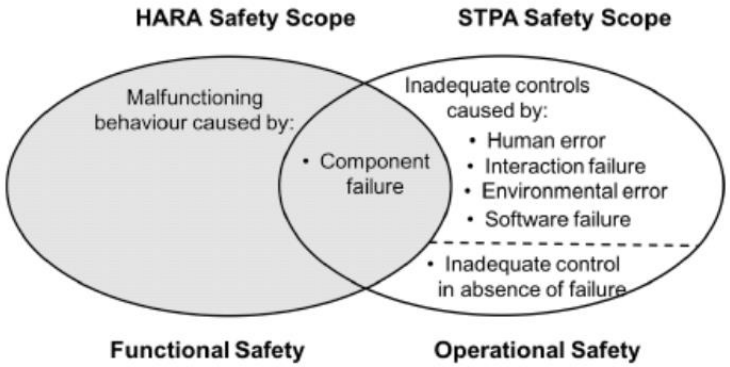
For each use-case, a set of "demonstrators" are identified as methodologies and tools necessary in order to assess the vehicle safety performance. As an example, AVL DrivingCube (test bed extended by physical sensor stimulators) is proposed as demonstrator to integrate the different tools and methods, related to the Highway Pilot testing functions that have been developed during the project.

2.6 Systems-Theoretic Process Analysis (STPA) approach

University of Stuttgart and Continental presented an approach based on Systems-Theoretic Process Analysis (STPA) to be applied in compliance with ISO 26262 for developing a safe architecture for fully automated vehicles (Abdulkhaleq et al. 2017a, 2017b). STPA was developed as an holistic approach alternative to Fault Tree Analysis (FTA) and Failure Mode and Effects Analysis (FMEA), which are currently used in the most recent ISO 26262 applications to identify component failures, errors and faults that lead to specific hazards (in the presence of faults). Indeed those methods are not suitable for addressing new hazards caused by complex human-automated system interactions (dysfunctional component interactions, software failure, and human error), while STPA can address more types of hazards and treats safety as a dynamic control problem rather than an individual component failure. The methodology aims at applying STPA to extend the safety scope of ISO 26262 and support the Hazard Analysis and Risk Assessments (HARA) process.

In fact, while the safety scope of the HARA in ISO 26262 is to identify the possible hazards caused by the malfunctioning behaviour of electronic and electrical systems (individual components), STPA also focuses on identifying the potential inadequate controls (caused by human error, interaction failure, environmental, software failure) that could lead to the hazards (Figure 5), also in the absence of component failure.

Figure 5. Safety scope of STPA and HARA in ISO 26262.



Source: Abdulkhaleq and Lammering, 2017.

The main starting point of STPA is to identify potential accidents and hazards at the system level and draw hierarchical safety control structure of the system (**Step 0**). Then such results are used to define an item and item information needed (e.g. purpose, content of item, functional requirements etc.). The list of hazards, accident, the high-level system safety constraints identified in Step 0 is also used as an input to the HARA approach.

Step 1 identifies the unsafe control actions of an item while **Step 2** identifies the causal factors and unsafe scenarios deriving from each of them. Finally, results of STPA Step 1 & 2 are used to develop the system functional safety concept and safety requirements at this level.

An example of application of the proposed concept to a current project of a fully automated vehicle at Continental was presented. As a result, 24 system level accidents, 176 hazards, 27 unsafe control actions, and 129 unsafe scenarios were identified.

STPA approach can potentially be used to: (i) support the safety lifecycle and HARA process in ISO 26262; (ii) identify the operational safety requirements and develop operational safety concepts of fully automated driving vehicle; (iii) evaluate and develop a reliable architecture for fully automated driving vehicle.

2.7 TÜV Rheinland

TÜV Rheinland carried out a number of vehicle safety assessments for the German government in the framework of EU exemption procedures for driver assistant systems (SAE level 2 systems) on the basis of current legal framework. TÜV Rheinland has experience in assessing vehicle safety in the absence of harmonised rules, requiring the relevant information by manufacturers, carrying out the risk assessment and requiring the tailored tests. TÜV has therefore ideas on how to improve the current EU exemption framework for new technologies.

3 Conclusions

Various approaches regarding the safety assessment of AVs are being considered within the EU and worldwide by governments, industry and other stakeholders. The aim of the study was to prepare the discussion on the state of play at the 1st Technical Workshop on New Approaches for Automated Vehicle Certification, addressing different merits/limits of the different methodologies and the way forward.

In this context, the most important result of the present study was understanding the complementarity of the proposed approaches, both in terms of readiness and perspective. This finding was also confirmed by the subsequent workshop discussion. The increasing complexity of AV systems requires deeper understanding of safety-critical aspects and further research on innovative safety assessment methods. Moreover, all participants also acknowledged the importance of this workshop as the first step towards the direction of a common European AV safety assessment approach and confirmed their availability to take part in follow-up discussions.

The next step of this process will include the extension of the discussions to other Member States and stakeholders and the elaboration of a potential harmonised approach by the European Commission's Joint Research Centre.

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List of abbreviations and definitions

ACPS	Automated Cyber Physical System
AD	Automated Driving
AI	Artificial Intelligence
AV	Autonomous Vehicle
BMWi	German Federal Ministry for Economic Affairs and Energy
DG GROW	Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs
ENABLE-S3	European Initiative to Enable Validation for Highly Automated Safe and Secure Systems
EU	European Union
FMEA	Failure Mode and Effects Analysis
FTA	Fault Tree Analysis
HAD-F	Highly Automated Driving Function
HARA	Hazard Analysis and Risk Assessments
HiL	Hardware in the Loop
HMI	Human Machine Interface
ISO	International Organization for Standardization
ITS	Intelligent Transport Systems
JRC	Joint Research Centre
MiL	Model in the Loop
MRM	Minimal Risk Manoeuvres
ODD	Operational Design Domain
PEGASUS	Project for the establishment of generally accepted quality criteria, tools and methods as well as scenarios and situations for the release of highly automated driving functions
RDW	Dutch Vehicle Authority
RSS	Responsibility-Sensitive Safety
SAE	Society of Automotive Engineers
SiL	Software in the Loop
STPA	Systems-Theoretic Process Analysis
TÜV	Technischer Überwachungsverein
UNECE	United Nations Economic Commission for Europe
US	United States
USA	United States of America
V&V	Verification and Validation
V2X	Vehicle to Everything
vDL	Vehicle Driving License
ViL	Vehicle in the Loop
VSSF	Vehicle Safety Security Framework
WP	Working Party

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Annex – 1st Technical Workshop on New Approaches for Automated Vehicle Certification agenda

Technical Workshop on new approaches for automated vehicle certification

November 22nd, 2018

JRC HEADQUARTERS, Rue du Champ de Mars 21 - Brussels

Meeting Room 05/A228

AGENDA

9:00 – 9:30	Welcome and introduction by EC
9:30 – 10:00	Presentation Mobileye
10:00-10:30	Presentation French Government
10:30-11:00	Presentation PEGASUS Project
11:00-11:30	**Coffee break**
11:30-12:00	Presentation RDW
12:00-12:30	Presentation ENABLE-S3 Project
12:30-13:00	Presentation Continental
13:00-13:30	Presentation TÜV Rheinland
13:30-14:00	Presentation IDIADA
14:00-15:00	**Open Discussion & Sandwich Lunch**

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