Homologation of automated vehicles

The regulatory challenge

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White paper

Abstract

The homologation of automated and connected vehicles according to global regulations is essential for their safe and reliable development and deployment around the world. But existing regulatory safety frameworks applicable to conventional vehicles and their components are insufficient to fully assess the operational characteristics of current and future automated vehicle technologies. As with increasing automation vehicles transform into cyber-physical systems that no longer require a human driver, new safety challenges will have to be considered. This paper discusses those challenges and presents a six-point approach for developing a regulatory framework that can effectively support homologation for automated vehicles. .

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About the TÜV SÜD expert

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Christian graduated from the Technical University of Munich with a major in mathematics and a strong background in computational science and control engineering. After spending a brief time conducting robotic research, Christian worked for more than 15 years in the automotive industry in various technical and management positions, specialized in the development of electronic control units. He joined TÜV SÜD in 2018 and is currently in charge of the team responsible for testing and validation in the context of the homologation of automated vehicles.

How do we define an “automated vehicle”?

Over the past decade, automotive manufacturers have developed several automation technologies that have helped to improve overall vehicular safety. Advanced systems such as blind spot detection, lane departure warnings and automatic emergency braking serve to increase driver responsiveness and have contributed to a significant reduction in injuries and deaths connected to preventable accidents. Indeed, even the most basic new vehicles on the road today include some automation technologies and driver assistance systems as standard equipment.

In 2030, approximately 370 million vehicles will have some automated features.

Nonetheless, the term “automated vehicle” is widely misapplied by the general public and even many journalists to any vehicle incorporating advanced technologies that serve to lessen its dependence on the human operator. In fact, vehicle-based automation technologies exist at multiple levels, as detailed in the SAE International Standard J3016, *Taxonomy and Definitions for Terms Related to Driving Automotive Systems for On-Road Motor Vehicles.*[1]

J3016, which was most recently revised in June 2018, distinguishes between what it calls “driver support features” and “automated driving features,” and then classifies driving automation technologies into one of six levels, as follows:

DRIVER PERFORMS PART OR ALL OF A DYNAMIC DRIVING TASK (DDT)

Level 0

NO DRIVING AUTOMATION

The performance by the driver of the entire DDT, even when enhanced by active safety systems.

Level 1

DRIVER ASSISTANCE

The sustained and operational design domain (ODD)-specific execution by a driving automation system of either the lateral or longitudinal vehicle motion control subtask of the DDT (but not both simultaneously) with the expectation that the drive performs the remainder of the DDT.

Level 2

PARTIAL DRIVING AUTOMATION

The sustained and ODD-specific execution by a driving automation system of both the lateral and longitudinal vehicle motion control subtasks of the DDT with the expectation that the driver completes the object and event detection and response (OEDR) subtask and supervises the driving automation system.

AUTOMATED DRIVING SYSTEMS (ADS) PERFORM THE ENTIRE DDT

Level 3	Level 4	Level 5
		
CONDITIONAL DRIVING AUTOMATION	**HIGH DRIVING AUTOMATION**	**FULL DRIVING AUTOMATION**
The sustained and ODD-specific performance by an ADS of the entire DDT with the expectation that the DDT fallback-ready user is receptive to ADS-issued requests to intervene, as well as to DDT performance-relevant system failures in other vehicle systems, and will respond appropriately.	The sustained and ODD-specific performance by an ADS of the entire DDT and DDT fallback without any expectation that a user will respond to a request to intervene.	The sustained and unconditional (i.e., not ODD-specific) performance by an ADS of the entire DDT and DDT fallback without any expectation that a user will respond to a request to intervene.

Based on this framework, the term "automated vehicle" is probably best characterized by those vehicles that incorporate automated technologies that are classified at either Levels 3, 4 or 5.

From "automobile" to "cyber-physical system"

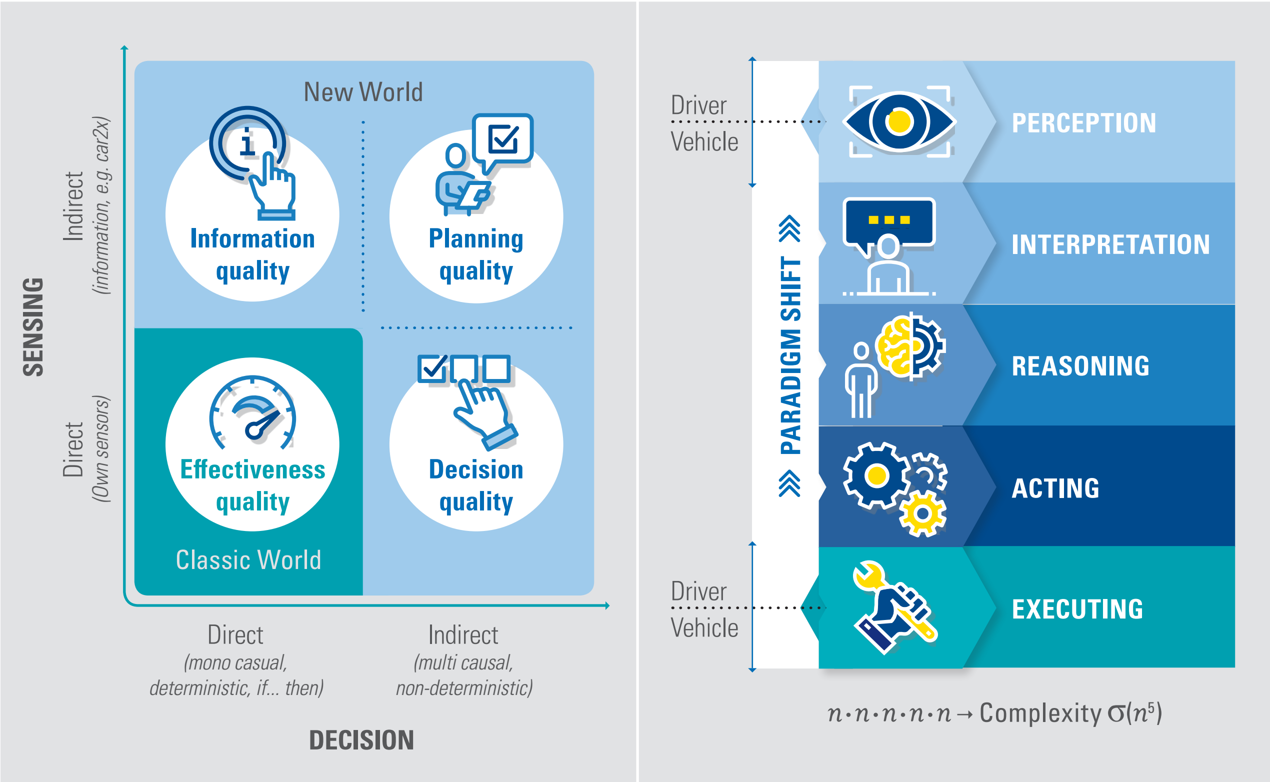
Although forecasts vary widely, most observers predict dramatic growth in the market for partially- or fully-automated vehicles in the coming years. According to one projection, the global market for automated vehicles (i.e., vehicles incorporating Levels 3, 4 or 5 technology) will reach nearly $560 billion (U.S.) by the year 2026, with an estimated compound annual growth rate (CAGR) of nearly 43 percent within Europe alone.[2] A separate projection of global demand estimates there will be as many as 21 million fully automated vehicles on the road by the year 2026, with the U.S. accounting for 25 percent of that total.[3]

Beyond making automotive travel safer for people and reducing roadway congestion, the widespread adoption of automated technologies in vehicles will also have important economic impacts. Many speak about the potential of the "passenger economy," in which the deployment of driverless vehicles will support the development of new markets and industries that provide a broad range of products and services. One estimate puts the global economic value of products and services directly linked to autonomous vehicle use at $7 trillion by the year 2050.[4]

But realizing the full potential of automated vehicular transportation will also require revaluating our traditional conceptions of automobiles and automotive technologies. That is because, despite nearly a century of technical advancements and increasingly sophisticated systems and equipment, conventional automobiles are essentially machines, represented in their simplest form as a combination of a vehicle body, wheels and tires and some method of propulsion, and designed for the unique purpose of directly supporting human efforts to move from place to place.

Automated and driverless vehicles, on the other hand, are perhaps better understood in the context of cyber-physical systems. Cyber-physical systems are systems or devices are comprised of "interacting digital, analog, physical and human components engineered for function through integrated physics and logic."[5] In real-world applications, cyber-physical systems utilize a sophisticated array of wireless sensors that actively monitor physical and environmental conditions and then send data back to a central processing unit. This unit then assesses these conditions against the system's library of preprogrammed operating scenarios and executes changes in the relevant mechanical or electromechanical systems as appropriate.

AUTOMATED VEHICLES AS CYBER-PHYSICAL SYSTEMS CHANGE COMPLEXITY



Today, examples of cyber-physical systems are everywhere. Modern air transportation makes extensive use of cyber-physical systems, for instance, auto-pilot systems used to safely navigate airplanes and jets over extended routes. Cyber-physical systems are also widely deployed in today's smart utility grids, process control and robotic systems used in advanced industrial production, and even in medical monitoring systems and devices.

When viewed from this perspective, automobiles incorporating automation technologies introduce a previously unimagined level of complexity to our efforts to assure the effectiveness and safety of automobile operations. In this new world order, the ultimate reliability of critical systems depends on a number of key factors. At a minimum, these include:

- the quality of data used as the basis for algorithms that inform operational systems;
- the quality of the operating scenarios against which that data is then compared; and finally,
- the quality of the decision-making capabilities of the autonomous systems and their ability to consistently make the right operating decisions.

The regulatory gap: Why current automotive regulations and standards are insufficient for autonomous vehicles

The current framework for addressing the performance and safety of automobiles and automotive technologies represents a complex web of national and international legislation, regulations, and industry-accepted standards. At the core of this framework is the United Nation's World Forum for Harmonization of Vehicle Regulations, which is charged with creating unified automotive standards and regulations to facilitate international trade. Currently, under the auspices of the Forum, more than 100 separate regulations applicable to passenger vehicles have been developed, covering vehicle safety, energy efficiency, theft resistance and environmental issues. Regulators from most jurisdictions around the world are participants in the Forum, and typically rely on the Forum's regulations in developing testing and certification requirements for automotive technologies in their respective countries.

The testing of essential operational and safety systems in automobiles is also the focus of national new car assessment programs (NCAPs). First established in the late 1970s by the U.S. National Highway Traffic Safety Administration (NHTSA), NCAPs have been subsequently adopted by the automotive industry in other parts of the world, including the European New Car Assessment Program (Euro NCAP), Japan's New Car Assessment Program (JNCAP) and the China New Car Assessment Program (C-NCAP).

International standards also play an important role in the current framework. For example, the functional safety of electric and/or electronic systems in automobiles is the focus of ISO 26262, "Road vehicles – Functional safety." Originally published by the International Organization for Standardization (ISO) in 2011, ISO 26262 represents an adaptation of IEC 61508, "Functional safety of electrical/electronic/programmable electronic safety-related systems."
The safety requirements in ISO 26262 are based on a qualitative assessment of specific risks linked to the malfunction of electrical and electronic systems under anticipated operating scenarios.

Existing regulations do currently not address the effectiveness and safety of automation technologies and systems before road usage.

However, from our perspective, the scope of the current framework applicable to automobiles has not evolved rapidly enough to keep pace with many of the advanced technologies being deployed in automated vehicles today. For example, automated technologies are specifically excluded from the scope of the current version of ISO 26262. And, although discussions are now underway at the UN Forum over a potential regulatory framework for automated vehicles,[6] there are no regulations that currently address the effectiveness and safety of automation technologies and systems prior to their actual deployment on the road.

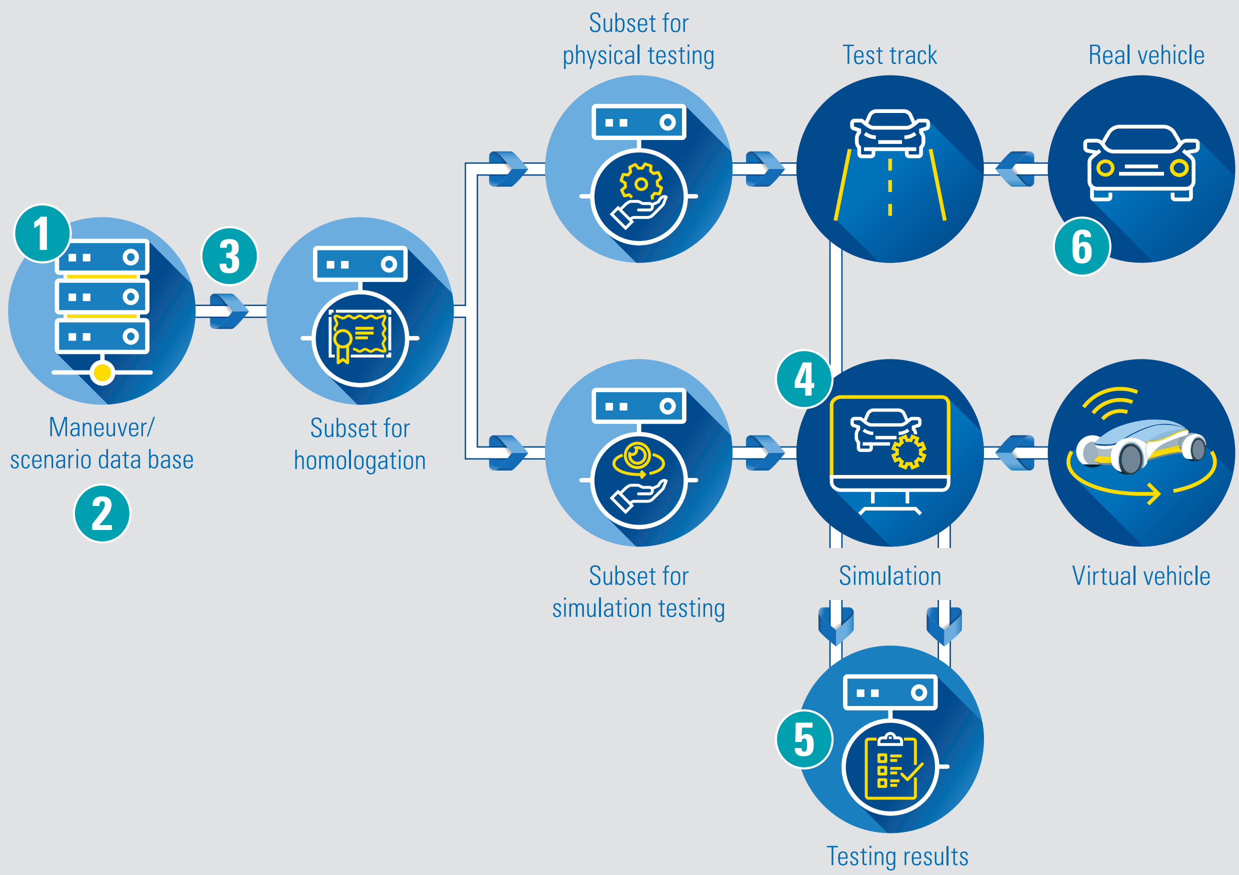
In an effort to address this gap, manufacturers and suppliers have been relying extensively on testing automated vehicles in supervised real-world traffic conditions. They then use the data collected to validate the algorithms supporting the automation technologies, or to modify them to better address previously unanticipated scenarios.

The problem is that, while on-the-road testing is an essential element in the process of qualifying automation technologies, it is inefficient for validating their operational effectiveness. Ultimately, relying on on-the-road testing alone would require traveling millions of kilometers to amass sufficient data to provide meaningful information. And doing so places both test drivers and the general public at unnecessary risk of injury or death.

A six-point approach for developing future homologation and approval regulations for automated vehicles

Clearly, a more comprehensive and rigorous approach to standardization and testing is required for the effective assessment and certification of automated vehicles. To help address this need, we propose a six-point approach for defining appropriate regulatory requirements for the homologation of driverless vehicles that address the use of simulation combined with physical testing, as well as real-world driving test and, finally, an appropriate safety assessment according to state-of-the-art functional safety for automated vehicles.

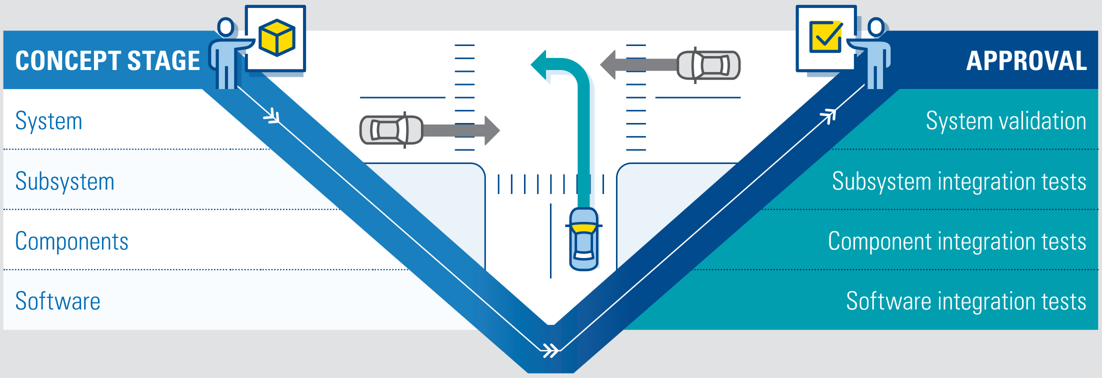
A SIX-POINT APPROACH TO EMPOWER HOMOLOGATION OF AUTOMATED VEHICLES



The following sections offer a summary explanation of the six points of our proposed framework:

1. **Establish scenario-based testing approach as state of the art**
   As noted previously, on-the-road testing alone is an inefficient method for the validation or verification of the safety of automated vehicles and technologies. Therefore, it's important to structure planned testing to account for potentially millions of likely relevant or critical scenarios (corner cases), so that virtual simulations can be effectively used in combination with proving ground and real-world testing.

SCENARIO-BASED TESTING APPROACH FROM CONCEPT TO APPROVAL



2. Establish a comprehensive and globally-accessible database for testing scenarios

To establish a valid, scenario-based testing approach, an up-to-date database compiling data on all relevant testing, validation and verification scenarios is required. We believe that an industry-wide database hosted by a neutral and independent entity or institution and open to the public is essential for achieving that objective. A dedicated committee or subgroup can be formed to add or modify scenarios to the database as required to reflect new or updated technologies and to ensure its ongoing value and relevance. Taking this approach would enable the automotive industry to scale automated vehicle development more quickly and with reduced risk, and also support regulators' efforts to develop harmonized safety requirements, thereby contributing to the goal of global homologation.

3. Determine the criticality metrics essential to safe automated operation

Not all scenarios are created equal, and not every possible scenario can be tested. Therefore, it is important to establish objective, industry-wide criteria to measure the criticality of the scenarios. These criticality metrics should reflect the relevant pass/fail criteria metrics for each use case and adopt threshold performance levels for validation and verification. With this foundation, a criticality coverage analysis can be conducted, allowing regulators to more effectively evaluate whether a certain technology has been sufficiently demonstrated safety and roadworthiness prior to certification.

4. Integrate simulation into the homologation process and recognize the validity of virtual methods in regulatory approval schemes

As previously mentioned, physical testing alone is an inefficient method for validating or verifying vehicle automation technologies. Simulation and other virtual assessment methodologies support large-scale testing requirements by enabling producers to conduct significantly more tests than would otherwise be possible. Therefore, it is essential to integrate simulation as part of the homologation process. But it is crucial to prove the trustworthiness of the used simulation This can be define based on characteristics, such as perception (e.g., sensor simulation), interpretation (e.g., sensor fusion), reasoning (e.g., decision algorithms), acting (e.g., E/E and control algorithms) and executing (e.g. vehicle dynamics). Finally, industry and regulators should consider the potential benefits of an open-source approach for the development of an affordable simulation framework for future approval.

5. Enforce the assessment of functional safety in the certification or homologation process

Currently, compliance with the requirements of ISO 26262 is not mandatory for vehicle homologation. But the introduction of automation technologies makes functional safety assessment essential. We would also encourage further revisions of the standard to more specifically address functional safety performance directly associated with the operation of driverless vehicles, such as the safety of the intended functionality (SOTIF).

6. **Use real-world driving as a final validation of operational safety**
Last but not least, field testing of automation technologies witnessed and audited by regulators or authorized third parties should become an essential aspect of the overall homologation process. If new issues essential to safety are discovered as a result of such field testing, manufacturers should be made responsible for addressing them and for submitting information that can be used to update the scenario database recommended in Point #2. The benefits derived from field testing can be further enhanced by mandating the use of event data recorders in all automated vehicles to capture specific safety-related data. Such data could then also be used to further update the scenario database and to refine other elements in the homologation framework

In the application of this framework, all test cases that are potentially relevant to the safety of automated vehicles and technologies would be captured in a single, centralized database. Because the number of potential scenarios will be significant (on the order of 10^9 or greater), it would obviously be impossible to physically test an individual vehicle or technology under each of the scenarios to verify compliance with safety requirements under the approval process. Therefore, we recommend that, in each regulatory assessment, a randomly selected subset be identified, one that is comprised of the critical scenarios most likely to be applicable to a given vehicle or technology. Then, verification of both safety and compliance under each of the scenarios in the criticality subset would employ a combination of both simulation and proving ground testing.

We believe that, by applying this approach in the homologation process, regulators, automotive manufacturers and suppliers can more efficiently and effectively identify and address the complex performance and safety issues, while helping to ensure the performance and safety of automated vehicles and automation technologies deployed on the market.

How TÜV SÜD is contributing to a safer, driverless future

With more than a century of experience in automotive safety and performance evaluation, testing and certification, TÜV SÜD is actively involved in a number of important global efforts that directly support the development and introduction of automated vehicles to markets around the world.

As the only technical service organization TÜV SÜD is participating in the German government's PEGASUS project, a consortium of regulators and automotive industry participants involved in the assessment and validation of highly automated driving systems on highways.

TÜV SÜD participates in various global autonomous driving projects.

TÜV SÜD is also working with local governments and universities to facilitate the deployment of driverless vehicles in urban settings, for example, the Centre of Excellence for Testing and Research of AVs (CETRAN) initiative being led by Nanyang Technological University in support of Singapore's Land Transport Authority's development of AV test requirements and standards. Besides that, TÜV SÜD experts are also involved in the world's first standard for the approval of fully automated vehicles in Singapore.

To support the adoption of the six-point framework for the homologation requirements of automated vehicles summarized in this paper, TÜV SÜD is an active member of the Eclipse Foundation's openPASS working group, which is a driving force in the development of core frameworks and modules for virtual simulation testing of advanced driver assistance systems. TÜV SÜD is also a charter member of the newly-formed International Alliance for Mobility Testing and Standardization (IAMTS), together with SAE International, the China Automotive Technology and Research Center (CATARC), A NICE CITY and the International Transportation Innovation Center (ITIC). The alliance aims to interconnect leading international standardization institutions, test fields and highly automated driving vehicle validation methodologies. Thereby, IAMTS develops and establishes best practices and state of the art testing and validation methods for manufacturers and mobility-as-a-service companies and provides them with a set of physical and virtual test environments. It follows the mission to develop and grow an international portfolio of smart mobility testbeds that meet the highest quality implementation and operational standards.

In addition, TÜV SÜD is a founding member of the openGENESIS project. Working under the auspices of the Eclipse Foundation, the openGENESIS is a collaborative platform intended to foster the exchange of information, methods and tools being developed to assess artificial intelligence (AI)-based systems used in automated vehicles. The openGENESIS project ultimately provides relevant approaches for the public and regulatory authorities to support them in dealing with the challenges for approval and certification of AI-based systems used in automation technologies.

Finally, many countries including the U.S., Germany and China require permits to test SAE Level 3+ prototype automated vehicles and technologies on public roads. TÜV SÜD is currently providing automobile manufacturers and OEMs and AV operators with the support they need to obtain these permits. This support includes technical advice, reviewing existing documentation and safety concepts to ensure the functional safety of the prototype, and assistance in preparing the necessary technical report and supporting documents consistent with AV permit requirements.

Summary and conclusion

The expected widespread deployment of automated vehicles will provide important convenience, safety and economic benefits to people around the world. At the same time, the current regulatory framework for the homologation of automated vehicles is inadequate for fully evaluating the complex safety issues associated with automation technologies. Further, without significant changes, the current homologation framework will continue to restrain the development of advanced technologies, delaying the introduction of driverless vehicles to the market.

We believe that the adoption of the six-point approach proposed in this paper, can essentially contribute defining the regulatory requirements for the homologation of automated vehicles to ensure the safety of automated vehicles and to foster its safe future deployment. Current gaps in the existing regulatory framework need to be addressed to consider new and innovative testing and validation methodologies and to provide an open platform for the sharing of critical data and intelligence. Together, these changes can help to establish fundamental safety regulations to effectively support homologation for automated vehicles.

The six-point approach can contribute to establish safety regulations support the homologation of automated vehicles.

GLOSSARY OF ACRONYMS

ADS – Automated Driving System
AV – Automated Vehicles
CAGR – Compound Annual Growth Rate
CATARC – China Automotive Technology and Research Center
CETRAN – Centre of Excellence for Testing and Research of AVs
C-NCAP – China New Car Assessment Program
DDT – Dynamic Driving Task
Euro NCAP – European New Car Assessment Program
IAMTS – International Alliance for Mobility Testing and Standardization
ITIC – International Transportation Innovation Center
ISO – International Organization for Standardization
JNCAP – Japan's New Car Assessment Program
NCAP – New Car Assessment Program
NHTSA – National Highway Traffic Safety Administration
ODD – Operational Design Domain
OEDR – Object and Event Detection and Response
OEM – Original Equipment Manufacturer
SOTIF – Safety of the Intended Functionality

FOOTNOTES

[1] "Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles," J3016_201806, SAE International, 15 June 2018. Available at https://www.sae.org/standards/content/j3016_201806/ (as of 7 May 2019).

[2] "Autonomous Vehicle Market by Level of Automation (Level 3, Level 4, and Level 5) and Component (Hardware, Software and Service) and Application (Civil, Robo Taxi, Self-driving Bus, Ride Share, Self-driving Truck, and Ride Hail)–Global Opportunity Analysis and Industry Forecast, 2019-2026," industry report by Allied Market Research, May 2018. Summary available at https://www.alliedmarketresearch.com/autonomous-vehicle-market (as of 7 May 2019).

[3] "Self-Driving Market Becomes a Reality in the U.S. by 2026, As 1 in 4 New Vehicles Sold Becomes Driverless," press release issued by Juniper Research in conjunction with the release of their report "Autonomous Vehicle & ADAS Readiness Index, Player Positioning & Forecast 2018-2026," 23 May 2018. Available at https://www.juniperresearch.com/press/press-releases/self-driving-market-becomes-a-reality (as of 7 May 2019).

[4] "Intel predicts a $7 trillion self-driving future," posted to the website The Verge, June 1, 2017. Available at https://www.theverge.com/2017/6/1/15725516/intel-7-trillion-dollar-self-driving-autonomous-cars (as of 7 May 2019).

[5] "Cyber-Physical Systems," from the website of the U.S. National Institute of Standards and Technology (NIST). Available at https://www.nist.gov/el/cyber-physical-systems (as of 7 May 2019).

[6] "Framework document on automated/autonomous vehicles," prepared by the Secretariat of the United Nations World Forum for Harmonization of Vehicle Regulations, 15 April 2019. Available at https://www.unece.org/fileadmin/DAM/trans/doc/2019/wp29/ECE-TRANS-WP29-2019-34e.pdf (as of 7 May 2019).

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