International Alliance for Mobility Testing and Standardization™

CITA International Motor Vehicle Inspection Committee

Whitepaper

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Assuring Regulatory Compliance of Connected and Automated Vehicles during their Operational Lifetime

Rationale

Engineers of all countries are making a significant contribution to the success of automated driving in a variety of development, standardization, and testing organizations. New regulations, standards and directives for automated driving already determine for a considerable part the engineers' work, today. They must have precise knowledge of the relevant legal regulations and comply with these rules in their daily work. At the same time, they have an ethical duty to point out gaps and inadequacies in standardization, regulation and usage of the correct terms and language. In doing so, they help to draw attention to potential risks to people and society and call for new regulations to address them.[1] The present white paper "Assuring regulatory compliance of connected and automated vehicle during their operational lifetime" reflects this ethical duty of professional engineers of IAMTS and CITA. Both organizations intend to invite for a debate on the safety of automated vehicles in their operational mode as well as to inform and involve the public from an independent and unbiased point of view. Resulting from the debate and broad involvement, the authors also seek for support from other associations, regulators and politics in tackling the tasks ahead.

The white paper shows that there are several approaches for whole life vehicle-compliance tests depending on the individual responsibility of the vehicle manufacturer, the country's safety authority and the owner or operator of the vehicle.[2] While test procedures for product monitoring and market surveillance are addressing the manufacturer and the safety authority of each country, regular roadworthiness inspections carried out by independent organizations are under the responsibility of the vehicle owner. All the whole life-cycle vehicle compliance tests pursue the intention that the vehicles remain fully functional and roadworthy. Finally, the outcomes and consequences of all these programs show that they are effective in their stated aim of mitigating roadway fatalities. Realistically, even in the near future, we will see different methods and approaches to regulatory work in the various regions of the world. Mainly also due to different regulatory systems. However, greater coordination and alignment of regulation would be desirable. Among other things, a more generic approach to the standardization of automated driving functions would be desirable. Such approaches have the potential to enhance the effectiveness of future regulations and enable safety features to be brought to market sooner, as well as making safety improvements more affordable.

However, considering current challenges and trends in the mobility sector such as software embedded intelligence in highly and fully automated vehicles whole life-cycle vehicle compliance tests have to be adjusted and extended. The systems are sensitive to vehicle and sensor conditions, by themselves adaptable and underlie updating cycles very different from traditional in-vehicle systems. The paper demonstrates evidently that the desired improvement in road safety based on automated and connected mobility must not be jeopardized by system-inherent weaknesses or even lead to their opposite.[3]

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[1] Brauckmann, Jürgen, Hähnel, Rainer, Mylius, Gerd, Motor vehicle experts in Germany, Bonn 2008, p. 19.
[2] UNECE/TRANS/WP.29/2021/148/Proposal for a Framework Document on Vehicle Whole-Life Compliance, November 2021; https://unece.org/sites/default/files/2021-10/ECE_TRANS_WP.29_2021_148E.pdf (last access: 2-11-22).
[3] Avenoso, Antonio, Letter: Autonomous vehicles are no miracle cure for crashes, in: The Financial Times, February 1st, 2022.

Specifically, the white paper calls for the necessity that Advanced Driver Assistance and Automated Driving Systems (ADAS/AD-systems) have to be safe for production and that they continue to be safe after they have been released in a vehicle and can become even better in operation and during future updating cycles during the vehicles' lifetime. Valid results and data from vehicle compliance tests can contribute to this improvement. The paper also posits that especially safety inspections will only become even more important as ADAS/AD-systems become more prevalent. Particularly, this holds true for over-the-air updates, an increasingly common method of updating car software that avoids forcing the owner to visit a garage or dealership. While several international jurisdictions in the EU have already adapted safety inspections to include testing and calibrating ADAS/AD systems[4], this has yet to be applied in other world regions such as the United States or China.

Finally, the paper ends with concrete observations to streamline the creation and adoption of regulations and standards for the life-time compliance testing.

Preface

IAMTS is a global, membership-based association of organizations that are stakeholders in the testing, standardization, and certification of advanced mobility systems and services. IAMTS brings together testing consumers and providers at a global scale to help develop a commonly accepted framework of test scenarios, validation and certification methods, and terminology.

Our mission is to develop and grow an international portfolio of advanced mobility testbeds that meet the highest quality implementation and operational standards.

Our vision is to create a global community of advanced mobility testing service providers with companies, organizations, and agencies in need of such services; to learn, develop, and share best practices to ensure consistent, replicable, and reliable testing; to maintain a global directory of physical, virtual, and cyber-physical testbeds and support and promote their audited capabilities; and to promote the rapid evolution of standards and certifications to ensure the safe deployment of advanced mobility systems and services.

CITA, the international motor vehicle inspection committee, is the worldwide association of authorities and authorized companies active in the field of vehicle compliance.

CITA is the impartial partner to enable programs and policies for safe and clean vehicles. Its members include public and private sector organizations, inspection companies, national and regional inspection associations, and regulatory authorities from all around the world. The association's mission is to promote vehicle safety and environmental protection through the development and implementation of high-quality international standards, best practices, and information sharing among its members.

[4] E.g.: Commission implementing regulation (EU) 2022/1426 laying down rules or the application of Regulation (EU) 2019/2144 of the European Parliament and of the Council as regards uniform procedures and technical specifications for the type-approval of the automated driving system (ADS) of fully automated vehicles (August 2022); Germany Ordinance implementing the Act amending the Road Traffic Act and the Compulsory Insurance Act (June 2022).

1. Introduction

In spring 2012, Google published a remarkable video clip on YouTube.[5] In this video, Steve Mahan, a blind man, is taken by a self-driving car to a Taco Bell on the other side of the city of San Jose, CA. Steve is overwhelmed by this gain in individual mobility and touched to tears. Since at least this event the advancing development of connected and automated driving has become a fundamental driver of structural change in the automotive industry. According to the consultancy McKinsey, around 106 billion U.S. dollars were invested in the development of the necessary software and hardware between 2010 and 2021 - significantly more than in the drive revolution, the electrification of vehicles, in which 62 billion U.S. dollars were invested in the same period.[6]

The ongoing technological disruption is supposed to evoke a paradigm change in deployment and operation and usage of new vehicles and mobility concepts. Ultimately, it is assumed that automation in mobility will result in sweeping social and economic changes and lead to breakthrough gains in transportation safety and efficient use of resources and road space. Specifically in combination with electro-mobility and sharing services, and as an addition to public transportation, automated driving points the way toward an environmentally compatible, enhanced mobility that particularly is of benefit to people.[7]

As the example shows, the automated driving functions of a vehicle redefine the role of vehicles and owners and of the surroundings - other traffic participants, infrastructure etc. On one hand, the vehicle functions in a different role, enabling a societal benefit. On the other hand, the system wants to be and needs to be taken care of in a different way than traditional mobility concepts - including validation and aspects of operation like maintenance or in-use checks. Accordingly, the realization of a brighter future for society by automation, new concepts of mobility and technological progress is inextricably linked to the safety, availability, and reliability of these technologies over their entire lifecycle.

Safety, availability, and reliability will create acceptance and trust in society for the breakthrough of higher levels of automation and new mobility concepts in future. In this context, the ultimate question of “how safe is safe enough for connected and automated vehicles in real operation” must receive a higher amount of attention.[8]

Various private and governmental organizations, such as the joint project PEGASUS, funded by the German government, have proposed a wide range of approaches and methodologies for measuring or demonstrating safety of automated and connected vehicles.[9] These measures must ensure that the systems perform better than humans and that the remaining unavoidable risk is significantly less than a pure human driving performance. While these methodologies focus mainly on the design and approval process as well as the deployment stage of a new vehicle model, current standards and regulatory requirements for the safety of automated and connected vehicles in their aftermarket lifecycle have not been sufficiently addressed.

In this white paper IAMTS and CITA point out that in particular the safety and the independent proof of regulatory compliance of connected and automated vehicles throughout the entire life cycle has literally a pivotal role for both the social acceptance and the successful introduction and dissemination of these new technologies. In addition, it will have an impact on the affordability and operational practicability of roadworthy systems. Specifically, because a valid statistical proof that the vehicles completely fulfil the corresponding prerequisites and prove themselves in real operation cannot be provided before market launch.[10]

The basis for the whitepaper was a series of workshops with numerous experts from the fields of automotive, traffic safety, and standardization. These experts came from the USA, EU, and China, providing a diverse and comprehensive perspective on the subject matter.

During the workshops, the experts discussed various aspects of the topic and shared their insights, experiences, and knowledge. They explored different approaches, strategies, and technologies for improving automotive safety and reducing accidents. It became very obviously, that questions related to automated driving, including ethical aspects and the processes for approving and inspecting these systems in road traffic, cannot be answered by single stakeholders.

[5] https://www.youtube.com/watch?v=cdgQpa1pUUE (last access: 2-11-22).
[6] McKinsey, Mobility’s future: An investment reality check, April 2021.
[7] Shladover, S.E. Opportunities, Challenges, and Uncertainties in Urban Road Transport Automation. Sustainability 2022, 14, 1853. https://doi.org/10.3390/su14031853 (last access 2-11-22).
[8] Stilgoe, J. How can we know a self-driving car is safe?. Ethics Inf Technol 23, 635–647 (2021). https://doi.org/10.1007/s10676-021-09602-1 (last access 2-11-22).
[9] Pegasus, Projekt zur Etablierung von generell akzeptierten Gütekriterien, Werkzeugen und Methoden sowie Szenarien und Situationen zur Freigabe hochautomatisierter Fahrfunktionen, Berlin 2020; https://www.pegasusprojekt.de/files/tmpl/pdf/PEGASUS_Abschlussbericht_Gesamtprojekt.PDF (last access 2-11-22).
[10] U. Steininger, J. Mazzega, S. Witkowski, T. Form, K. Lemmer, Nachweis der Betriebsbewährung automatisierter und autonomer Fahrzeuge, VDI-Tagung Fahrerassistenzsysteme und automatisiertes Fahren, 17.-18. Mai 2022, Aachen, VDI-Bericht Bd. 2394.

The creation of guiding principles to define standardized testing methods for a whole life compliance approach of connected and automated vehicles has to involve best practice of all stakeholders of the automotive value chain. In this respect, this white paper calls for cooperation among the entire automotive sector from OEM to supplier start-up companies to leverage the full potential of connected and automated driving to improve road safety. More agile and generic approaches to standardization such as technical reports, whitepapers and publicly available specifications can allow a quicker reaction reaching a consensus of state-of-the-art and best practice. In this regard, the intention of this paper is to provide all relevant stakeholders in the automotive sector a working basis for proving the operation safety and regulatory compliance of automated and connected vehicles throughout the entire cycle in real world operation.

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2. Scope

The main goal of the whole-life vehicle compliance approach is that in-use vehicles technical conditions shall not cause any traffic accidents resulting in injury or death that are reasonably foreseeable and preventable, shall resist cyberattacks and shall be environmentally consistent with their current type approval status. The assurance of whole-life vehicle compliance is made up by different approaches depending on the individual responsibility of the vehicle manufacturer, the country's safety authority and the owner or operator of the vehicle. While test procedures for product monitoring and market surveillance are addressing the manufacturer and the safety authority of each country, regular roadworthiness inspections carried out by independent organizations are in the responsibility of the vehicle owner.

Diverging global regulatory schemes increase complexity and costs in the system, potentially delaying the market entry of safety enhancements beyond what is necessary. Despite of differences in terms of jurisdiction and performance, whole lifecycle vehicle compliance programs have significant commonalities. They pursue the intention that they are effective in their stated aim of mitigating roadway fatalities and that the vehicles remain fully functional and roadworthy. Accordingly, all of these programs face similar challenges in evaluating the safety of automated driving and should be collectively and broadly considered from the beginning.

This being said IAMTS and CITA are inspired to provide pioneering answers in this white paper to current critical questions in vehicle safety in real operation such as:

- What are the key elements of trustworthiness for connected and automated driving?
- What are the major risks and vulnerabilities in the operational mode of a vehicle?
- How to identify and prioritize relevant use cases/examples during the lifecycle of a vehicle?
- How to test and verify/validate such a safety case, security case?

For answering these questions, this paper intends to illustrate what progress has been made by legislation and standardization worldwide to enhance the regulatory framework for the automotive industry. Simultaneously, gaps for an adequate operational safety of connected and automated vehicles are identified. For this purpose, expected scenarios and hazard potentials in the life cycle of these vehicles that are relevant for regulation are evaluated. Finally, requirements and proposals for appropriate test procedures in the life cycle of connected and automated vehicles are addressed for improving the safety validation and the roadworthiness of motor vehicles beyond Level 3 SAE J3016.

3. Excursus: Defining the term “autonomous”

Excursus: Defining the term “autonomous”

Highly automated cars will be smart due to computerization and software embedded intelligence. They will communicate digitally with each other and the infrastructure, sense and landscape the surrounding, and maneuver in an ever more changing environment according to their capabilities. Drivers will be operators and eventually passengers.

While the internationally recognized SAE J3016 standard (see Figure 1) already describes the taxonomy and definition of terms for on road motor vehicles with automated driving systems, there is obviously still a debate among experts about the term “autonomous”. One group is arguing that the vehicle needs to be able to make all decisions on the vehicle level to operate to be called “autonomous”. In this respect, Alex Roy made a very definite statement about the concept of automated driving recently:

“The concept of autonomy is totally binary: a vehicle is either capable of driving itself without human supervision, or it isn’t. If it requires any human supervision, it is not autonomous.”[11]

Another group is arguing that decision support could also come from the backend or the edge, in particular if the network allows real-time response with extremely low latency to be called “autonomous”. In this case more scalable computing power could be allocated to the vehicle through the edge or the backend.[12]

In sum, this debate is more or less a linguistic confusion that certainly does not contribute to a fact-based debate about increasing automation and its impact on vehicle safety. Instead, it would be better to argue explicitly against the existing SAE standard J3016, without using the popular term "autonomous". In fact, only humans are autonomous and free. In

[11] Alex Roy, “Alex Roy’s Glossary of BS in Mobility, Self-Driving and Autonomy (Winter 2019/2020),” The Drive, January 31, 2020.
[12] Hetzer, D., Muehleisen, M., Kousaridas, A. et al. 5G connected and automated driving: use cases, technologies and trials in cross-border environments. J Wireless Com Network 2021, 97 (2021). https://doi.org/10.1186/s13638-021-01976-6 (last access 2-11-22).

contrast, the machine is programmed and unfree. Autonomy, autonomous operation and reasoning powers are all human abilities and characteristics that are solely reserved for the free-willed human being, but not for things and programmed process machines. The latter cannot be perceived as beings of freedom and act in a self-determined way.

In fact, there are two kinds of automated motor vehicles in the debate and scope of this publication. Firstly, passenger and multi-purpose vehicles for private and commercial use with assisted and automated driving technology that help humans drive (SAE Level 2 and 3) and secondly, fully automated vehicles with no human driver present in the vehicle such as a local driverless taxi or goods and people mover for commercial use only (SAE Level 4).

Cars with assisted driving technology have been available for purchase around the World for a number of years. These cars require a human driver in the driver's seat paying attention at all times and ready to take full control of the car. The assisted driving technology might be as simple as adaptive cruise control that slows down when the traffic ahead slows down or could include things like automatic emergency braking or steering on the freeway.

A system defined by level 3 of the SAE categorization of vehicle automation is a hybrid solution where the system is driving conditionally automated as long as the system is operating within its parameter ranges (i.e. a traffic jam chauffeur). However, if the system is leaving those parameter ranges, the human driver is asked to take over control within a certain timeframe. The system will be brought into a risk minimal condition by the machine itself, if the system operation leaves its parameter ranges.

However, fully automated, i.e. driverless, systems are defined by level 4 of the SAE categorization. Fully automated driving in the sense of level 4 SAE, enabling drivers or passengers like Steve Mahan to get from A to B without human assistance, risk-free and unrestricted in normal road traffic does not really exist in road traffic yet. Although Waymo's advanced robot cab service in Phoenix, Arizona, and Apollo Go's robotaxis in Wuhan and Chongqing can perform the entire Dynamic Driving Task ("DDT") without any human assistance. This does not necessarily mean that these fully automated vehicles can drive everywhere under all conditions by themselves within a defined operational design domain (ODD). It is just the case, that the vehicle knows where and when it can operate. And if it needs help in an unforeseen situation when the vehicle has reached system limits or has to leave the ODD, it can reach a safe state. In such situations, a human is still sitting in a remote place, helping the vehicle control system (i.e. by tele-operation). Each of these vehicles manufactured or used by a company may have different constraints or specific ODD. The AD-system of the vehicle always comes with the ODD and the ODD sets the requirements and scenarios of operation.

For automated driving not to be limited to suburbs in American deserts or designated zones in China's cities that have been optimized for car traffic, the vehicle's perceptual and decision-making skills and its ability to avoid accidents must first really surpass those of humans.[13]

Regarding regulations for the approval of SAE Level 4 driving features and the definition of their ODD, the adoption of the German Act and Ordinance on Autonomous Driving in May 2022 was a fundamental step forward. At least, the Act on Autonomous Driving is an interim solution until internationally harmonized provisions enter into force. But it is likely that the German approach will be a blueprint for a worldwide harmonized regulation for the approval of SAE Level 4 vehicles.[14]

Level **0**	Level **1**	Level **2**	Level **3**	Level **4**	Level **5**
NO DRIVING AUTOMATION	DRIVER ASSISTANCE	PARTIAL DRIVING AUTOMATION	CONDITIONAL DRIVING AUTOMATION	HIGH DRIVING AUTOMATION	FULL DRIVING AUTOMATION
Only supportive e.g. ABS or ESC)	Specific execution by a driving automation system of either the lateral **or** longitudinal e.g. ACC, AEBS	'hands-off' autonomy Specific execution by an ADS of either the lateral **&** longitudinal e.g. GM's Super Cruise, Mercedes-Benz Drive Pilot.Tesla Autopilot, other..	'eyes off' autonomy Execution of DDT by an ADS in specific ODD; driver must be ready to take over where necessary (after alert) e.g. ALKS	ODD-specific performance by an ADS of the entire DDT, no expectation that a user will respond to a request to intervene	Sustained and unconditional Performance by an ADS (i.e. not ODD-specific) of the entire DDT
EU 2018/858 e.g. UN R 140	EU 2018/858 e.g. UN R 152	EU 2018/858	EU 2018/858 e.g. UN R 157	e.g. EU 2018/858 + e.g. EU 2022/1426 + e.g. AFGBV & StVG	

COMPLEXITY

Figure 1: Development of ADS/AD according to SAE J3016[15]

[13] Kompass, Klaus, Sicheres automatisiertes Fahren – mehr als nur höher, schneller, weiter, in: Eichelmann, A., Prokop, G., Reiter, B. (Hrsg.), Innovator, Ingenieur, Idealist – Festschrift anlässlich der Verleihung der Ehrendoktorwürde an Dr.-Ing. E.h. Jürgen Bönninger, Bonn 2022, p.45-57.
[14] Germany Ordinance implementing the Act amending the Road Traffic Act and the Compulsory Insurance Act (June 2022).
[15] https://www.sae.org/news/2019/01/sae-updates-j3016-automated-driving-graphic (last access 2-11-22).

4. Status Quo

This chapter discusses key challenges of a mobility based on CAVs and presents the different regulatory frameworks from an US-American, Chinese, and European perspective. As international standards also play an increasingly important role in the current framework an executive summary of the state-of-art situation is also provided in this chapter. The chapter pursues the goal of uncovering ambiguities and gaps in the applicable legislation and standardization. The legal framework for automated and connected driving must be designed to keep pace with innovative technical and technological developments and market changes. A future legal framework for the operation of automated and connected vehicles on public roads must be technology-friendly, flexible and optimally harmonized internationally.

4.1. Existing Regulatory Approaches to Assuring Compliance of Automated and Connected Vehicles

The homologation of automated and connected vehicles according to global technical regulations is essential for their safe and reliable development and deployment around the World. Many countries have established safety standards for vehicles, including those that are automated or connected. These standards often include requirements for crashworthiness, occupant protection, and other safety features. As automated and connected vehicles become more common, legal and liability frameworks are being developed to address issues related to accidents, insurance, and responsibility for accidents. Some countries require certification and testing of automated and connected vehicles to ensure compliance with safety and cybersecurity standards. This can include testing on closed tracks or public roads, and certification by third-party testing organizations.

Today, the framework for addressing the performance and safety of vehicles and automotive technologies represents a more and more complex web of national and international legislation, regulations, and industry accepted standards. At the core of this framework stands the United Nation's World Forum for Harmonization of Vehicle Regulations. The International Organization founded a special Working Group, named GRVA (Working Party on Automated/Autonomous and Connected Vehicles) that is in charge with creating harmonized automotive standards for automated driving. According to both agreements of 1958, providing UN Regulations and 1998, providing UN Global Technical Regulations, UNECE is aiming to improve the safety of automotive technologies to be deployed on the market.

However, from our perspective, the scope of the current framework applicable to vehicles has not evolved rapidly enough to keep pace with many of the advanced technologies ready to be deployed and used in automated vehicles. For example, harmonizing the requirements of individual systems takes more than half a decade. In addition, there are only limited approaches in today's regulations that address the effectiveness and safety of automation technologies and systems after their actual deployment in real operation on the road. As with increasing automation, vehicles transform into cyber-physical systems that no longer require a human driver. New safety challenges and their management in terms of functional requirements and their validation methods as well as the principal role of the vehicle driver in vehicles with automated driving functions have to be considered now.

4.1.1. UNECE – GRVA-Working Party on Automated/Autonomous and Connected Vehicles

The UNECE (United Nations Economic Commission for Europe) Working Party on Automated/Autonomous and Connected Vehicles is responsible for developing policy and regulatory frameworks for automated and connected vehicles. The working party's main task is to develop and harmonize international regulations, standards, and guidelines for automated and connected vehicles. The structure of the working group, hosted by the World Forum for Harmonization of Vehicle Regulations, is shown in Figure 2.

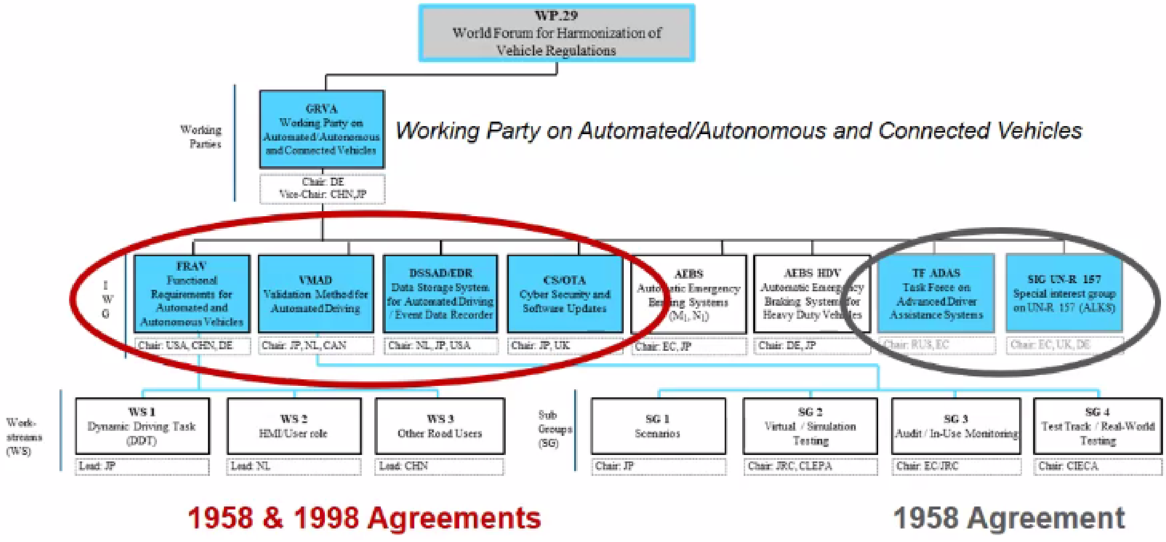

Figure 2: UN ECE WP.29 Structure GRVA, Source: Kraftfahrt-Bundesamt – all rights reserved[16]

Since 2005, UNECE-R79 includes parking steering assistants in speed range up to 10 km/h according to automation (Level 1 SAE). Regarding SAE Level 2, in 2018 UNECE-R79 allowed automated steering functions including lane changes, which must be instructed by the driver. In January 2024, UN Regulation No. 79 is to be replaced by the new regulation DCAS (Dynamic Control Assistance Systems). This regulation takes a more generic approach to evaluating ADAS performance and focuses on functional safety. In addition, specifications are being developed for so-called Level 2+ systems, which should make automated driving easier in vehicles in lower price segments.

With the UNECE- R157, which describes the requirements for Automated Lane Keeping System (ALKS), there is the first harmonized regulatory framework for a SAE Level 3 system. By using simulation as a crucial role for safety argumentation, it also considers the first time the idea of virtualizing major parts of the validation and homologation process. Furthermore, it is unique to the regulatory and standardization framework that there is a definition for a reasonable risk.[17] Approval has so far been granted for one vehicle model in Japan and one in Germany. Since January 2023, the scope of UN Regulation No. 157 has extended among other things to a maximum speed of 130 km/h with lane-change procedure.

To deal with the rapid increasing deployment of automation and digitalization the framework for automotive cybersecurity or even a precondition for the use and operation of advanced assistance technology have been set with the UNECE-R155 (Cyber Security and Cyber Security Management Systems) and UNECE-R156 (Software Updates and Software Updates Management Systems). In order to obtain approval from now on manufacturer need to provide a certified cyber security-management system (CSMS) and software update-management system (SUMS), including over-the-air updates.

UNECE-R156 will be introduced into European law by EU Regulation (EU) 2022/2236 as an amendment to EU Type Approval Regulation (EU) 2018/858 in accordance with extensive transitional provisions between July 2022 and July 2029.

The fact that it took more than six years to draw up the regulation for just one system is a point of criticism. In view of the rapid technological development, this period is clearly too long. The UN ECE is currently facing the challenge of adopting a more generic approach to the development of regulations that is not limited to individual systems.

Scope and Limits

The UNECE regulations currently provide the possibility for Type Approval until Level 3 ADS in certain ODDs without further restrictions from national road authorities but only for specific defined functions. The expectations are that more regulations for functions or ODDs will follow.

Of central importance for the safety of automated driving have been the GRVA working groups FRAV (Functional Requirements for Automated and Autonomous Vehicles) and VMAD (Validation Method for Automated Driving). As their names suggest, the working groups elaborate the functional requirements for automated vehicles and the corresponding evaluation criteria. In addition to technology neutrality, it was specified that, with the exception of two-wheeled vehicles,

16 Source:https://www.jasic.org/meeting_docs_admin/contents/uploads/doc/meeting3/5.%20Recent%20discussions%20and%20prospects%20of%20Automated%20%20Autonomous%20and%20connected%20vehicles%20at%20UNECE%20-%20GRVA.pdf, slide 5.

17 see UNECE R157 Annex 4 Clause 2.16.

there should be no limits on vehicle categories and vehicle speeds. Existing national/regional guidelines provide the basis for the harmonization work. The definitions for functional safety are currently being coordinated in the FRAV working group until June 2023. In addition, both working groups are to be linked with each other in a timely manner. The objective in doing so shall be to determine whether the defined functional requirements are verifiable with the assessment methods. Which test scenarios are necessary in this regard? The test scenarios focus on the four pillars of Test Track, Real World, Simulation and In-Service Monitoring. This phase of collaboration between the two working groups is to be completed by June 2024. A decision will then be made on whether to publish the results of the working groups in a global technical regulation (GTR).

4.1.2. EU – Commission implementing regulation (EU) 2022/1426 laying down rules or the application of Regulation (EU) 2019/2144 of the European Parliament and of the Council as regards uniform procedures and technical specifications for the type-approval of the automated driving system (ADS) of fully automated vehicles (August 2022).

In the Sustainable and Smart Mobility Strategy of the EU-Commission, one of the milestones specifies that by 2030 automated mobility will be deployed on a large scale across the EU.[18] In this context the European Commission presented the Implementing Regulation (EU) 2022/1426 “uniform procedures and technical specifications for the type-approval of the automated driving system (ADS) of fully automated vehicles” in summer 2022. The Implementing Regulation is the first comprehensive regulation allowing the type of approval of high driving automation (SAE Level 4). However, the EU regulation do not cover ODD-specific testing. ODD-specific testing remains solely in the jurisdiction at national/local level.

The Implementing Regulation (EU) 2022/1426 is based on the Whole Vehicle Type-Approval (WVTA) system already in place in Europe for traditional vehicles. Under the WVTA, a manufacturer can obtain certification for a vehicle type in one EU country and market its EU-wide without further tests. The certification is issued by a type approval authority and the tests are carried out by designated Technical Services.

Specifically, the implementing regulation lays down rules for application of the EU General Safety Regulation 2019/2144 for type-approval of automated driving systems of highly automated vehicles and gives provisions for roadworthiness tests.

Nevertheless, the EU framework alone is not enough. It still needs additional national legislation modification. That means the amendments of the Vienna Convention need to be implemented in national law. However, the individual European member states have taken different paths of implementation. The approach of each country differs primarily in terms of practical implementation. France, the Netherlands, Austria, and Great Britain are leading the way, having implemented the Vienna model primarily following guidelines and regulations for testing automated vehicles (AV) on public roads. Their main focus is on operational safety, functional safety, and cybersecurity. Overall, the member states present a quite heterogeneous picture. The status of Germany’s regulatory approach is comprehensively considered in chapter 1.1.6. Norway, for example, has also already implemented the framework conditions for tests, while Spain on the other hand is still in the early stages of developing specifications. Italy has already published its first law for tests on certain roads. Finland is also well advanced in this area, having stipulated the framework conditions for tests and passed the first laws that form the basis for later AV approval.[19]

Scope and Limits

he published Implementing Regulation (EU) 2022/1426 on the approval of fully automated driving systems with regard to their automated driving system (ADS) is crucial for harmonizing type approval requirements for autonomous vehicles in the EU. However, the regulation limits the type approval of fully automated vehicles to small series, which allows only 1500 units per vehicle type to be sold annually in the whole European Union and only 250 units of one type of vehicle per Member State.[20] “As next stage, the Commission will continue the work to further develop and adopt by July 2024 the necessary requirements for the EU whole vehicle type approval of fully automated vehicles produced in unlimited series.”[21]

Regulation (EU) 2022/1426 has chosen an open regulation approach, with high-level requirements. The scope in the framework would apply to the following use cases:

- **“Self-driving shuttles”**, which are designed to carry passengers or goods on a predefined area in an urban or suburban environment.

[18] https://www.europarl.europa.eu/doceo/document/E-9-2022-001676_EN.html - Parliamentary question - E-001676/2022
[19] Whitepaper: “Automated driving requires international regulation” by Benjamin Koller & Robert Matawa – TÜV SÜD
[20] https://www.europarl.europa.eu/doceo/document/E-9-2022-001676_EN.html - Parliamentary question - E-001676/2022
[21] EU Reg 2022/1426 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32022R1426

- **"Hub-to-Hub"** transport, which covers fully automated vehicles or dual mode vehicles that carry passengers or goods on a predefined route with fixed start and end points, and which may include urban or suburban or motorway environments; and
- **"Automated valet parking"**, which are vehicles that have a fully automated driving mode for parking applications.

The following limits still need to be evaluated and clarified.

- The interaction with different types of vulnerable road users in urban environments is not sufficiently covered by the draft act
- It remains unclear how type approval authorities or their technical services would validate compliance with the performance requirements in the context of vehicles designed to also operate in other countries, and in particularly their compliance with the other country's/countries' traffic rules.
- The current testing provisions do not guarantee that the compliance with the required anticipatory behaviour by the vehicle/system is verified.
- As a principle, acceptable safety levels should be set by regulators, and it should be up to manufacturers to demonstrate their compliance with it.[22]

Annex II No.12 of the implementing regulation gives specific technical and functional provisions of the Automated Driving Systems (ADS) for the purpose of periodic roadworthiness tests. It shall be possible to verify correct functionality and the software integrity, by the use of an electronic vehicle interface, such as the one laid down in point I. (14) of Annex III to Directive 2014/45/EU, where the technical characteristics of the vehicle allow for it and the necessary data is made available. Manufacturers shall ensure to make available the technical information for the use of the electronic vehicle interface in accordance with Article 6 of Commission Implementing Regulation (EU) 2019/621. The manufacturer shall enable the traffic service operator, type-approval authorities, market surveillance authorities or other authorities designated by the Member States to make available the vehicle data referred to in paragraph 5.4 and the ADS data and specific data elements of the event data recorder (EDR) collected in accordance with Section 9 of Annex II.

With the entry into force on 1 September 2020, regulation (EU) 2018/858 provides requirements for the market surveillance of motor vehicles in the European Union.

In the regulations for EU type approval (Regulation (EU) 2018/858, 167/2013 and 168/2013), there are no harmonized specifications on software updates for licensed motor vehicles and motor vehicle trailers of classes M, N, O, T, C, R, S and L1e-L7e.

4.1.3. Roadworthiness Package of the European Union (2014/45/EU)

A growing demand for vehicles for private or business purposes resulted in the conviction that a technical inspection of these vehicles is needed, which contributes to the safe operation. Vehicles in good technical condition are a prerequisite for fulfilling their intended task. Although there are still various discussions being held on this topic in some countries (especially in the US and Australia), most countries in the world have introduced mandatory technical inspections into their jurisdiction. According to EU Directive 2014/45/EU in all EU countries, there is the obligation of technical inspection of vehicles registered in the EU on regular intervals and in a harmonized way.[23]

Scope and Limits

A comprehensive roadworthiness framework for the evaluation of the safety performance of advanced driving assistance systems (ADAS) and automated vehicles of SAE Level 3 and higher are currently not covered directly in the Directive. First concrete indications deliver the implementing regulation EU 2022/1426 laying down rules for the application of Regulation (EU) 2019/2144 as regards uniform procedures and technical specifications for the type-approval of the automated driving system (ADS). Yet the indication is limited to visual inspection failure warning signal and the necessity of an electronic vehicle interface. The complete scope which is described in Implementing Regulation (EU) 2019/621 still needs to be extended and adjusted. Directive 2014/45/EU is currently under revision. A legislative proposal for a new roadworthiness directive is announced for the second half of 2023.[24]

4.1.4. Germany Ordinance implementing the Act amending the Road Traffic Act and the Compulsory Insurance Act (June 2022)

Besides the overarching regulations of the EU and the UN ECE, regulatory gaps must be closed in the operation of vehicles. Therefore, the German Autonomous Vehicles Approval and Operation Ordinance (AFGBV) provides a quite

[22] https://etsc.eu/response-to-the-draft-implementing-act-on-certain-automated-driving-systems-ads/
[23] Hudec, Juraj, Sarkan Bratislav, Effect of periodic technical inspections of vehicles on traffic accidents in the Slovak Republic, in: University of Zilina Communications 24 (3), 2022, p. A142-A159.
[24] https://ec.europa.eu/info/strategy-documents/commission-work-programme/commission-work-programme-2023_en (last access 2-11-22.)

advanced enhancement. This regulation for passenger and goods vehicles with automated driving function will enable type approval and operation for category L4 (SAE) in Germany. The detailed scopes and definitions are still under development, but it is a first step in the right direction for the AD regulatory world. As a precondition to enable operation on public roads the amendments of the Vienna Convention have been adopted by modification of the German Road Traffic Act (StVG). Currently, in the first quarter of 2023, intensive work is taking place to better align the approval of the vehicle with the operating design domains. In addition, criteria for the qualification of the assessing bodies for the operating design domains are being drawn up. The German federal states have the legal responsibility for granting approval for the operating domains.

Scope and Limits

The scope in the framework would apply to the following use cases:

- No limitations in scope (as in EU draft)

The following items are regulated in the framework:

- Issuing of operating licenses for vehicles with autonomous driving functions as well as approvals for subsequently activatable automated and autonomous driving functions and "upgrades" with regard to ADS
- Approval of Operational Design Domains (ODD) defined operating areas
- Approval of vehicles with autonomous driving functions to the road traffic
    - Market surveillance of vehicles with autonomous driving functions, as well as of subsequently activated automated and autonomous driving functions and vehicle parts
    - Requirements and obligations for the manufacturer, the vehicle operator and the technical supervision of motor vehicles with an autonomous driving function
- Frequency of vehicle testing intervals
- Furthermore, *"the provisions of Regulation (EU) 2018/858 of the European Parliament and of the Council of 30 May 2018 on the approval and market surveillance of motor vehicles and their trailers, and of systems, components and separate technical units intended for such vehicles […] shall remain unaffected."*[25]
- The German regulation require systematic safety assessment according to ISO 26262 and ISO PAS 21448 and refer to UNECE-R155 regarding cyber security.
- Regarding market surveillance and a process to monitor the safety of the intended functionality, the law considers corresponding requirements and measures.
- Regarding the periodic vehicle inspection (PTI) the regulation prescribes a higher frequency of the test intervals, which in future means a quarterly overall test and a half-yearly *"classic" main vehicle inspection. However, the concrete scope is not defined and there is only "the assumption [...] that a test of motor vehicles with autonomous driving function has a significantly higher degree of complexity."*[26] Corresponding specifications for the testing of vehicles with automated or highly automated driving functions are currently being developed and will be made available in a timely manner. The scope of the test will correspond to the provisions of the EU implementing regulation 2022/1426 as mentioned above.

4.1.5. United States of America

In the United States of America, the federal government regulates and specifies the safety of motor vehicles and related equipment, and manufacturers must certify compliance before selling vehicles. Therefore, we are talking about a market of self-certification in matters of safety in which product liability plays an important role. Federal and state governments have regulated vehicle safety in numerous ways regarding seatbelt laws, new-vehicle standards, etc. Most of these standards only apply to new vehicles.[27]

Since FMVSS (Federal Motor Vehicle Safety Standards) were written with the natural assumption that a human being would be the driver of the vehicle, there are no national regulations that apply specifically to AVs at the moment and the same FMVSS must met by all different variations of vehicle technologies. NHTSA can approve a limited number of exemptions from the FMVSSs (e.g., vehicle without mirrors.) which needs to be considered on case-by-case basis but looking from a long-term perspective the FMVSS need to be updated and modernized.

In addition, there are the state rules which deal with operation but also safety and they have considerable independence in matters of transport. This leads to a huge variation in traffic regulations and system interpretation regarding local traffic rules. Nevertheless, NHTSA is providing interpretations via their analysis of issues, upon suspicious incidents and accident.

[25] see: AFGBV - § 1 Scope of application; subject satter and definitions, article (4)
[26] see: AFGBV - VII Execution of the main inspection according to § 13 Paragraph 8
[27] Congressional Research Services, Issues in Autonomous vehicle testing and deployment, April 2023; https://sgp.fas.org/crs/misc/R45985.pdf (last access 2-11-22).

Furthermore, unlike in the EU, for example, the federal requirements do not override requirements of the individual states.[28] They can even set stricter requirements than the ones on federal level. As a federal pre-emption gives independency to most of the states, deployment/ testing of highly automated vehicles is already legal within specific operational design domains on public roads in the US.

States on the West Coast, such as California and Nevada, began to create legal frameworks for automated driving and testing already over ten years ago.

In the following is an overview of the different states and the enacted legislation and executive orders:

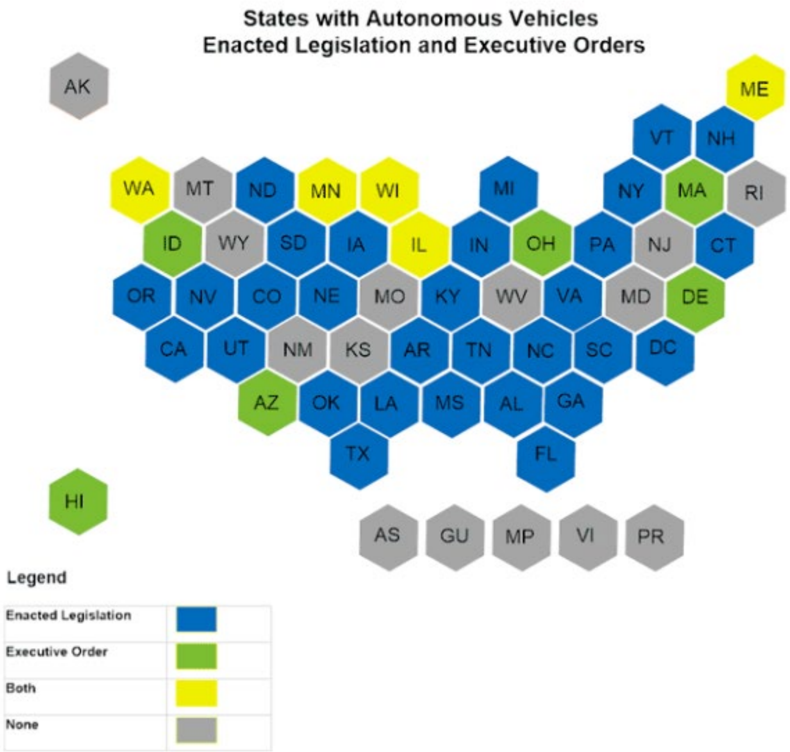

Figure 3: Overview of US states[29]

- Alabama, California, Florida, Michigan, Nevada, North Carolina, Tennessee, Texas, Utah, … authorizes full **deployment** without a human operator
- Washington, Ohio, … authorizes **testing** without a human operator
- District of Columbia authorizes full **deployment** with a human operator
- Connecticut, Hawaii, Illinois, Massachusetts, New York and Vermont authorize **testing** with a human operator

This shows a progressive status in deployment and testing but also a huge disunity and a lot of different variations and regulative approaches which requires to be harmonized and uniformed either on federal or on state level. Some states took an incredibly open approach to enabling automated driving in their territories while other states, such as Florida, took a more conservative approach reminiscent of the European approach. Starting with updating guidance, considering industry standards, install additional safety measurements for trust and update FMVSS).

Scope and Limits

As before mentioned, there is no specific scope, the vehicles are individually assessed but automated and highly automated vehicles can be tested and deployed within specific operational design domains on public roads and certain exemptions of FMVSS.

Indeed, the (self) certification system allows a technology-driven race of deployment. However, there are no boundaries for a safe race that would be essential for market acceptance and to achieve the goal of less traffic fatalities and safer roads. [30]

[28] 49 U.S. Code § 30103 - Relationship to other laws
[29] https://www.ncsl.org/research/transportation/autonomous-vehicles-self-driving-vehicles-enacted-legislation.aspx
[30] Merkl, Stefan, Ensuring the Safety and Security of Mobility Technologies for the U.S. Market, June 2021; https://www.linkedin.com/pulse/ensuring-safety-security-mobility-technologies-us-market-stefan-merkl/ (last access 2-11-22).

Although with a harmonized legal framework the product liability risk may still exist since there is not a homologation comparable to the procedure in countries within the UNECE region. This means manufacturer may need to consider additional safety mechanism as Voluntary Safety Self-Assessments (VSSA => Templates are already provided by NHTSA)[31] or even think about independent validation or certification according to the model of European technical services.

Furthermore, monitoring of the individual vehicle's roadworthiness is crucial for safety, especially when it comes to CAVs (Connected Automated Vehicle) due to its complexity and risk of fatality in case of failure.

Presently, 15 U.S. states require passenger vehicles to undergo periodic safety inspections. Inspection and maintenance (I/M) programs are designed to ensure that vehicles are maintained to meet safety standards throughout their lifetime. I/M programs are primarily designed to prevent roadway fatalities by mitigating those caused by vehicle failure or insufficient vehicle maintenance.[32]

A current report called "The impact of periodic passenger vehicle safety inspection programs on roadway fatalities: Evidence from U.S. states using panel data"[33] presents strong evidence that jurisdictions experience lower roadway fatality rates due to the presence of an active safety I/M program for passenger vehicles. The report clearly shows that States with periodic vehicle safety inspections have 5.5% fewer fatalities than those without. Considering that about 6.5 million roadway accidents occur in the United States each year, costing upwards of $240 billion, and causing over 30,000 fatalities, the U.S. Centers for Disease Control and Prevention (CDC) list motor accidents as a leading cause of adult mortality in the United States. Nevertheless, there are currently no discernible plans to introduce I/M programs on a federal-wide basis.[34]

4.1.6. China – Guidelines for the Construction of the National Internet of Vehicle Industry Standard System

AV testing in general in China is already an important industry section so several testing permits for AVs have been granted to large Chinese and international automotive and tech companies and more are expected.

On August 22, 2022, China's Transport Ministry (MOT) issued draft guidelines for the commercial use of fully AVs in public transport. This shall *"encourage the use of self-driving vehicles as buses in an enclosed Bus Rapid Transit or BRT system, and allow autonomous vehicles to offer taxi services under simple and relatively controllable scenarios"*[35]

In addition, there are some local government policies either on province-level or city-level which enable and support the possibility to permit CAVs to run on roads even before the nationwide law. For example, Shenzhen is the first city in China to legalize automated driving (L3-5) from August 1, 2022 (without a human in the driver's seat, but only within areas designated by the city's authorities).

Furthermore, there are several projects for pilot or even commercial projects. For example, in July 2022 Beijing launched China's first pilot area for commercial automated driving vehicle services paid rob taxi services, without a safety operator behind the steering wheel, within a 60-square-kilometer area in Yizhuang, a southern suburb of Beijing. Since it is still a pilot, there will be a supervisor in the front passenger seat to ensure safety.

Scope and Limits

According to the national draft guidelines, there is a classification of autonomous vehicles into three types depending on the degree of their autonomous capacity: conditionally, highly and fully automated vehicles.

Therefore, it is requested that conditionally and highly automated vehicles should have human drivers and fully automated vehicles should have remote drivers or safety supervisors.

Furthermore, it is mentioned that operating area *"should be far away from densely populated areas such as schools, hospitals and large shopping malls"*[36] and it is forbidden for AVs to carry dangerous goods.

The government of the People's Republic of China has identified highly automated driving as one of those future technologies for serving as a growth engine for the country. From experience, China is moving the legal wheels much more quickly and flexibly than is possible in most Western democracies.

[31] *https://www.nhtsa.gov/automated-driving-systems/voluntary-safety-self-assessment*
[32] Prithvi S. Acharya, Laila AitBihiOuali, Daniel J. Graham and H. Scott Matthews, The impact of periodic passenger vehicle safety inspection programs on roadway fatalities: Evidence from U.S. states using panel data, 2022.
[33] See reference 30
[34] See reference 30; Zipper, David, US Traffic Safety Is Getting Worse, While Other Countries Improve, in: Bloomberg, 2 November 22 https://www.bloomberg.com/news/features/2022-11-03/why-us-traffic-safety-fell-so-far-behind-other-countries (last access 4-11-22).
[35] https://global.chinadaily.com.cn/a/202208/10/WS62f2e7bda310fd2b29e71420.html
[36] https://global.chinadaily.com.cn/a/202208/10/WS62f2e7bda310fd2b29e71420.html

4.2. Standards regarding life-cycle management of automated and connected vehicles

In context of regulation and legislation there are usually taxonomies and standards to be considered which define common definitions, language, and safety minimums and those are driven by a large number of standardization bodies and standards development organizations such as ISO, SAE, ETSI, IEEE, OAS, UL, ASAM.

Many standards and guidelines were created dealing with topics regarding AD/ADAS functions, connectivity, human interaction, in-vehicle systems, networks, data & interface definition, mapping & positioning, privacy & security, safety, testing, verification & validation, and terms & definitions. Beside the complexity of the topic itself the variety is also quite high due to there is no one-approach-fits-all.

Nevertheless, a certain number of standards have already reached the general acceptance and mandatory status e.g. ISO 26262 as the core framework for functional safety, ISO 21434 as a foundation for cyber security, ISO/PAS 21448 for SOTIF or SAE J3016 for general “understanding” of the different automation levels. A technical specification of ISO to introduce methods to ensure a positive risk balance and the avoidance of unreasonable risk is currently under elaboration (to be published as ISO TS 5083 in mid-2023).

The standards applicable to vehicles with electrical and electronic (E/E) systems for automated driving are:

- ISO 26262:2018 for functional safety,
- ISO/PAS 21448:2019 for safety of intended function (SOTIF), and
- ISO/SAE 21434:2021 for cybersecurity.

Compliance with these standards ensures that no unacceptable risk arises from the intended or foreseeable use of the product.

Most of the existing standards with a few exemptions are not linked to type approval requirements or recommendations in this context but provide a useful collection of best practices and are highly relevant to manage consumer, customer and regulator expectations.

5. Challenges and trends to encompass the operational life cycle of automated and connected vehicles

The field of whole life compliance tests of automated vehicles is still in its infancy, with many fundamental research questions remaining unanswered. This chapter evaluates expected scenarios and hazard potentials in the life cycle of automated vehicles that are relevant for regulation. It also provides and discusses prerequisites to develop efficient and scalable methodologies for testing, verifying, and validating of automated vehicles.

5.1. Degradation of advanced driver assistance system

Type approval regulation ensures that the critical safety and environmental protection related systems of a vehicle meet agreed minimum standards, and subsequent in-service checks (periodic technical inspection) help ensure that they function as intended throughout a vehicle’s life. This ‘whole-life vehicle compliance’ is particularly important because without it the benefits on which regulatory action was justified and implemented will probably not be realized.

Currently vehicles are increasingly being equipped with Advanced Driver Assistance Systems (ADAS). These types of systems will form the basis for automated driving systems where they will become even more critical to the safe operation of the vehicle. Therefore, it is important to understand how their ‘whole life compliance’ can be ensured and the role of periodic technical inspection within this process.

Findings and derivation of CITA/TÜV Rheinland/TRL study[37]

The overall aim of the 2021 CITA / TÜV Rheinland / TRL project was to identify failure mechanisms that are not automatically detected by the on-board diagnostics system of the vehicle and subsequently indicated by the Malfunction Indicator Light (MIL) and to estimate their frequency of occurrence and consequences. This is important because appropriate methods to ensure the safe operation of the vehicle throughout the vehicle’s life are necessary, and in order to assess these, the scale of current issues should be quantified to ensure any proposals for methods are proportionate.

The identification of mechanisms that lead to failures that affect system performance was achieved via a structured literature review of Lane Keep Assist (LKA) system performance and failure mechanisms in general, coupled with

[37] https://wiki.unece.org/download/attachments/123667402/PTI%2021-02.pdf?api=v2

stakeholder discussions on this topic. This information was then used to develop a risk assessment to quantify the frequency – and where possible, the effects – of the failure mechanisms that lead to specific system defects that are not flagged by vehicle self-diagnosis and therefore cannot easily be checked during use. Ultimately, such analysis will determine what strategies can be justified to ensure whole vehicle life compliance.

The failure mechanisms identified focused on the following areas of the LKA system:

- The LKA sensor
- Collision and vibration / shocks affecting sensor position
- Windscreen, view damage, poor or no camera calibration at replacement
- Aftermarket fitment of SAE Level 2 systems
- External electromagnetic interference (EMI) or electrostatic discharge (ESD)
- The LKA system
- Electrical degradation
- Degraded data from other sensors/ECUs
- Software error
- The LKA actuators
- Degraded LKA actuation components, e.g., braking or steering actuators

The study then investigated the main causes of potential LKA-system malfunctions:

- Incorrect installation or retrofitting
- Effects of ageing, degradation
- Impact of (minor) accidents, replacement of parts and components
- Camera position affected by minor collision, replacement/no calibration, screen damage in front of camera
- Software error or vital software updates not done
- Incorrect sensor fusion
- Tampering

External disturbance to the LKA sensor was the main issue identified, with this leading to the failure mechanism of a poorly calibrated camera and the hazard that the LKA activation could be either early or late in relation to the vehicle's lane position, with subsequent implications for collision risk.

Estimates of frequency were made for these failure mechanisms, based on the EU fleet size:

These estimate that in 2029, the frequency LKA risk assessment Final 2 CPR2843 of estimated annual risk events will be greater than the range 232,722 to 2,284,239. *This gives a mid-estimate of 790K annual risk events in the EU* and potentially substantially greater because frequency estimates were not made for electrical degradation (ageing) and installation of aftermarket SAE Level 2 "autopilot" systems.

Furthermore, because the average age of ADAS vehicles in the fleet will be older in future years, the effects of ageing failure mechanisms on the fleet may be greater.

Overall, the true annual number of risk events is considered to be substantially greater than the numerical estimates made in this report. Effects on the LKA sensor and LKA system from degradation of sensors (moisture, contamination, corrosion) and the wider electrical system undoubtedly also occur, but estimating their frequency was not possible because of a lack of data for these failure mechanisms, primarily precisely because current on-board diagnostics systems may not detect them.

Examples of what can happen when the LKA system goes wrong:

In case of incorrect camera calibration but still within the OEM tolerance:

- *Incorrect system reaction, a strong pull towards one side and sporadic self-disabling during the first 10 minutes of the drive*
- After approx. 10 min of driving, stabilization and correct operation of the system reoccurred

In the case of stone chip of medium size (6-9 mm) in the field of view of the cameras:

- *Functional degradation and sporadic system deactivation without warning*
- *These effects led e.g. to vehicle leaving the lane in the bend*

In case of reduced visibility due to dirt on windscreen and in front of camera:

- *Sporadic system deactivation without acoustic warning*

- *These effects led to e.g., vehicle leaving the lane in the bend*
- Increasing the level of dirt eventually led to a system failure with MIL warning

In case of loose connections in power supply:

- Error injection in the dynamic condition (in the middle of a steering maneuver) led to the system immediately deactivating and the MIL was active
- *The abrupt return of the steering wheel to the middle position surprised the driver and the vehicle moved significantly into the adjacent lane*
- After approx. 10 min of driving, stabilization and correct operation of the system reoccurred

Therefore, this demonstrates LKA performance that contradicts the safety goals determined via a functional safety assessment to ISO26262, since the LKA performance could be affected such that, it exhibits late activation, and the vehicle does not display the expected action (e.g. issue a fault via the MIL and return the system to a safe state).

Conclusions

In order to improve whole vehicle life compliance, methods to verify the status of the ADAS systems are desirable that do not involve extensive performance testing incompatible with proportionate third-party verification.

This could be achieved by:

- Improving the on-board diagnostics capability of all vehicles, including the development of a common standard to ensure that self-diagnosis can detect the failure mechanisms highlighted, flag these via the MIL, and exhibit functionally safe, fail-passive behaviour.
- Refining the technical requirements of the ADASs to include the facility to access current status data (e.g., an interrogation mode), such that systems that could be quickly verified by a third-party, i.e., at PTI.
- Glazing damage in front of the camera could also be addressed with revisions to PTI requirements.

As vehicles develop to offer high levels of automation, a different functional safety approach will be necessary to ensure a fail-operational strategy. Systems will therefore require sensor redundancy; this will provide the data to facilitate superior on-board diagnostics systems.

5.2. Managing the increasing complexity of ADS with software updates

When it comes to software updates there needs to be a differentiation between updates through hardware connection e.g., during a workshop or the transmission over the air (OTA). Especially the second mentioned will increase their importance and even necessity for the operation of ADS. Currently most of the updates from the common OEMs are related to navigation and infotainment. Only Tesla sends out more complex software updates which also affect the behavior of ADS. Still these updates are "*mostly for minor bug fixes, but a few times a year, Tesla owners can look forward to extensive OTA updates*"[38] When it comes to such extensive updates it is expected that this will affect the existing approval and therefore these changes need to be validated first. Regarding the increasing complexity of ADS, it is also expected that these safety critical changes/updates will increase massively due to several reasons. These updates could be triggered by ODD extensions, activation of services on demand, accident data feedback and many more.

Technical Integration of Software-updates in registered vehicles

The homologation of the motor vehicle is not adjusted during its lifecycle. Rather, the condition of the individual vehicle must be adjusted. In response to this technological development, it is necessary to ensure during homologation that after the vehicle's approval, these changes to the vehicle can be performed safely and that the vehicle complies with safety requirements even after the adjustment.

All participants in this process need to be considered. The manufacturer and his supplier base need a clear framework and the possibility for a fast reaction to ensure the products safety but also operation. The technical service which is required in most of the worldwide markets needs the possibility for a holistic assessment for compliance and the authority needs complete comprehensibility and transparency for the final approval. In this approach the right connectivity between the participates is essential and the automation, digitization and virtualization needs to be improved to the highest possible degree.

- In 2021, UN Regulation No. 156 "Software update and software update management system" (SUMS) defined a systematic procedure for controlling software updates. An essential part of this procedure are uniform software identifiers, so-called "RX Software Identification Number (RXSWIN)". Starting with UN Regulation No. 157 ALKS

[38] Compare: Over-the-air updates: How does each EV automaker compare? - Electrek

– the RXSWIN (Regulation No.X Software Identification Number) it describes a dedicated identifier defined by the vehicle manufacturer which is representing information about the type approval relevant software of the Electronic Control System. It also specifies the conditions under which this RXSWIN must be changed: *"When type approval relevant software is modified by the vehicle manufacturer, the RXSWIN shall be updated if it leads to a type approval extension or to a new type approval."*[39] In the case of changes relevant to type approval, the approval authority must also be notified. Figure 4 shows how a software update based on UN Regulation No. 156 is to be handled. In accordance with this regulation's procedure, it is the vehicle manufacturer's responsibility to determine if a software change has an impact on parameters that are relevant to approval. Although these decisions need to be documented and reviewed annually by authority or designated body the question remains if the decision making should be just in responsibility of manufacturer.

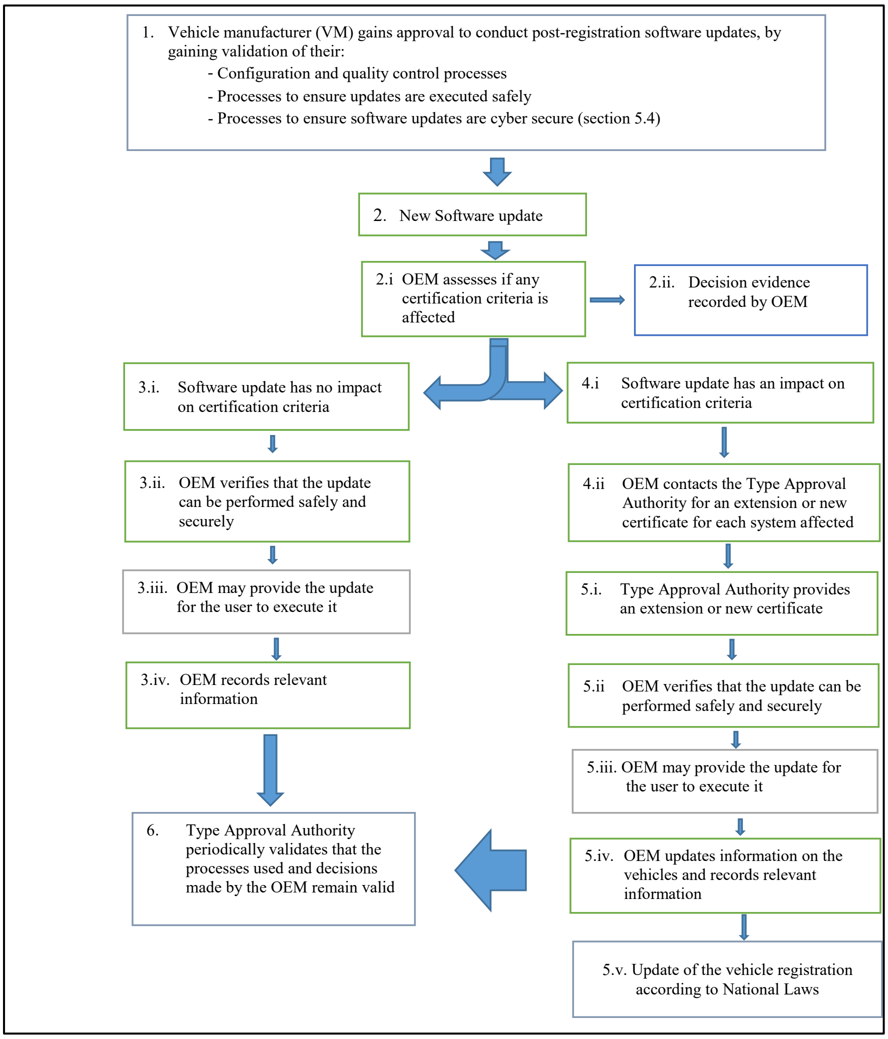

Figure 4: Software update processing according to UN Regulation No. 156 (source UNECE)

[39] https://unece.org/sites/default/files/2021-02/ECE-TRANS-WP29-2021-060e.docx

At the moment, the RXSWIN is only mandatory for ALKS System. However, following the right path of Figure 4 it could also lead to an effect to another system or component approved state (see Software Update Category IV & V explained in the passage below).

This means that for each regulation that must be complied with by a vehicle, an identification number must be written in the vehicle and made available to the authority.

Individual regulations do not refer to individual ECUs and their software, but usually to several different ECUs. These then map a function, for example steering systems. However, in addition, each control unit can also be affected by several regulations.

This means, each type approval relevant software in a vehicle shall have an unique identification. This identification number may be the software version(s) of the vehicle or single ECUs with the connection to the relevant type approvals or an UN Regulation specific RXSWIN number. This identification number has to be stored in the vehicle and made be available to the competent authorities.

So especially when it comes to technical inspection it will be a big challenge to put together the right software approved state for each individual car to the ECUs installed in combination.

Figure 4 also shows that registered vehicles are subject to their respective national admission laws. These laws are not harmonized internationally and apply only within their national boundaries. This fact has direct implications for how the technical integration of software updates in already registered vehicles should be carried out in an appropriate way.

Software updates of motor vehicles are basically to be differentiated into software changes not relevant for type approval and software changes relevant for type approval, which were taken into account during the type approval of the vehicle or its extensions, and which steps have to be taken for an extension.

For classification and assessment of the risk potential of the individual vehicle, it is recommended to categorize software updates accordingly in order to take further safety-relevant measures. Neither in the regulations for type approval in Europe (Regulation (EU) 2018/858, (EU) No. 167/2013 and (EU) No. 168/2013) nor in UNECE-R 156 or in the self-certification systems in the US, are currently specifications for the categorization of software updates.

Based on initial discussions between technical services, manufacturers and authorities in Germany, a distinction has been drawn up between 5 categories of software updates with the following categorizations:

- *Category I:*
  Software modifications in this category involve restoring the conformity of a motor vehicle or vehicle type with the underlying type approval.

- *Category II:*
  Category II can be assigned to software updates that do not change or impair any function(s)/system(s) relevant to safety and/or type approval.

- Category III:
  Category III includes software updates for activating additional type-approval-relevant functions that have already been approved by the type-approval authority as part of the vehicle type-approval at the time of initial approval, but which had not yet been activated in the individual vehicle by the manufacturer.

- Category IV:
  Software updates which will additional type-approval-relevant functions that were not covered by the original vehicle type-approval at the time of initial approval.

- Category V:
  The software updates of this category are comparable to the software updates of category IV and entail a revision or an extension of the underlying type approval, but in addition changes of approval-relevant data of the motor vehicle which makes it necessary to adopt the vehicle registration papers.

The categorization of the five stages and more detailed explanations were published in February 2023 in the German Transport Gazette (Verkehrsblatt) with the headline "Merkblatt für die Durchführung von Softwareänderungen durch Fahrzeughersteller als Inhaber der Typgenehmigung oder EU-Fahrzeug-Einzelgenehmigung (Leaflet on Manufacturer Software Modifications)".

The leaflet deals exclusively with software modifications provided by the vehicle manufacturer as the owner of the approval.

The leaflet applies to all motor vehicles registered in Germany for circulation in categories M, N and O under Regulation (EU) 2018/858, for motor vehicles in categories T, C, R and S under Regulation (EU) No. 167/2013 and for motor vehicles in categories L under Regulation (EU) No. 168/2013, which have been approved in accordance with the European type approval regulations within the scope of a type approval, EU small series approval or an EU individual vehicle approval, provided that the technical prerequisites have been created on the part of the vehicle manufacturer for the implementation of a software modification for these motor vehicles.

For motor vehicles whose manufacturers have an approval according to UN Regulation No. 156 for the vehicle type, this leaflet specifies and amends the procedures and processes between the manufacturer and the type approval authority. The procedures described in UN Regulation No. 156 shall be given priority in the event of deviations from this leaflet for these motor vehicles. However, the existence of an approval according to UN Regulation No. 155 or UN Regulation No. 156 is not a prerequisite for the application of this leaflet.

The contents of this national regulation should serve as a reference for the creation of an internationally harmonized application.

In any case, the manufacturer is obliged to document the software update in such a way that it is available via the software number and integrity characteristics on the one hand via the electronic vehicle interface and on the other hand to the competent authorities and technical services and, on request, to the vehicle owner for the inspection of the vehicle with regard to the condition and design of its components, systems and functions.

With regard to the identification of the current software status of individual vehicles in the field, it is advisable for all countries to set up a digital register. This digital register can be used as part of regular technical inspections and market surveillance activities to ensure that the vehicles in the field comply with all applicable requirements. Changes to vehicles can be entered automatically via a digital register. With correspondingly standardized interfaces, international exchange between the respective safety authorities would be also possible.

5.3. Cybersecurity engineering and testing over the whole cybersecurity life cycle (continuous system care)

In the meanwhile, it has become state of the art to introduce a form of cybersecurity risk governance into the automotive development process. Usually, during design time a Threat Analysis and Risk Assessment (TARA) is performed, resulting in requirements tested and verified in later stages of a V model process. With the transition of traditional automotive systems to CAVs and the paradigm shift towards software-defined vehicles, such kind of static analysis is not sufficient anymore. Therefore, the effective UNECE regulations R.155 (cybersecurity)[40] and R.156 (software updates)[41] mandate a continuous system care of a vehicle through a cybersecurity management system, i.e., also taking care of the “tail” in a V model process. While not explicitly required, there is only one recognized global standard of such a system which is ISO/SAE 21434[42]. This standard defines cyclic processes to continuously (i.e., periodically as well as through triggers) assess the security of vehicular systems, define appropriate security mechanisms (a security concept), implement the latter and verify them through testing.

Unfortunately, there are completely different approaches for the UNECE economic area and China on how to design cybersecurity regulations for vehicles. China's GB/T 29246-2017 and 28628-2020 specify in extreme detail what an intrusion detection system must be capable of, for example: It lists the functionalities and attacks that need to be monitored and how this functionality should be tested. Concrete specifications such as those in the GB/T tempt people to rely on the fact that, once all requirements have been implemented, the vehicle will be maximally secured. This leads to a false sense of security that becomes obsolete in just a few years. The legal requirements would have to be continuously revised and adapted to current developments, but this is by no means possible in a protracted legislative process. In this case, it is also important that the legislator acts with great foresight and is absolutely on top of technical matters. A differentiated risk approach, as in UNECE-R155, which focuses on scenarios and specifies which threats have to reacted is the clearly preferable path. If similar or new attack vectors emerge, it is possible to incorporate them into the test procedures without having to completely revise or supplement the guidelines.[43]

[40] United Nations Economic and Social Council - Economic Commission for Europe, “Uniform provisions concerning the approval of vehicles with regards to cyber security and cyber security management system,” United Nations Economic and Social Council - Economic Commission for Europe, Brussels, Regulation 155, 2021.
[41] United Nations Economic and Social Council - Economic Commission for Europe, “Uniform provisions concerning the approval of vehicles with regards to software update and software updates management system,” United Nations Economic and Social Council - Economic Commission for Europe, Brussels, Regulation 156, 2021.
[42] International Organization for Standardization and Society of Automotive Engineers, “Road Vehicles – Cybersecurity Engineering,” International Organization for Standardization, ISO/SAE Standard 21434, 2021.
[43] Have a closer look in: IAMTS, Automotive Cyber Security: An Overview of Tools, Procedures, Testing Methods, and Regulations, September 2022.

Vulnerability management and incident response

In order to obtain a meaningful security posture of and to distill security requirements for the overall system, it is necessary to get a bill-of-materials (BOM) of its components. These can be difficult to obtain due to the complexity and potentially long supply chains of the components, therefore analyzation tools might be useful. Once the hard and software inventory of a component is known, it can be analyzed for vulnerabilities through a couple of ways:

- Static and dynamic code analysis (if the code is available)
- Comparing the software version of external libraries with public vulnerability databases
- Scanning of compiled binaries for patterns of vulnerabilities

If, despite best efforts in a priori securing the system, a breach has become apparent, an appropriate procedure must be in place. This usually follows the schema of references [44] and [45]:

- Planning, preparation, and training.
- Identify, validate, and record the incident.
- Assess and classify the incident.
- Define and implement measures and react to the incident.

5.4. Access to vehicle data as prerequisite for whole life vehicle compliance

Already in 2018, over 85% of all new cars were connected wirelessly; over 470 million connected vehicles are expected to be on the roads in Europe, the USA and China by 2025. Connected vehicles make it possible to remotely access vehicle data. They also give remote access to functions (e.g., remote door unlocking for car sharing, launching diagnostic routines) and resources (e.g. displaying information on a vehicle's dashboard). Access to vehicle data, functions and resources is the decisive factor for a successful data economy in a digital, democratically organized environment. However, access to vehicle data is still limited and not standardized. Although access to vehicle data has been regulated at EU level since 2007 for repair data and on-board diagnostics (OBD)[46], there are no legal specifications for the digital transmission of this data. A regulative proposal regarding access to vehicle data over-the-air is expected in 2023 for the EU.[47] A regulation classifying the conditions of both remote access and sharing of in-vehicle generated data would be highly beneficial in terms of enhancing appropriate compliance methods such as safety and consumption monitoring of a specific vehicle or fleet.[48]

The People's Republic of China regulated the transmission of data generated by electric driven vehicles, trucks for the transportation of dangerous goods and coaches. For electric driven vehicles, it is foreseen that data of a real-time monitoring system (RTM) is directly sent to test centers on both provincial and country level. Data are sent first to a central server and in "real-time" to the server of the test center. The RTM should transfer, besides GPS data also vehicle data like acceleration, rotational speed, battery temperature, voltage, and others. All electric vehicles should be homologated for this RTM. Trucks for the transport of dangerous goods and coaches have to be equipped with a system that should send data (e.g., speed, collision information, GPS) to a Chinese state supervision platform.[49]

In 2014, manufactures and aftermarket associations came to a 'Memorandum of Understanding' for the U.S. market according to which vehicle owners and technicians are supposed to have the same access to information, tools, and software that car companies make available to licensed dealers. However, given the growing complexity and greater importance of information technology (and driver's data) for electric and other recent vehicles, independent repair shops appear to be increasingly locked out from the aftermarket. Against this backdrop, a proposal for a 'Right to Equitable and Professional Auto Industry Repair (REPAIR) Act' has been introduced to the House of Representatives in February 2022, but its prospects of success are still unclear.[50]

In the current international market, there is neither a technical nor a legal solution to ensure that an independent third party (state authority, technical service, vehicle inspection body etc.) can verify the safe operation of automated driving features via a remote access to vehicle. There are distinct reasons for this unsatisfied situation. Firstly, there are technical limitations due to e.g., availability of specific data and/or driver communication in a consistent and standardized

[44] International Organization for Standardization, "Information technology – Security techniques – Information security incident management," International Organization for Standardization, ISO Standard 27035, 2016.
[45] AUTO-ISAC, "Incident Response," AUTO-ISAC, 2017. [Online]. Available: https://www.automotiveisac.com/best-practices/download-best-practice-guides/
[46] See Article 6 (5) of EU Regulation 715/2007/EC.
[47] See reference 24.
[48] PwC,The 2019 Strategy& Digital Auto Report Time to get real: opportunities in a transforming market, https://www.strategyand.pwc.com/de/en/industries/automotive/digital-auto-report-2019/digital-auto-report-2019.pdf (last access 2-11-22).
[49] Informal document GRVA-12-11 12th GRVA, 24-28 January 2022 Provisional agenda item 5(c); https://unece.org/sites/default/files/2022-01/GRVA-12-11e.docx (last access 2-11-22).
[50] Schweitzer, Heike, Metzger, Axel, et.al., Data access and sharing in Germany and in the EU: Towards a coherent legal framework for the emerging data economy. A legal, economic and competition policy angle, Berlin 2022, p. 58.

manner from across vehicle brands as well as commercial and contractual limitations faced for data and function access via backend solutions provided by the manufacturers.

For the sake of road safety of automated vehicles, and in the interest of vehicle manufacturers not to risk an international patchwork around vehicle data regulation, a targeted discussion on how to handle the transmission and sharing of data of connected and automated vehicles over the air shall be started.

Horizontal regulations for different world regions can help set general rules to make data available to third parties or to provide a broad terminology to define categories of actors. However, policies should seek to avoid creating uncertainties or any roadblocks. Consequently, specific rules for the automotive sector are highly recommendable to clarify any gaps and give space for technological development.[51]

The following paragraph provide some concrete indications from IAMTS and CITA for this discussion.

Conditions and technical approach covering data sovereignty, accessibility, transmission and security.

The automotive sector is currently facing the challenge of adapting the procedures for development, validation, homologation, and inspection in the life cycle of motor vehicles due to increasingly digital and connected systems, components and parts. All steps for evaluating the safety of the motor vehicle in the life cycle are growing closer together in this sense. In this context, access to vehicle data is required to ensure whole life vehicle compliance, which addresses the appropriate individual coverage of safety and, if applicable, emission relevant functions of a specific vehicle under test.

Firstly, as shown in chapter 2.1, test procedures for efficient detection of malfunctions of any kind, wear, and tear, aging and manipulation of automated assistance and driving functions need to be implemented as part of technical vehicle compliance checks.

Secondly, the automated driving function (ADS) of a motor vehicle is a much more open and changeable system that must also be understood as an integral part of its environment, with which it is in constant communication. In the future, further technological developments, and new findings for improving the automated driving function will also be made available to vehicle systems that have already been deployed. Particularly, over-the-air updates, which are installed at increasingly shorter intervals, can change a vehicle's driving behavior and performance. With UN Regulation No. 156 adopted in 2021, safety-relevant function updates will also be made available over-the-air in the foreseeable future. The retrospective modification of the motor vehicle by software updates initially requires an assessment of its relevance for the type-approval of the specific vehicle and, if necessary, an approval addendum if the relevance has been identified.[52] In other words, the actual status of the hard- and software needs to be known for implementing appropriate vehicle compliance testing.

As a consequence of these data-driven development approaches, independent and trustworthy access to valid, original data and diagnostic functions in the vehicle is necessary for authorities and authorized companies. They must have assured confidence that data from the vehicle is original and unmodified. Appropriate over-the-air interfaces with the highest level of tamper protection and encryption-based data transmission policies must be created for this purpose. A design without legal regulation would restrict the possibilities for sovereign tasks, specifically carried out by state authorities and third parties.

Based on these technological changes, the necessary access to vehicle data over-the-air should include the following basic principles for the performance of sovereign tasks by independent testing bodies:

a. **Fair and independent access by separation of functions**
   Data handling and access, especially for sovereign applications, must not be influenced by economic vested interests. Administrative rules for access would ensure maximum independence if the tasks associated with data exchange are technically and legally separated in accordance with the principle of separation of functions ("separation of duties").
b. **The vehicle defines the scope of the data**
   The scope and characteristics of the available data and functions are determined by the technical development of the vehicle. This includes, for example, manufacturer-specific vehicle data for safety-related systems. A predefined minimum list of data would not be sufficient.
c. **Provision of reference information**

[51] more details: OECD Digital economy papers, Data in an evolving technological landscape. The case of connected and automated vehicles (December 2022), No. 346.

[52] Vgl.: T-Systems, C3 White Paper, Digital Loop – datengetriebene Fahrfunktionsentwicklung, 2022. Hallerbach, Eberle, Koester, Simulation-Enabled Methods for the Development, Testing and Validation of Cooperative and Automated Vehicles, 2022. https://zenodo.org/record/6542050#.Yp80uuhBwiw (letzter Zugriff: 7. Juni 2022)

The manufacturer must provide all relevant data and information in a digitally processable format over the air to query and interpret manufacturer-specific vehicle data.

Respecting this three-column-approach an equal and secure access to vehicle data, functions, and resources for assessing the regulatory compliance of vehicles in services could be facilitated. Ultimately, this approach would create a level playing field and a greater incentive for investment in the independent provision and development of new services in the mobility sector. There could also be an even more beneficial impact on the environment, e.g., thanks to better monitoring of CO2 and pollutant emissions and better access to vehicle sharing and recharging services for electric vehicles. This all may result in additional security and safety gains.

5.5. Performance of the entire dynamic driving task (DDT) without human intervention

Dynamic Driving Task (DDT) means all real-time operational functions and tactical functions required to operate the vehicle, excluding strategic functions such as trip planning and destination and waypoint selection, and includes, without limitation, the following subtasks:

a. Lateral movement control of the vehicle by steering (operational).
b. Longitudinal vehicle motion control by acceleration and deceleration (operational).
c. Monitoring of the driving environment through object and event detection, classification, and response preparation (operational and tactical).
d. Execution of response in relation to object and event (operational and tactical).
e. Driving manoeuvre planning (tactical).
f. Improving detectability through lighting, horn activation, signals, hand signals, etc. (tactical).

Here two different types of functions are categorized:

Operational functions are functions that are executed over a time constant of milliseconds and include tasks such as steering inputs to maintain lane or braking to avoid an emerging hazard.

Tactical functions are functions that are executed over a time constant of seconds and include tasks such as lane selection, waiting for gaps, and overtaking.

Implications for definition and performance of the road infrastructure and facing complexity of variations

In order for the connected and automated vehicles (CAV) to fully or partly perform their operational and tactical functions within their ODD, they are dependent on signals and communications from other road users as well as infrastructures and additionally installed Road Side Units (RSU). In this respect, secure communication paths must be implemented in the vehicles. Moreover, future ADAS functions will also be based on or supported by connectivity functions (Vehicle-to-Everything (V2X)). For this reason, it will not be sufficient in the future to consider only the vehicle and its components, systems and functions, but also those that are established in the infrastructure, which are enabling the V2X communications and therefore improve and expand the performance of the DDT of CAVs, by also creating redundancies. Additionally, the inputs derived by connectivity features have to be proven to be cyber secure, to ensure, that the exchanged data cannot be manipulated in any way. At the end V2X communication can provide extra redundancy and enhance the automated driving functions as well as solving long-tail problems and edge cases, such as driving during tough weather, bad lighting, or poor environmental conditions.

Furthermore, not only the safety and correctness of the V2X communication is sufficient. Equally important for example, is the proper and clearly visible placement of road markings and traffic signs or other traffic infrastructure, so that these infrastructure elements should also be included in the overall consideration.

6. Consideration of applicable compliance testing methodologies

In the previous chapters, requirements for the assessment of the performance and functionality in the lifecycle of connected and automated vehicles were discussed. A valid proof that automated vehicles fully meet all relevant requirements and prove to be reliable in real-world operation over the whole life-cycle in each possible situation cannot be provided before entering the market. For this reason, the marketing of motor vehicles in many economic areas around the world is followed by necessary safety measures for the regulatory compliance of motor vehicles during their period of use. In particular, these measures include product monitoring, market surveillance and regular roadworthiness test activities. Depending on the measure, the legal and factual responsibility for such measures falls to the manufacturer, the approval authorities, and the owner or operator. As shown in Chapter 1, product monitoring, market surveillance and regular roadworthiness tests are already finding their way into international and national approval legislation. At present, these safety measures still have considerable weaknesses. Consequently, these measures need to be optimized and expanded to include targeted activities. In principle, the results of the safety measures in the life cycle of the vehicle contribute to the further development and improvement of the systems by the manufacturers. Regarding the limits of existing measures for product monitoring and market surveillance as well as proposals for their methodical solution approaches, attention is drawn at this point to the academic contribution by Steininger, Mazzega, Witkowski, Form, Lemmer "Proof of operational reliability of automated and autonomous vehicles".[53] Promising work in this direction has also been done for a good while in the GRVA subgroup VMAD (Validation Method for Automated Driving) as shown in chapter 1. VMAD will develop methods to assess the safety of the driving performance for automated driving systems that fulfil the role of the human driver when undertaking driving tasks, including safe responses to the environment as well as safe behavior towards other road users.

In this respect, this chapter will highlight measures and approaches for independent, regular compliance tests for the proof and continuity of safety in the life cycle of vehicles. The explanations provided shall be understood as preliminary, not yet conclusive approaches, as they were discussed in the joint working group meetings. Suggestions include measures that could usefully complement the activities of both market surveillance and roadworthiness tests.

6.1. The V-Model as a concept for approval and operation of connected and automated vehicles

The assessment of the performance and functionality of connected and automated vehicles is extraordinarily complex, as practical testing of a large number of traffic scenarios can hardly be carried out comprehensively. Conventional test methods for the assessment of CAV's will therefore no longer be sufficient in the future. Therefore, new assessment methods must be developed to ensure compliance of connected and automated vehicles during their operational lifetime. This includes a prospective safety assessment on the one hand and a validation in operation as a retrospective safety assessment on the other hand.

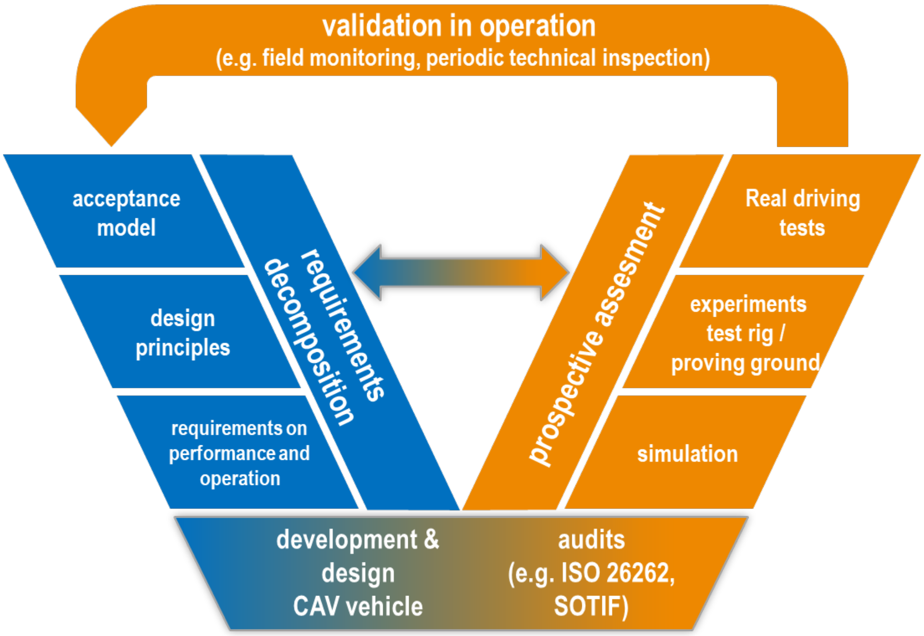

Figure 5: scheme approval process of CAV's

Figure 5 illustrates the approval process of CAV's schematically. The left branch describes the requirements that connected and automated systems have to fulfil. With the introduction of first regulations on automated driving systems, it is already apparent today that constraint regulations with specific technical requirements will be replaced by generic, functional, and technology-neutral requirements for the vehicles and traffic systems. This enables the approval of innovative technologies, but also requires an extensive evaluation of the performance of the systems.

As illustrated with the right branch, a prospective safety and risk assessment is necessary before a CAV can be approved. Lately, a multi-pillar approach has been established that includes e.g., virtual (scenario-based) analyses to prove an increase in safety potential with the corresponding driving function. In addition, auditing of a safety-compliant development process as well as experimental verifications on test rigs, closed test areas and in real traffic are part of the assessment and approval process (cp [1]).

[53] U. Steininger, J. Mazzega, S. Witkowski, T. Form, K. Lemmer, Nachweis der Betriebsbewährung automatisierter und autonomer Fahrzeuge, VDI-Tagung Fahrerassistenzsysteme und automatisiertes Fahren, 17.-18. Mai 2022, Aachen, VDI-Bericht Bd. 2394.

Although there are many novel developments concerning virtual testing and despite extensive and state-of-the-art safety analyses – performed by the manufacturers, the technical services, and the authorities – it seems impossible to represent completely the complexity of all possible traffic scenarios and environmental conditions. Furthermore, future changes in road traffic regulations cannot be assessed when approving connected and automated vehicles today. Additionally, it is not possible to assess future adaptations to changing traffic conditions at the time of approval. Moreover, deterioration due to degradation, wear, tampering or damage as well as modifications due to regularly (over-the-air) software updates cannot be comprehensively determined at the time of approval, i.e., at the beginning of the product life cycle. Hence, a validation in operation as a retrospective safety assessment is vital to ensure road safety (as well as compliance with other requirements such as ethical, environmental or security behaviour). Therefore, in-service monitoring and reporting (ISMR) performed by the manufacturers themselves is mandatory to apply for a type-approval of the automated driving system (ADS) of fully automated vehicles according to the Implementing Regulation (EU) 2022/1426 (cp. [2]).

6.2. Retrospective safety assessment (field monitoring) as approach for a lifecycle compliance test

In addition to ISMR performed by the manufacturers themselves, the validation of the performance of connected and automated vehicles should be performed by neutral, sovereign bodies as this supports a trusted third-party principle and complies with the market and field surveillance tasks of many countries. For example, the Implementing Regulation (EU) 2022/1426 requires that the manufacturer must enable the transport service operator to provide the type-approval authorities, market surveillance authorities or other authorities designated by the Member States with the selected vehicle data.

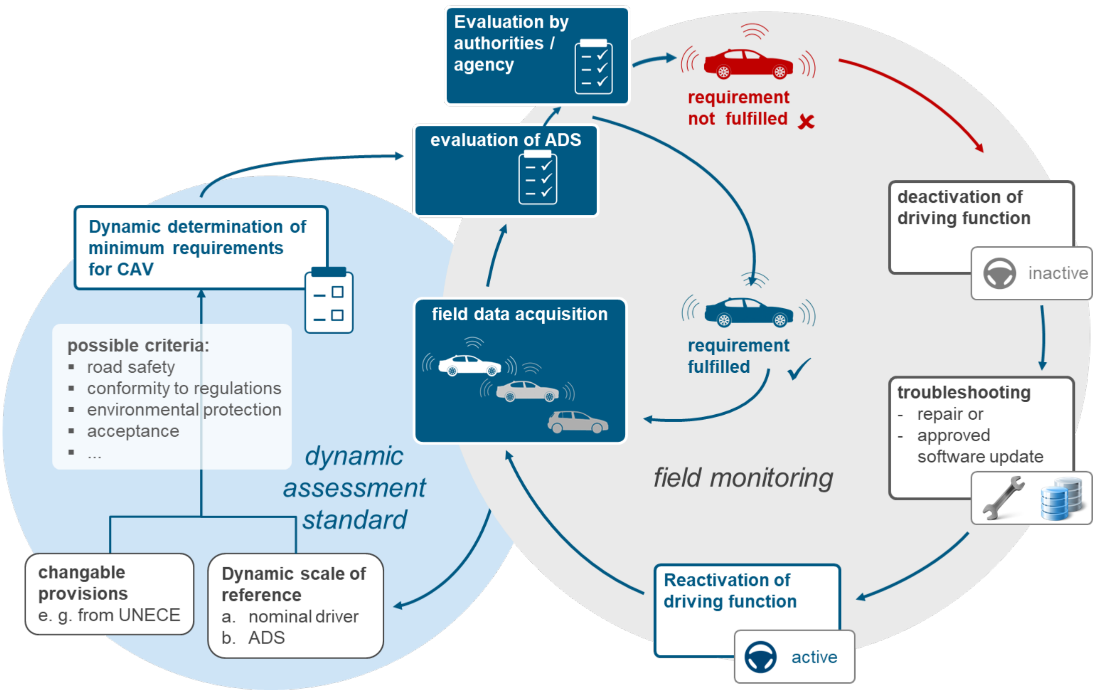

Figure 6: scheme field monitoring

Figure 6 illustrated the field monitoring approach (cp. [3, 4, 5]). For implementation of a working process, driving and environmental data (without reference to persons) must be recorded, transmitted, and evaluated. If safety-relevant anomalies are detected, in worst case, the deactivation of the corresponding automated driving functions can be initiated by the authorities. To reactivate the functionalities, measures (such as hardware upgrades or software updates) can be demanded from the manufacturers.

This disruptive approach of a dynamic vehicle approval is comparable to an ordered recall by the authorities in case of safety-relevant issues. Moreover, the procedure corresponds with regulatory law for human drivers. If a driver has committed an administrative offence, a driving ban can be imposed. In addition, a retraining can be demanded to obtain the driver's license. Transferred to a technical system – that is responsible for the Dynamic Driving Task (DDT) – e.g., a software update can be demanded.

The left cycle of Figure 5 illustrates the development of an adaptive assessment standard. Based on minimum requirements for the performance of selected automated driving functions, the performance of the driving task must be evaluated by appropriate algorithms. For this purpose, generally applicable, unambiguous and objective evaluation criteria and methods must be developed for validating the automated driving functions. On the one hand, criteria can be derived from provisions (e.g., UNECE or national traffic regulations), that are usually underlying changes. On the other hand, the normal driving behaviour of a good human driver can be used as an initial evaluation benchmark. Therefore, a comprehensive analysis of real driving data is essential. Only if nominal driving behaviour can be described comprehensively, incidents in driving behaviour can be detected and evaluated.

6.3. Digitalized inspection for testing of connected and automated vehicles

The implementation of the periodic technical inspection (PTI) still contributes significantly to guarantee road safety of vehicles. However, a PTI that focuses exclusively on mechanical components of the vehicle will no longer meet the safety requirements of modern road traffic. It must be ensured that a proper and professional inspection of the performance and functionality of connected and automated vehicle is conducted by a neutral third party to assure a high level of safety throughout the vehicle's life cycle. Therefore, today's test content must be extended and further developed.

One part is to test the performance and functionality of safety relevant driving systems digitally by the electronic vehicle interface. This includes to verify the conformity and integrity of software (as an elementary component of electronically controlled vehicle systems) during the PTI. Thus, it becomes important to make in-vehicle data available, not only for mobility services, but also for sovereign tasks. Self-determined and independent access to safety-relevant data and diagnostic functions in the vehicle for administrative and sovereign tasks are the necessary basis for the definition of universally valid, unambiguous, and objective evaluation criteria and methods for independent roadworthiness testing during the whole vehicle life cycle. Neutral and independent access to mobility and vehicle data (via OBD / Over-the-air vehicle interfaces) must be ensured and adapted to the technical state of the art of the vehicles.

6.4. Scenario-based testing of connected and automated vehicles as part of the periodic-technical inspection

In addition to static and electronic condition tests, vehicle tests within the scope of PTI are becoming more dynamic. In particular scenario-based test methods offer the possibility to test the reaction of a vehicle to a specific input by using an appropriate representation of the traffic environment. The development of PTI-capable targets, as known from development projects, and the implementation at inspection sites could be an effective solution to evaluate the performance and functionality of connected and automated driving functions.

Continuous testing of safety relevant ADAS/AD functionality in standardized scenarios during a PTI facilitates the trust and acceptance of drivers/owners, operators, and passengers of highly automated and fully automated vehicles. It ensures that intended - and initially homologated - functionality of the systems is still given and not affected by degradation, occlusion, displacement, attenuation, or other factors influencing system behaviour. It should verify that the systems not only work in a functional manner (e.g., is the distance to a known target object correctly assessed?), but also in a timely manner (i.e., is a warning issued and/or vehicle reaction executed within a defined time span?) or even an ethical manner[54] (e.g., is the minimum risk or evasive manoeuvre feasible and appropriate?).

However, such tests require the provisioning of relevant data from the perception-, path-planning, decision-making and actuating (sub-)systems in a standardized format and equally important, in a defined and sufficient time interval or known delay. Currently, neither of which is available to third parties to effectively validate the intended functionality and ensure the promoted safety.

It should also be mentioned that the PTI and its executing facilities, have vastly different requirements, capabilities and limitations than current test facilities from OEMs or TIER1s. Besides financial and space constraints, a suitable test system shall be ruggedized, modular, upgradeable and guarantee interoperability between manufacturers, models, and variants. OEMs and TIER1s should provide the (testbed-)operator with up-to-date information on the ADAS/AD capabilities, sensor specifications and their mounting positions of the actual vehicle under test and with an easy yet effective workflow to guide through the preparation, test, and documentation process.

A vehicle-in-the-loop testbed, where the vehicle is placed on a roller test bench, could satisfy the vehicle-conditions for the ADAS/AD systems to be activated/enabled (i.e., minimum vehicle/wheel speed, D(rive) mode, etc.) and minimize the necessary space requirements.

An additional environmental simulation, comprising visual (camera) stimulus in coherence with the corresponding RADAR stimulus, could provide the necessary input for the ADAS/AD sensors and thus allow for reproducible testing of comfort as well as safety-critical functionality, in a quasi-static PTI/workshop setting.

A standardized scenario database for the environmental simulation enables for comparable, yet vehicle, country, and market-specific testing of PTI-relevant ADAS/AD features. Such scenarios can originate from the vehicle development phase, which consolidates scenarios and potentially enhances the overall test-case coverage, or from post-development experience such as homologation or consumer assessment tests.

[54] A. D'Amato et al., Exceptional Driving Principles for Autonomous Vehicles, 2022 J. L. & Mob. 2.

7. Recommendations and perspectives for assuring compliance of automated and connected vehicle during their operational lifetime

In the previous chapters, the white paper identified gaps in standardization and regulations as well as presents challenges for assuring compliance of automated and connected vehicle during their operational lifetime. It also provides proposals for technical applicable procedures and measures in the interest of the vehicle's product safety and the improvement of road safety.

Observations to streamline the creation and adoption of regulations and standards for the life-time compliance testing:

- Frankly speaking, it is still a long way to go to achieve an internationally harmonized framework of standards and regulations for a proper safety validation of automated and connected vehicles. Obviously, there is still a vast variety of different standards across the globe. All countries and single markets in focus of this paper have a quite different approach in handling whole life-cycle vehicle compliance testing programs. This situation creates a significant cost factor for launching new mobility concepts on the market, as the specifics of each single market have to be considered separately. A lack of internationally harmonized standards and rules is a main hurdle for the successful take-off of automated and connected vehicles. So, the leading question remains, which national regulations are suitable as a blueprint for internationally binding regulations.
    - **UNECE's** global harmonization efforts face the challenge of adopting a more generic approach to evaluating the ADAS performance of automated vehicles in the future. Experience with UN ECE Regulation No. 157 shows that the harmonization of individual systems cannot be completed in a timely manner. Regarding to the criteria for functional safety and their evaluation methods, uniform specifications must be made in a timely manner. Intensive work is also required to define corresponding test scenario catalogs.
    - Speaking of the **U.S. market** the ADS manufacturers have already the possibility of deployment of CAVs and collecting data and experience from real driving and operating in many States. For a broader baseline of credibility and trust in new vehicle technologies, the authors recommend strengthening the system of self-certification. Strengthening implies that in the future, compliance with relevant regulations, standards, and best practices for vehicles with higher levels of automation should be independently certified in "pre-market approval" to make more transparent the capabilities and risks of automated vehicles. When it comes to evaluating and monitoring the lifecycle roadworthiness of vehicles, established approaches from individual states should be applied nationwide by implementing a federal jurisdiction.[55]
    - A high diversity of regulatory approaches also characterizes the **Chinese market**. Although China is on the forefront of introducing automated driving, local authorities in China are following very different paths in approving and monitoring automated vehicles.[56]
    - Harmonized requirements of the **EU** regulations opened the possibility to get an approval for vehicles and functions up to SAE Level 4. For the operation of fully automated vehicles, there is still the need for each member state to provide rules for the enhancement of the ODD and to develop a detailed and appropriate scope and specifications for periodical technical inspection.
    - To sum up, the preconditions and requirements to obtain approval or certification is on a good way to be detailed out. Regarding the compliance maintenance of the vehicle there are needs to be more catch up with regard to abrasion, scope of roadworthiness testing and the experience in how to handle necessary and continuous software updates in a viable but safe way. The interaction between approval law and operational safety law in the life cycle has not yet been comprehensively clarified and needs higher attention in future.
- Continuous testing of safety relevant ADAS/AD functionality in standardized scenarios during a technical inspection facilitates trust and acceptance of the drivers/owners, operators, and passengers of highly and fully automated vehicles. It ensures that the intended – and initially homologated – functionality of the systems is still given and not affected by degradation, occlusion, displacement, or other factors influencing system behavior. Even mechanical modifications like bumper repair may lead to RADAR misalignment and/or attenuation or

[55] Zipper, David, There's no driving test for self-driving cars in the US – but there should be. Would a European-style regulatory system improve safety?, September 2022; https://www.theverge.com/2022/9/12/23339219/us-auto-regulation-type-approval-self-certification-av-tesla (last access 2-11-22).

[56] See: https://www.insidetechlaw.com/autonomous-vehicles/05_china

windshield replacement may lead to camera misalignment or obstruction that effect the performance of the ADAS/AD system. European jurisdiction has already picked up this observation and calls for improving the on-board diagnostics capabilities und refining the technical requirements of the ADAS/AS systems to include the facility to access current status data for quickly verifying the system during a technical inspection.

- Software updates for vehicles in service initiated by the manufactures can be a potential source of damage that jeopardizes the roadworthiness of the system. These updates can affect only the less safety critical navigation or infotainment system but can potentially also affect the performance of the ODD, activate of new performance services on demand and much more. For identifying the individual risk scenario, the paper calls for an internationally harmonized categorization of software updates. In the case of software updates that change the approval status of the vehicle, authorities and authorized companies of the country must be able to carry out a holistic assessment for compliance or other evidence activities to verify the compliance of the vehicle. The white paper also argues that all changes to vehicles during their lifecycle should be automatically stored in a digital registry. With standardized interfaces, this would also ensure their international availability.
- Security assessments of AI components of the vehicle should be performed regularly throughout their lifecycle, in order to ensure that a vehicle always behaves correctly when faced with unexpected situations or malicious attacks. It should also be decided on the adoption of continuous risk assessment processes supported by threat intelligence that could enable the identification of potential AI risks and emerging threats related to the uptake of AI in fully automated driving. Proper AI security policies and an AI security culture should govern the entire supply chain for the automotive sector.
- The paper concludes that a proper and professional inspection of the performance and functionality of connected and automated vehicle shall be carried out by an independent third party to assure a high level of safety throughout the vehicle's life cycle. At first, the performance and functionality of safety relevant driving systems have to be tested digitally by the electronic vehicle interface. This includes to verify the conformity and integrity of software (as an elementary component of electronically controlled vehicle systems) during a technical inspection. In addition to static and electronic condition tests, vehicle inspection tests are becoming more dynamic. In particular scenario-based test methods offer the possibility to test the reaction of a vehicle to a specific input by using an appropriate representation of the traffic environment. The development of capable targets, as known from development projects, and the implementation at inspection sites could be an effective solution to evaluate the performance and functionality of connected and automated driving functions.
- However, such tests require the provisioning of relevant data from the perception-, path-planning, decision-making and actuating (sub-)systems in a standardized format and equally important, in a defined and sufficient time interval or known delay. The availability of in-vehicle data and infrastructure data are an indispensable prerequisite for performing such tests. OEMs and TIER1s should provide authorities and authorized companies as well as other relevant operators with up-to-date information on the ADAS/AD capabilities of the actual vehicle under test and with an easy yet effective workflow to guide through the preparation, test, and documentation process. In the current international market, there is neither a technical nor a legal solution to ensure that an independent third party (state authority, technical service, vehicle inspection body etc.) receive access to this data for prospective and retrospectives status analyses of the vehicles. For the sake of road safety of automated vehicles, and in the interest of vehicle manufacturers not to risk an international patchwork in the area of vehicle data regulation, the white papers call for starting a serious discussion on guiding principles for data access and data transmission of connected and automated vehicles over the air. The paper shows basic principles for this data transmission.
- Considering future V2V/V2X capabilities improving and expanding ADAS/AD features, it is important to ensure the correctness of the derived data throughout their lifecycle, also besides the data, which is provided by the own perception systems. In addition, the systems and communication interfaces have to be proven to be cyber secure, especially when implementing regular updates. At the end V2X communication can provide extra redundancy and enhance the automated driving functions as well as solving long-tail problems and edge cases, such as driving during tough weather, bad lighting, or poor environmental conditions.
- Furthermore, the proper and clearly visible placement of road markings and traffic signs or other traffic infrastructure is equally important since the on-board systems and therefore the quality of the performed ADAS/AD functions depend on it.

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Appendix A: Abbreviations, Terms, and Descriptions

- **ADS:** automated driving system
- **ADAS:** advanced driving assistance system
- **AI:** Artificial Intelligence
- **ALKS:** Automated Lane Keeping Systems
- **ASAM:** Association for Standardization of Automation and Measuring Systems
- **CAV:** connected and automated vehicle
- **CITA:** International Motor Vehicle Inspection Committee
- **CSMS:** Cybersecurity Management System
- **DDT:** Dynamic Driving Task
- **FMVSS:** Federal Motor Vehicle Safety Standards; U.S. federal regulations specifying design, construction, performance, and durability requirements for motor vehicles and regulated Automobile safety-related components, systems, and design feature
- **IAMTS:** International Alliance for Mobility Testing and Standardization
- **ISMR:** In-service monitoring and reporting
- **ISO:** The International Organization for Standardization is an international standard development organization composed of representatives from the national standards organizations of member countries.
- **LKA:** Lane Keep Assist
- **MIL:** Malfunction Indicator Light
- **NHTSA:** National Highway Traffic Safety Administration; Agency of the U.S. federal government, part of the Department of Transportation charged with writing and enforcing FMVSS
- **OBD:** Onboard Diagnostic
- **ODD:** operational design domain; Description of the specific operating domain(s) in which an automated function or system is designed to properly operate
- **OEM:** Original Equipment Manufacturer
- **OTA:** Over-The-Air (OTA) is a software update distribution method which uses wireless transmission.
- **SAE:** Society of American Engineers
- **PTI:** Periodical Technical Inspection
- **RXSWIN:** Regulation No.X Software Identification Number
- **RTM:** Real-time monitoring system (China)
- **Software** refers to the part of an electronic system that consists of digital data and instructions.
- **Software update** means a data package used for updating to a new version, including a change of configuration parameters.
- **Software change** means any change in the software, including software updates.
- **SUMS:** Software update and software update management system
- **TARA:** Threat Analysis and Risk Assessment
- **TIER1:** First level of supplier
- **UNECE:** The United Nations Economic Commission for Europe is one of the five regional commissions under the jurisdiction of the United Nations Economic and Social Council. It was established in order to promote economic cooperation and integrations among its member states.
- **Whole-life vehicle compliance:** The assurance of whole-life vehicle compliance is made up by different approach with different level of responsibility depending on each of the stakeholders. The main goal of the whole-life vehicle compliance approach is that in-use vehicles technical conditions shall not cause any traffic accidents resulting in injury or death that are reasonably foreseeable and preventable, shall resist cyberattacks and shall be environmentally consistent with their type approvals. Whole life vehicle compliance is the ensemble of stages (Initial Assessment, Approval, CoP, ISC, I/M programs, PTI) in which vehicles shall fulfil certain requirements.