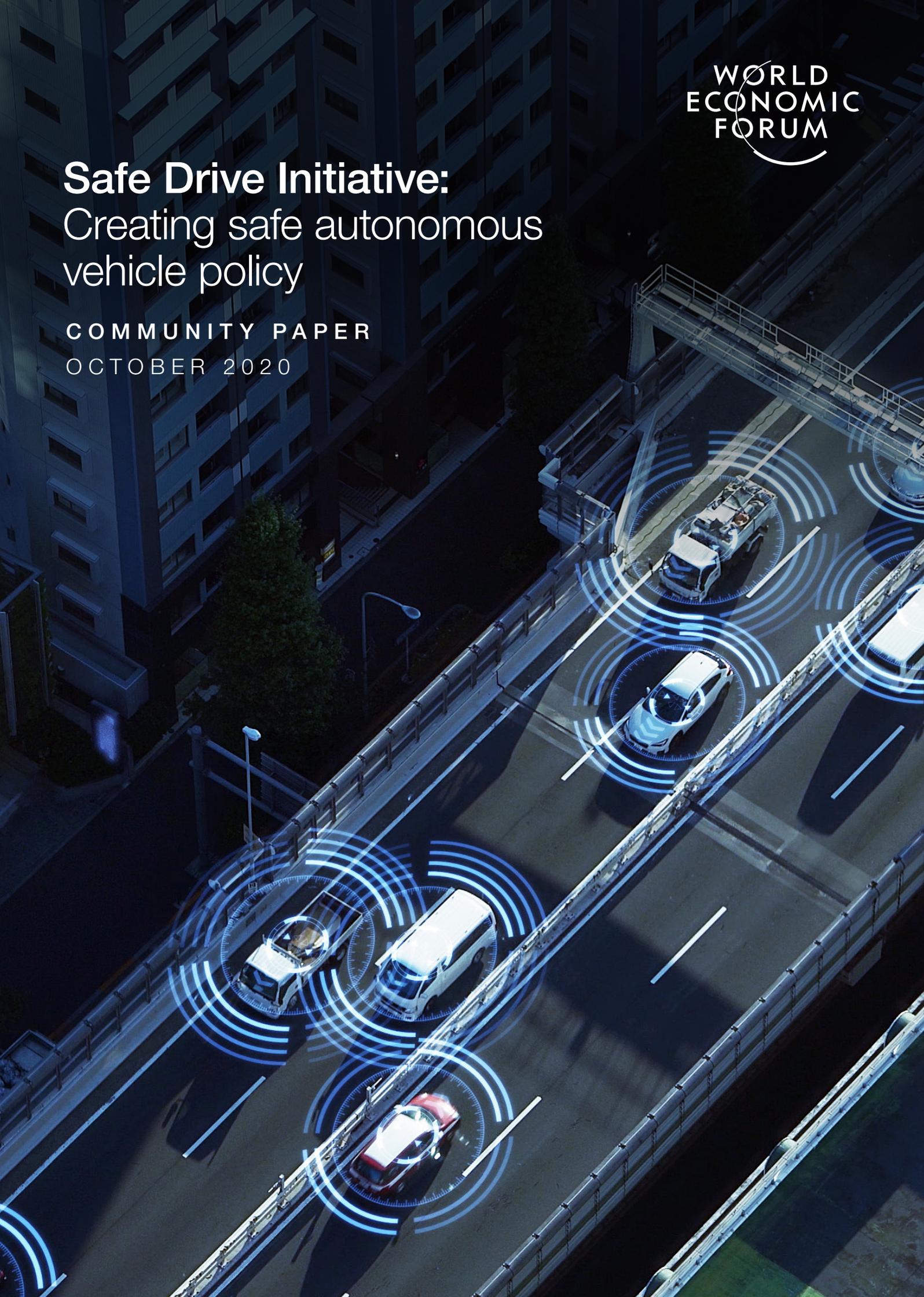


Safe Drive Initiative: Creating safe autonomous vehicle policy

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Preface



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“ A cohesive approach to autonomous vehicles is possible only when accompanied by a clear top-level vision for the future mobility ecosystem.

Autonomous vehicles (AVs) promise to revolutionize the future of mobility, from how we travel and commute to automating the operations of logistics and supply chains. While this promises a future of efficient transport with fewer road fatalities and injuries, the AV technologies remain under development, and policy-makers are trying to navigate the trade-off between facilitating testing and trials of AVs, and protecting their citizens from unproven self-driving vehicles.

Transport officials cannot be expected to maintain cutting-edge knowledge on the operational safety of autonomous systems. Moreover, the industry has yet to align on a common approach to demonstrating the operational safety of automated vehicles. This creates tensions between policy-makers and industry stakeholders, who may prefer that regulators trust their expertise in developing safe solutions, but simultaneously want to safeguard their intellectual property and other trade secrets.

So far, policy-makers are largely allowing for self-certification by AV companies, while making minimal amendments to their existing road traffic regulations to enable testing of automated vehicles. A small handful of regulators are taking a hands-on approach to evaluating AVs, creating a structured, graduated testing and approval process as the basis for a licensing programme.

Broadly, the Safe Drive Initiative seeks to improve regulators' decision-making abilities on automated vehicle technologies. In this paper, the World Economic Forum offers a holistic review of the leading approaches to AV policy, to identify and highlight the most effective techniques in these approaches in order to facilitate the testing and development of AVs. Following this review, we identify gaps that we believe can be addressed through a graduated, scenario-based approach developed in partnership with our multistakeholder Automotive and Autonomous Mobility community.

This framework will be detailed in a subsequent Safe Drive Initiative publication.

In the course of this policy review, we interviewed a range of national, state and local policy-makers and advisers to understand the thinking behind the various approaches that exist today. When coupled with a legal documentation review, this highlights a number of important success factors to developing an optimal policy environment for AVs. One message became abundantly clear: A cohesive approach to AVs is possible only when accompanied by a clear top-level vision or strategy statement for the future mobility ecosystem in the market. With a clear vision statement for the future of mobility, it becomes easy to define what role AVs can play in achieving that vision, and enabling the creation of an achievable policy roadmap for AV testing, development and commercialization.

While this is straightforward from a strategists' perspective, the reality is that many markets have various levels of state, ministerial and local regulations that may be affected by AV deployment, and these various levels of subnational regulators may also seek input on future AV policies. This tension is all too common, and may create unnecessary hurdles for AV developers to navigate. Without a cohesive top-down strategy, it is easy to see how regulatory patchworks emerge.

This project is continuing to study and propose optimal approaches to AV policy, as the technologies move from small trials to larger pilots and deployments. The recommendations and methodologies identified in this document are intended to provide actionable insights for global policy-makers, while also informing our own research into AV policy.

The World Economic Forum is grateful for the insights from several contributors and the analytical support of McKinsey & Company.

1

Executive summary

“ There is limited global consensus on how to define milestones for AV safety, because the definition of safety is a function of its operating environment.

The development of automated driving is far from complete. From software to hardware, the technology is still evolving, particularly in Level 4 and 5 systems. Meanwhile, regulators are still catching up with this fast-growing sector, and at best are reactive in creating policy to enable testing – with considerable variation in methodologies between nations and states. The United Nations Economic Commission for Europe (UNECE) recently proposed new autonomous driving guidance to ensure passenger safety, signalling the importance of this subject. Still the challenge of creating policy for high-level automation remains unresolved.

The industry's rapid development to this point has outpaced policy-makers' response to AVs. While the technology is continuing to evolve, regulators need to understand how these development activities and future deployments will affect their citizens' lives and influence their decision-making in everything from transport policy to urban development.

Some countries, such as Singapore, have been highly proactive in engaging with, and providing funding for, the industry and research institutions to study the technology and create regulatory sandboxes. This enables them to understand AVs intimately and shape policies that meet their own goals for mobility in their jurisdiction. Others, such as the United States, have taken a more hands-off approach, creating broad guidelines for AV development and relying on the industry to set the pace of investment and deployment. In the absence of suitable federal or state regulation, cities may also feel the need to set their own guidance, creating a fragmented and varied broad policy landscape for AV companies to navigate across the country.

Globally, there is limited consensus on how to define milestones for AV safety, since the problem of defining safety invariably becomes a function of the operating environment. Several technically driven initiatives have proposed validation frameworks,

but these have yet to be converted into workable policies. Moreover, AV developers are often reluctant to share any information about their own safety metrics regarding their operations out of fear of losing their competitive advantage, creating a siloed industry that essentially competes on safety.

Some authorities, such as the California Department of Motor Vehicles (DMV), require routine data reporting, including miles driven and disengagements, but these limited metrics are frequently refuted as poor indicators of safety by industry, academia and other governments alike. Despite this criticism, there is limited consensus among industry stakeholders as to what metrics could be used to indicate system safety.

While the progress of development to date has been rapid, AV technologies remain largely unproven for many operators, and the industry has not yet been able to align on a common framework for assessing the safety of AVs necessary for full deployment. While self-certification may be the preferred approach for AV providers during the testing phase, many regulators and members of the public will expect some form of independent assessment of AV safety in the future.

An effective validation process must strike a balance in order to create a rigorous process that ensures safety for all road users without demanding too much from AV providers, opening doors to costly litigation or exposing trade secrets. Policy-makers need to use this period of development to engage with the industry to advance their own understanding of these vehicles and establish suitable competencies to inform their future decision-making if they want to succeed in enabling safe deployments of automated vehicles when the technology matures.

Thus, the key research question behind the Safe Drive Initiative is the following: **How can policy-makers ensure an AV is safe to operate in their jurisdiction?**

This document provides several contributions towards answering this question:

- Review of existing safety validation and regulatory initiatives, identifying best practice in existing policy
- Case studies highlighting a range of policy approaches, to compare policy development strategy, design decisions and methodologies
- Gaps and anticipated requirements for a standardized safety validation approach

In summary, regulatory initiatives vary significantly from hands-off guidance with no formal permitting programme to structured performance evaluations. However, most policies that exist today are only temporary measures to enable testing. The lack of commonality presents challenges for AV developers who will want to expand into different markets without going through different validation processes in every city, state and country in which they wish to operate. Moreover, a lack of the technical knowledge required to implement regulation presents a major hurdle for regulators, who seek to promote innovative technology but are unsure how to certify that it is safe for the public.

An optimal AV safety assessment will benefit from a multistakeholder approach convening regulators, AV developers, safety experts and members of the public to ensure that a system is safe to use on public roads. The exact processes will vary across jurisdictions due to geographic, political and legislative differences, but harmonizing approaches will accelerate the development and deployment of AV technology around the world. Establishing a standardized process will reduce uncertainty for AV providers who desire to expand into new markets, and also equip additional stakeholders such as logistics companies with the tools to compare different AV systems when choosing which to purchase.

This review is the first in a series of documents published by the World Economic Forum to offer holistic guidance on autonomous vehicle policy. By engaging with industry partners, regulators, academia and civil society, the Safe Drive Initiative proposes a broad and actionable framework to enable policy-makers to create a graduated series of milestones to enable the safe deployment of automated vehicles.

2

Key terminology

2.1 Defining verification methods

- **Simulation:** Highly parameterized digital twins of roads that can be used to test AV systems under many different parameter values and estimate the vehicle's expected response.
- **Test track:** A controlled environment that mimics a city infrastructure and can be used to simulate real-world driving in a lower-risk situation. Can enable verification of simulation scenarios in a real-world analogue with minimal risk.
- **Naturalistic on-road testing:** Using public roads for testing in regular traffic, typically supervised by a safety driver or remote operator. This is necessary to prove the safety of the vehicle in the real world, but also presents the most risk to the public.

2.2 Other reference terms

- **Automated driving system:** The hardware and software that are collectively capable of performing the entire dynamic driving task on a sustained basis, regardless of whether it is limited to a specific operational design domain.
- **Autonomous vehicle (AV):** A vehicle equipped with an automated driving system designed to function without a human driver as a Level 4 or 5 system under SAE J3016.
- **Dynamic driving task:** All of the real-time operational and tactical functions required to operate a vehicle in on-road traffic, excluding the strategic functions such as trip scheduling and selection of destinations and waypoints.
- **Operational design domain (ODD):** A description of the specific operating domain(s) in which an automated driving system is designed to properly operate, including but not limited to roadway types, speed range, environmental conditions (weather, daytime/night-time etc.) and other domain constraints.
- **Scenario:** A traffic situation within the vehicle's operational design domain.
- **Scenario-based assessment:** Evaluating a system based on its performance when exposed to a variety of predefined scenarios that correspond to its intended deployment ODD.

3

Motivation

This paper is intended to review current autonomous vehicle policy initiatives in order to identify the governance gaps presented by AVs. To inform this analysis, the Forum conducted an initial review of relevant AV policy initiatives worldwide. Following this, the project team conducted a series of in-depth stakeholder interviews with a range of policy-makers, from top-level national regulators to municipal-level agencies, to understand the reality and implementation of each of these policy initiatives. A series of verbatim quotes from these interviews is provided to add further depth to this document.

3.1 State of the industry

To date, the industry's development efforts have focused upon three main applications of automated driving systems.

- Initially, the autonomous vehicle industry was heavily focused on autonomous mobility, developing vehicles for use in automated ride-hailing or transit services.
- Recently, there has been a pivot to developing vehicles for delivery purposes by many operators. These delivery applications span a range of applications, from heavy-duty trucking to small ground robots for last-mile delivery.
- Additionally, some original equipment manufacturers (OEMs) are developing highly automated driving systems for use in individually owned passenger cars, with a view to creating “chauffeur” functions, for example.

These applications of the technology represent very different business models, and require separate considerations in the engineering of the vehicle and its safety requirements.

Delivery has become a particularly attractive application of AVs, not just because of an increased demand for last-mile deliveries in light of the COVID-19 pandemic, but because it represents a more compelling business case for a complex and expensive vehicle to be a fleet-owned asset with a potentially high degree of use. This is also true for trucking and long-haul logistics, which is also viewed as a prime application of AV technologies.

As the technology development continues, autonomous vehicles are being piloted around the world to trial these solutions on public roads. Regulators are continuously challenged as they react to this evolving landscape and seek to understand the technology, and its role in their future mobility systems.

3.2 Current state of autonomous vehicle policy initiatives

A spectrum of initiatives exist globally to study and develop AV policy solutions. From the amendment of existing traffic laws to the development of structured

licensing programmes, the AV policy landscape remains a fragmented one globally. Some nations and cities have been highly proactive in developing a

“ The AV policy landscape is currently skewed by commercial incentives.

– Policy expert

“ Nothing comes close to the technical knowledge companies have.

– City regulator

roadmap for autonomous vehicles, and creating legal frameworks and standards to provide clarity to AV developers, while others have prioritized an industry-led open policy environment to facilitate innovation or devolve responsibility to regional governments.

Globally, AV policy initiatives can be placed into four broad categories:

- **Self-certification approach:** The regulator establishes a broad policy framework allowing for a range of autonomous vehicle solutions to be developed, while issuing guidelines as required on taxonomies and other definitions. The defining feature of this approach is that the government requires the AV operators to publish a self-assessed safety case, detailing the operational and organizational safety measures taken to regulators and the public alike, in exchange for a permit to test and develop on the roads.
- **Code of practice approach:** The regulator publishes guidance to AV companies seeking to conduct trials on public roads with minimal amendment to existing road traffic laws. A legal code of practice establishes the expectations of the AV providers to demonstrate the safety of their solution, along with a range of other considerations on subjects such as public engagement and interfacing with local authorities. There is no formal permitting as part of this process.

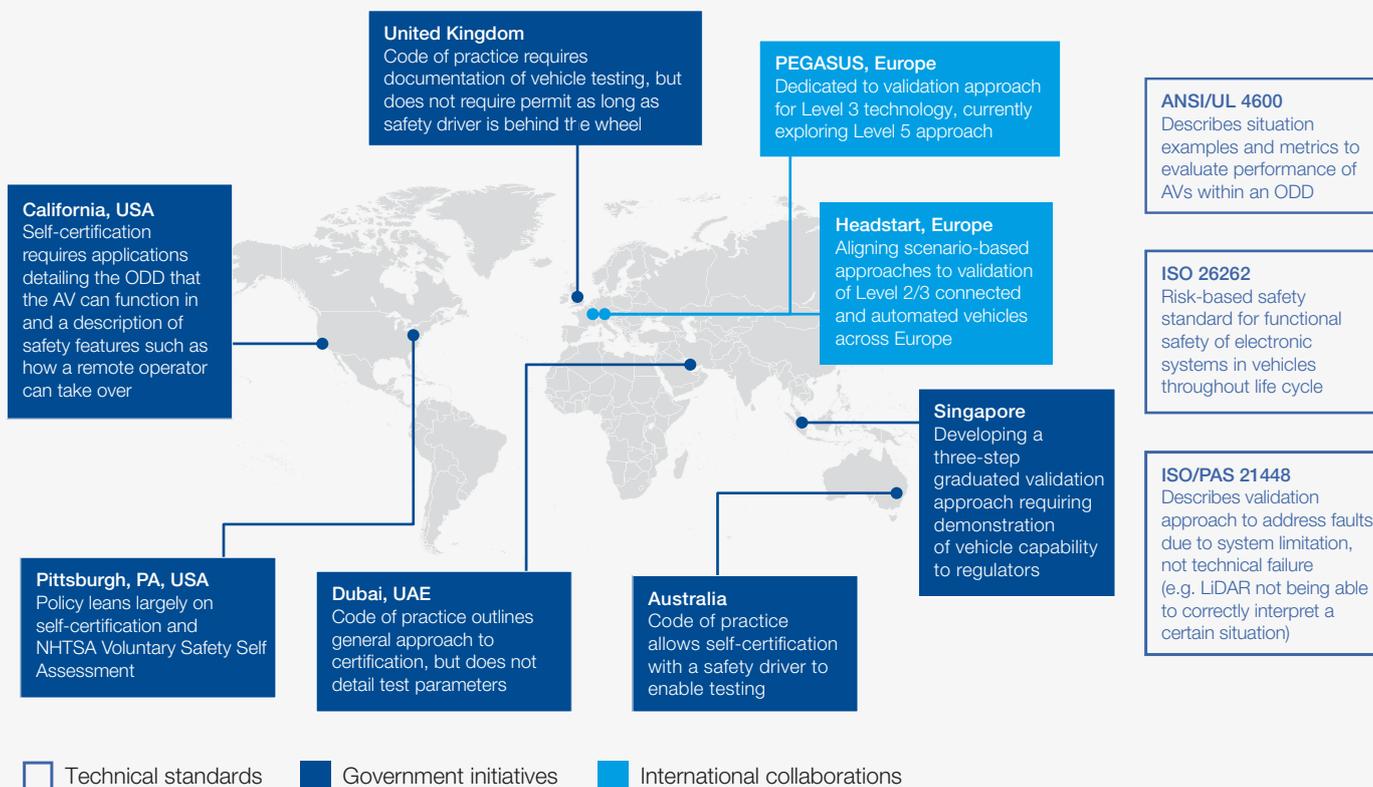
– **Operational safety assessment approach:** The regulator establishes a formal assessment of the safety of the vehicles, whether on a test track, simulation or on the public road, or a combination of the three. Passing this assessment grants an AV company a permit to test in a given environment; the regulator may also set a graduated series of milestones.

– **Type approval approach:** A super-national body sets harmonized safety standards for vehicles across markets. This is the current approach to setting regulations for automotive safety in UNECE signatory nations. While these regulations are largely geared towards conventional vehicle safety features, UNECE is actively working on standards for automated driving to enable common performance requirements across signatory markets. UNECE recently released standards for Automated Lane Keeping Systems (e.g. Level 3 Traffic Jam Pilots).

Examples of these different approaches are shown in Figure 1.

With the exception of type approval activities, these regulatory approaches have been developed to enable pilots, but are not intended to demonstrate the long-term viability or safety of AVs.

FIGURE 1 Global overview of AV governance initiatives



Source: World Economic Forum; McKinsey & Company analysis

Technical standards

Through industry coalitions, standards bodies and other ventures, a range of technical standards are currently under development to inform the technical development of AVs across a range of topics, from functional safety to building an end-to-end safety case. Many existing industry standards are geared towards mass-production passenger cars and their advanced driver assistance systems (ADAS), but several efforts to develop the necessary standards for highly automated driving systems are under way. However, these standards are largely industry-led, and may not be directly suitable for policy implementation.

There is a broad range of technical standards for autonomous vehicles – covering aspects from individual component performance to organizational safety measures. Policy-makers should not expect to follow the full technical spectrum of such standards, but should be made aware of cornerstone standards that are frequently referred to in AV safety development:

- **ANSI/UL 4600 – Standard for Safety for the Evaluation of Autonomous Vehicles and Other Products:** Safety principles and processes for evaluating fully autonomous products requiring no human driver supervision
- **ISO 26262 – Road Vehicles – Functional Safety:** Risk-based safety standard for the functional safety of electronic systems in vehicles throughout the vehicle's life cycle
- **ISO/PAS 21448 – Road Vehicles – Safety of the Intended Functionality:** Provides guidance on the applicable design, verification and validation measures needed to achieve safe system operation, reducing hazard risk of functional insufficiencies of the intended functionality even when components are operating correctly or are affected by foreseeable misuse

International validation initiatives

International collaborations on AV validation tend to focus on developing validation approaches to form the basis of operational safety assessments, such as the PEGASUS Project in Germany. The PEGASUS Project was initiated by the German Federal Ministry for Economic Affairs and Energy and is supported by a range of industry participants, including BMW, Continental, Daimler, the German Aerospace Center, IPG, Opel and Volkswagen. The project's mission is to define a standardized procedure for the testing and development of automated vehicle systems in simulation, on test tracks and in real-world environments, through a scenario-based assessment enabled by creating harmonized approaches to data acquisition, definition and labelling.

Other nations, including the UK and Japan, have sponsored similar coalitions to explore and develop scenario-based assessments for automated vehicles, and are employing a multistakeholder methodology to develop their initial requirements and structure their assessment programmes.

Successful regulatory implementation requires input from multiple stakeholders, but most stakeholders want someone else to make the first move: In an ideal world, city, state, federal, AV providers and the public would work together in the development of AV policy. In reality, governments are open to suggestions from the AV industry on the creation of safety metrics and assessments, and consultations with other stakeholders are fragmented at best.

4

AV policy case studies

4.1 USA – self-certification

Traditionally, the US federal government has been responsible for certifying conventional vehicles to be safe at the point of manufacture, and state governments have been responsible for certifying human operators to drive vehicles safely.

The US Congress has considered legislation in each of the last two congresses that would establish a national legislative and regulatory framework for AVs, but the efforts have ultimately fallen short of becoming law.

Meanwhile, the United States Department of Transportation (US DoT) has set out a series of top-level policy papers outlining the federal government's role in AV governance. The most recent publication, *Ensuring American Leadership in Automated Vehicle Technologies: AV 4.0*, builds upon previous publications by mapping the role of adjacent government departments such as the Department of Defense in future autonomous vehicle development and governance. Previous publications set out a range of reference terms and created a handful of safety requirements, such as the establishment of a Voluntary Safety Self-Assessment (VSSA) reporting programme.

Broadly, the spirit of the current US DoT policy is to provide an open regulatory environment for innovation, remain technology-neutral and allow the industry to set the pace of development and deployment through a self-certification approach.

The DoT's current policy acknowledges that responsibility for AV licensing and compliance with local traffic laws remains at the state level, as with conventional vehicles.

Each state's Department of Transportation or Department of Motor Vehicles has primary responsibility for the licensing of AV operators, and many states have implemented their own approval process for autonomous vehicles in the interests of safety assurance. The State of California has the best-known AV licensing programme, given the number of companies testing in the state. This programme is administered by the California DMV.

Across the US, cities and other local authorities have limited scope to influence federal AV regulatory policy, despite being directly affected by the presence of AVs on their streets. As a result, local authorities may wish to see stricter safety requirements than state or federal regulators request. However, the adoption of unique local requirements may create a patchwork of regulations across jurisdictions that undermines the ability of AV operators to develop compliant systems that can operate statewide. Some cities have created additional, albeit voluntary, reporting and operational requirements for AV operators.

For AV companies, the lack of federal AV laws has created a fragmented patchwork of regulations across the US market, with considerable differences in requirements at the state and, sometimes, local level.

California

California has implemented a self-certification-based permitting programme, requiring applicants to its Autonomous Vehicle Tester (AVT) programme to submit a range of information prior to deployment regarding the AV's development, capabilities, operational plans and organizational safety measures. The state does not directly conduct any validation tests, and reviews information submitted through this programme only. In all cases, California requires reporting of all collisions within 10 days as well as an annual report summarizing all disengagements of the automated driving system during testing.

There are currently three stages of permit in California, each requiring information to be submitted with the application by the AV developer:

- AV testing with a safety driver (66 holders as of 1 July 2020)
 - Acknowledgement that the driver is in immediate control of the vehicle and can take over at any time
 - Information regarding operator training course
- AV tests without a driver (three holders as of 17 July 2020)
 - Acknowledgement that the vehicle is capable of Level 4, Level 5 driving (SAE J3016) and can operate without a driver
 - Demonstration of system that allows two-way communication with passengers
 - Submission of law enforcement interaction plan to California Highway Patrol
 - Notification to local authorities of plan to test in jurisdiction (local authority approval is not required)
 - Intended ODD
- AV deployment programme (no permits issued at the time of writing):
 - Description of intended ODD, any commonly occurring restrictions
 - Description of vehicle safety mechanism in the event of ODD excursion, and when occupant is unable to take manual control of vehicle
 - Summary of manufacturer testing
 - Copy of VSSA if publicly available
 - Requires data recorder to capture at least 30 seconds of data before a collision with another vehicle, person or object

California's publication of disengagement data has become one of the de facto indicators of autonomous

vehicle system development, simply because of its widespread reporting and republication. However, this stand-alone metric provides a very limited insight into the maturity of the technology, and has been widely criticized by industry, academia and other policy-makers as insufficient for decision-making purposes.

In addition to satisfying the requirements of the California DMV, AV companies in California that intend to operate a passenger service are further subject to regulation by the California Public Utilities Commission (CPUC).

Beyond disengagement reporting, regulators in the US have struggled with how to measure and determine safe performance and continue to defer to AV providers to show that systems are safe to operate in public. City regulators have expressed a desire for deeper insight into AV providers' own metrics for system performance to improve upon the existing metrics such as miles per disengagement.

Arizona

In contrast to California, the State of Arizona has taken a very permissive approach to AV testing. In 2018, Arizona's Governor signed an executive order enabling testing of AVs without a safety driver, and Arizona is the only location in the US where driverless AVs have been commercially deployed to date: Waymo operates a driverless taxi service in the greater Phoenix area.

Testing with a safety driver requires companies to complete an online form attesting to the following requirements:¹

- The AV will operate within all applicable laws
- The operator of the AV may be issued a citation in the event that the AV does not comply with traffic laws
- The AV will be supervised by a trained employee of the AV company developing the technology

Testing and operation of an AV without a safety driver also requires companies to attest to the above requirements, as well as several further statements:

- The AV has all required federal certifications (unless an exemption from the National Highway Traffic Safety Administration [NHTSA] has been granted) and meets all required licensing and insurance requirements
- The AV can achieve a minimal risk condition in the event it is unable to perform the required driving task within the intended ODD
- AV developers must submit and follow a Law Enforcement Interaction Protocol instructing first responders on how to interact with the AV in emergency situations (e.g. how to interact with a fleet support specialist; how to move the vehicle from the roadway)

The state of Arizona does not require AV companies testing or operating in the state to submit any ongoing reports about their AV operations, such as accident reporting or disengagements. While there is a limited requirement for documentation, failure

on the part of the AV provider to submit the proper notice prior to testing or operation can lead to an immediate cease and desist notice on AV testing until the AV provider is in compliance with all laws and regulations.

Case insights

Devolution of vehicle licensing responsibility has created a fragmented market, which may harm widespread deployment of AVs in the US:

The federal government's hands-off approach has enabled states to set their own requirements for AVs, but this has led to a variety of different safety requirements in various states. California's AV permitting programme is the most stringent in the US, while other states, such as Arizona, place minimal requirements on AV operators. This lower bar may encourage some AV operators to trial their vehicles in other states, but the long-term viability of this patchwork approach is questionable.

While the DoT and NHTSA have recently launched new initiatives in AVs (such as the [AV TEST initiative](#)) these have done little to harmonize the regulatory patchwork across states.

Not all self-certification policies have the same level of oversight. California requires some supporting documentation regarding the AV's development process and safety procedures, while Arizona requires only that companies attest to the AV's ability to operate safely and achieve a minimal risk condition if it leaves its intended ODD. Arizona's approach leans entirely on companies to develop AVs safely, while California has attempted some level of independent assessment and ongoing monitoring.

Arizona's lack of regulatory oversight has been identified as a contributing factor in the first fatality from AV development. Following an investigation by the National Transportation Safety Board (NTSB) into the accident, in which an AV struck a pedestrian in Tempe, Arizona, in March 2018, the open policy environment was identified as one of the contributing factors in this collision. In addition to identifying a problematic safety culture and a range of other contributing faults on the part of the AV company, the NTSB wrote in its 2019 analysis of the accident that "Arizona's lack of a safety-focused application-approval process for ADS [automated driving system] testing at the time of the crash, and its inaction in developing such a process since the crash, demonstrate the state's shortcomings in improving the safety of ADS

testing and safeguarding the public". The NTSB also describes the NHTSA's voluntary safety self-assessment requirements as "inadequate".

The California DMV's disengagement reporting has been criticized as lacking suitable context and depth to indicate safety or technology maturity:

Many industry leaders have publicly criticized the use of disengagement reporting as a safety metric. Disengagements are a function of complexity of test conditions and the number of miles driven. In addition, a disengagement indicates only that a human test operator took over an AV at a given time, not necessarily that there was a failure of the automated driving system. Moreover, the way this data is reported varies considerably between operators, from lengthy descriptions of each disengagement and of system faults to single-word entries. This highlights the need to improve the way in which such data is reported to standardize inputs, making comparisons possible. Doing so would enable other stakeholders, such as cities, to derive their own insights from this dataset.

Despite such vocal criticism of the disengagement reporting approach, AV operators are reluctant to share publicly how they measure safety and development progress internally, as a means of protecting intellectual property. Given the varied approaches AV companies in the US are taking, and the fact that the AV industry as a whole is still in a testing phase, there is not yet consensus on exactly which metrics will be necessary to make this safety case.

The industry-led development in the US is creating an environment in which safety can be a source of competitive advantage: Without harmonized, uniform requirements across the country, AV operators treat information on their technology's safety and maturity as the most closely guarded industry secret. When combined with the race to launch commercial AV services, this creates an unhealthy competition where safety is something on which AV companies compete, rather than collaborate with one another.

4.2 United Kingdom – code of practice

In 2019, the United Kingdom published the non-regulatory *Code of Practice: Automated Vehicle Trialling*² following a review of existing road traffic laws, to provide guidance for AV companies seeking to test vehicles on UK roads. This code of practice outlines the need for compliance with existing traffic laws, covering subjects from insurance to vehicle roadworthiness, while encouraging engagement with the relevant government agencies and the public.

According to this code of practice, no further permit is required to conduct testing of an AV on UK roads, provided there is a safety driver or operator, in or out of the vehicle, ready to take control of the vehicle.

This code of practice is not a stand-alone policy in the UK; it has been accompanied by a series of strategic initiatives to strengthen the UK's development of, and investment in, AVs. This began in 2015 with the creation of the Centre for Connected and Autonomous Vehicles (CCAV), a government centre of excellence established jointly from within the Department for Business, Energy and Industrial Strategy (BEIS), and the Department for Transport (DfT). CCAV's mission is to work across the government to support and enable the development of connected and automated vehicles in the UK, through funding, conducting direct research and collaborating with other government entities.

Following the creation of CCAV, the UK government has continued to make connected and automated vehicles a priority for the nation's industrial policy, and it has embarked upon setting up a further non-governmental entity to create a strategic roadmap for CCAV policy in the UK, called Zenzic. This roadmap was issued in 2019 and establishes a range of policy priorities across subjects such as cybersecurity and creating test beds for AVs, until 2030.

Case insights

The British government has established a top-down strategy to position the UK as a leader in connected and automated vehicles:

By establishing and funding an initial mission to encourage the development of AVs and related technologies in the UK, the government has been able to subsequently create an achievable policy roadmap to ensure there are minimal barriers to AV testing on UK roads.

The broad code of practice provides guidance on how to test AVs on the road in the UK in compliance with UK law:

This enables AV operators to ensure AVs can be tested and developed on the public road legally and with the support of the government.

Additionally, the British Standards Institution (BSI) is actively developing a range of connected and autonomous vehicle publicly available specifications (PAS) standards to complement the UK's policy needs. The PAS 1880 series establishes relevant requirements for AV trials in a number of fields, including:

- PAS 1880: Guidelines for Developing and Assessing Control Systems for Automated Vehicles
- PAS 1881: Assuring the Safety of Autonomous Vehicle Trials and Testing
- PAS 1882: Data Collection and Management for Automated Vehicle Trials
- PAS 1883: Operational Design Domains (ODD) Taxonomy for Automated Driving System (ADS) – Specification

Furthermore, the UK is also undertaking the development of its own scenario library for the purpose of establishing a scenario-based operational safety assessment in a programme called CertiCAV, led by the Connected Places Catapult (a government-created non-profit organization) and Warwick Manufacturing Group (WMG), University of Warwick.

Finally, the UK Law Commission is currently undertaking a three-year review to understand the need to modify the legal framework to further support and enable AV deployment.

While this meets the objectives of not creating additional barriers to testing, and creates a level playing field for AV companies, this code of practice is not a suitable framework for AV deployment at scale, and may require additional stipulations for AV safety as the number of operators trialling in the UK increases. The UK government acknowledges this, and has further commissioned the creation of a certification and approval scheme, called CAV PASS, which is intended to create an assurance process for approving the sale and deployment of AVs at scale in the UK.

The UK is developing a scenario library for operational safety assessment: In future, the AV Code of Practice is likely to be superseded by further regulation, creating an operational safety assessment based on the CertiCAV library.

4.3 Singapore – operational safety assessment

Since 2017, Singapore's regulators have been highly proactive in creating policies to enable the development and testing of automated vehicles in their city-state. This approach has led to the establishment of a joint centre of excellence (CoE) with Nanyang Technical University (NTU) called CETRAN, and the creation of a series of technical standards and regulations for autonomous vehicles in Singapore.

One of the critical success factors of Singapore's approach to AV policy was establishing a vision early on for the authorities' role in Singapore's future mobility ecosystem – namely, they envision that high-capacity, shared and electric AVs are a crucial tool in addressing the city's problems with congestion, limited road space and shortage of drivers.

Beyond AVs, Singapore's future strategy for mobility seeks to encourage greater use of shared transport modes. To incentivize AV companies to develop solutions that fit with this vision, the Singapore government initiated the Singapore Autonomous Vehicles Initiative (SAVI), to support the development and trials of AVs on their streets. Hence, the Singapore Land Transportation Authority (LTA) sought to create a policy environment to enable this development to take place and to encourage the creation of solutions that meet with the city's future mobility strategy.

The mission of the resulting AV policy instruments issued by the LTA is intimately connected to the future mobility objectives; the LTA believes that consumer acceptance of these technologies as safe, useful and efficient is crucial, so a public-facing, proactive testing programme was devised

Case insights

Establishing a clear vision for the role of autonomous vehicles in Singapore's future transport ecosystem enabled the creation of a cohesive policy: Setting a clear mission statement early on enabled Singapore to dedicate resources and research efforts to develop a clear set of policies with the support of industry and other stakeholders.

This collaboration on AV research and development between regulators, AV providers and CoE creates a healthy tension: All stakeholders want to maximize safety, and this collaboration enables AV providers to supply input to developing a feasible test while also not hindering development. The government recognizes

to enable the regulator to assess the safety of the vehicles under development, while engaging the public and demonstrating a transparent series of assessments to assure the safety of the vehicles as they are tested.

In partnership with CETRAN, by using an incremental, consultative approach engaging AV developers, the LTA set out a tiered evaluation programme to study and license AVs, enabling the LTA to study and learn about the technology while licensing developers on the road.

Core to this evaluation programme are three milestones, each with a corresponding technical reference (TR) standard:

- Milestone 1: An on-road demonstration of basic behaviours such as turns, stopping and safety operator intervention, to permit the operator to conduct limited testing in the One North Business District
- Milestone 2: A combination of on-road and simulation-based assessment, using a scenario library representative of Singapore, to allow access to a subset of the city's public roads for further testing
- Milestone 3: Currently under development, but includes additional scenario edge cases and considerations for cybersecurity

These milestones were established, tested and improved through multistakeholder collaboration with the industry, CETRAN and the traffic police.

that industry leads in the area of technological expertise, so they should work closely with industry stakeholders to develop policies that serve all parties' needs.

Passing Singapore's test may also be a quality assurance mark: There is no one-size-fits-all answer to regulation, but it may help AV providers in other countries to demonstrate that one government has robustly tested them. Other governments can also adopt the technical reference standards developed by Singapore. For example, TÜV (a German road safety institute) was an external participant in the development of the Singapore AV standards.

4.4 Discussion

FIGURE 2 The case studies show a range of approaches



“ We keep in contact with other authorities to share experiences ... I don't think it's one-size-fits-all. We need to learn which approach fits best for each market and regulator.

– City regulator

These three case studies highlight the breadth of approaches taken in three different nations in enabling AV trials; each approach has its strengths and limitations and reflects the specific geographical, economic and political realities of the three countries. The level of external independent assessment varies between the approaches, directly correlated with the level of complexity in implementation on the regulator's side, as well as the burden of proof placed on the AV developer and country-specific societal norms relating to government regulation.

Singapore's operational safety assessment is the most hands-on approach for a regulator, to create a structured, independent assessment of AV safety. Due to Singapore's small land area, a finite scenario library is easier to develop and parameterize than, for instance, a large country such as the US. In addition, such a hands-on process is also more challenging to implement in a decentralized government such as the US.

The UK's code of practice provides a clear path for AV developers to begin trialling on public roads because it provides guidance on safe and lawful operation without requiring additional permitting or an additional demonstration of safety. While effective for promoting on-road testing, this policy will likely be superseded following the Law Commission review and the creation of the CAV PASS programme to allow for commercial services to be launched. This will be further compounded by the public's expectation that the government will provide assurances of AVs' safety through independent assessment.

In the US, the combination of historical delegation of vehicle operator regulation to the states and the lack of a federal statutory or regulatory framework

for AVs has led to states stepping into the policy vacuum and establishing a patchwork of state-level certification requirements. Similar to the UK, the US currently relies exclusively on AV developers to certify that their systems are safe to test. Acknowledging the importance of public trust, AV companies assert that they are operating as safely as possible and do not need external oversight to do so.

Moreover, each company operates differently and companies assert that different measures of safety would be difficult to standardize into a universal regulation. Hence a performance-based approach to regulation becomes an attractive solution.

As AV technology continues to evolve, different jurisdictions will have varying appetites for regulation, as well as varying authority to implement it. Governments with more unilateral regulatory power (such as Singapore) and a history of investment in research and development will likely have an interest in developing and authority to implement high-touch policy frameworks, such as operational safety assessments, if they wish to dictate requirements for AV safety in their market.

The US, with its complex network of local, state and national government regulations will find implementing such an operational safety assessment much more challenging. The federal government's lack of standardized regulations will keep the door open for AV regulation at the state level, but AV providers will not want to go through a different process for every state. As such, in the continued absence of a federal framework, regional coalitions of states with similar requirements may decide to work together to implement such assessments (e.g. western states, southern states, New England etc.).

5

Synthesis

The opportunity for AVs to radically transform transport systems has motivated national, state and city governments to implement policies that promote testing and development in their jurisdictions. Some policies are driven by an existing, nascent AV industry that seeks to capitalize on the strong business case for autonomy. Other policies have been implemented for the express purpose of attracting AV development to a country or region not only for societal benefit, but also for economic benefit in the form of jobs and public visibility, often through close alignment with broader industrial policy, or a high-level vision for the future of mobility. Varied motivations and regulatory contexts have led to a range of policy approaches, none of which has yet become standard practice around the world.

In any AV policy framework, safety considerations should be paramount. While it is in the best interests of the public, governments and AV developers for AVs to be acceptably safe, there are examples in history of when the economic incentives to bring new technologies to market have led to the cutting of corners, which has endangered the public. The

fatal AV accident in Tempe, Arizona, highlights the importance of a strong safety culture within AV companies, as well as the need for independent oversight by competent regulators with suitable technical knowledge to verify that transport systems are safe to use before they are widely deployed.

While no approach to AV validation will guarantee safety in all circumstances, regulators have an opportunity to proactively implement policies that enable safe trials and pilots of AVs, which will maximize the broad benefit of AVs to society while minimizing the risk to the public. Ultimately, trust in AVs will be earned through companies demonstrating good behaviour over time, and regulators should seek to ask AV developers to provide suitable assurances that their technologies are safe as deployment increases. Moreover, now is the time for regulators to develop their knowledge, understanding and competencies in autonomous mobility in order to inform their future policy decision-making in a way that will enable the safe, long-term implementation of AVs around the world.

5.1 Opportunities

“ We’ve finally gotten to a place where we’re comfortable to demand a demonstration of safer than a human driver, not just self-certification.

– City regulator

Approaches to AV regulation lack commonality between markets, and policies currently implemented are frequently intended to serve as temporary guidance to promote innovation. One of the greatest challenges to AV regulators is that there is no widely accepted measure of safety, in part because AV developers are still determining exactly how to measure this themselves. These and other gaps will present long-term challenges to public acceptance of AVs, with citizens likely demanding that AV players undergo independent, external assessment to ensure that AVs are safe to use.

Regulations, where implemented, are generally temporary guidance to enable testing. Even for Singapore, existing regulatory policies are interim solutions to facilitate trials and promote innovation and development. AV developers will likely want to keep light frameworks such as self-certification because these impose minimal effort. However, it is too early to create AV policies that can be considered “final” because the technology is continuing to evolve. Due to the technical complexity and knowledge required, coupled with a preference for minimal regulation by the AV industry, **few governments have successfully created a formal safety assessment for AVs.**

Existing measures of safety, such as disengagement reports, are inadequate safety indicators, but AV developers' varied and constantly iterating approach to AV technology development and testing, as well as the need to protect intellectual property, make establishing one universal metric impracticable at this time. To generate meaningful insights for safety assessments, other metrics or data reporting will be needed for safety assurance as the technology matures and moves towards commercial deployment. Moreover, in the interest of public safety, policies must not create an environment in which AV providers compete on the basis of safety.

There is no clear, objective milestone for when it would be safe to remove a driver. While some markets allow driverless operation, the exact requirements for this critical milestone are ambiguous and poorly defined at present, reflecting the nascent nature of the industry and the reality that AV companies are still in the testing phase of development.

AV companies must not compete on the basis of safety. Safety is a shared goal, not a competition, and regulators should seek to encourage active cooperation with industry for safe development, testing and deployment. This can be done in a number of ways, from funding research to creating test beds and pilot environments.

In future, the public will expect assurance that AVs are safe. As with other forms of transport, citizens will expect some level of oversight to assure them that AVs are safe to use.

Regulators largely lack the technical knowledge to develop technical regulation that evaluates specific elements of AV technology. At best, regulators expect to treat AVs as a "black box" and do not possess the necessary understanding to assess subsystems, such as perception or path planning, separately. Their desire for the technology is motivated by the potential safety, environmental and social benefits of a more efficient transport ecosystem, and many are prioritizing open innovation over safety through hands-off policy tools. While some regulators desire more assurance of safety from AV developers, they may be unsure how to achieve this.

Existing validation efforts have not yet been converted into implementable policy. There are numerous efforts to create scenario libraries, technical standards and validation approaches for AVs. However, translating these into achievable policy is challenging, due to the technical complexity of AVs, the evolving technology landscape and the challenge for regulators to engage on the technical details of a system. **While it may be premature to expect to develop a lasting policy solution for AVs, more can be done to ensure the safety of the public as testing and development continues.**

Local governments want to ensure that their needs will be met, but AV developers will push for standard policy at the market level. An AV that is safe to operate in one city may not be safe in another, and local regulators will desire proof that AV developers have considered regional differences. At the same time, AV developers will not want to go through extensive validation processes for every city in which they wish to operate.

5.2 Addressing the safety gap in AV policy

“ A scenario-based assessment allows for a range of vehicles to be subjected to the same test, which considers AV's behavioural competencies in the context of its environment.

A new policy approach, with a more proactive approach to safety assessment, should address each of the above pain points. Standardizing a new approach across local and national governments could reduce overheads for all stakeholders. Any successful AV policy should minimize burdens on AV developers so they can focus on core technology development while also providing regulators with tools to verify the safety of AV systems without extensive technical knowledge. This approach should also be communicable to the public, because public trust in AVs is critical to long-term AV adoption.

The value of a scenario-based assessment
Every company developing AV technology uses a different development process, hardware/software stack and safety metrics to evaluate system performance. As such, an external assessment to evaluate multiple AV platforms will require a highly abstracted evaluation of a system's behaviour, not the performance of individual components. In simple terms, this means that two different AVs operating on

the same street should be held to the same standard of safety, regardless of the hardware that they use.

Such an assessment should be focused on practical exposure to naturalistic situations because the highly complex nature of on-road driving is impossible to fully account for in a deterministic, rule-based system.

Such an external assessment could be beneficial not only to government regulators responsible for assuring system safety, but also to additional stakeholders such as logistics companies that will likely need to evaluate different AV systems when they choose to implement autonomy at scale. It is likely that AV developers will continue to see safety as a competitive advantage for the foreseeable future, and therefore someone choosing to purchase an AV system will be challenged to objectively choose between multiple options.

A **scenario-based assessment** represents one approach for this independent safety assessment.

“ Collaboration is a building block to safe deployment.

– City regulator

“ A scenario-based assessment is the direction in which we need to head.

– City regulator

A scenario-based assessment would codify the key situations to which an AV system will be exposed in the intended deployment ODD, and systematically evaluate the performance of the AV system in each scenario. This assessment could be conducted through a combination of on-road testing, testing in a controlled environment and simulation, provided that the fidelity of the simulation is also valued as part of the assessment..

An ODD-defined scenario-based assessment allows for a broad range of vehicles to be subjected to the same assessment regardless of their engineering approach, since the assessment is of the AV’s behavioural competencies in the context of its environment. Avoiding diving into the technical design of a system will make it easier for regulators and the public to understand how the validation approach works. In the long run, this transparency has the potential to improve public adoption of AVs, which remains a significant hurdle to full-scale implementation of the technology.

It is true that scenario-based assessments seek to validate *known situations*; however, by using a *graduated milestone*-based approach using all modes of testing – namely, simulation, closed-course and on-road – test assessors can unearth and vastly reduce the risk of unknown situations as well.

How to implement a scenario-based assessment

Following this review, a potential framework to address these gaps could adopt elements of Singapore’s approach in a broader context:

- Designating a technically minded independent body with representation from the public sector, private industry, academia, traffic engineers etc. to develop and administer a safety assurance programme

- Specifying graduated milestones, constraining the ODD until the AV operator is able to demonstrate sufficient maturity to advance. The milestones should reflect increased functionality, as well as the complexity of the environment. Graduated milestones also ensure that the testing and development processes are conducted in a safe manner, as all requirements must be met for a specific milestone/ODD before exposing the public to greater risk. Each milestone’s assessment should combine simulation, controlled test-track scenarios and/or on-road testing to demonstrate competence across a broad range of routine scenarios, high-risk situations and edge cases. Each test type has strengths, weaknesses and limitations that must be considered when specifying an assessment
- Monitoring and reporting the AV’s operation close to its ODD boundaries and excursions from the ODD. This will further necessitate demonstration of safe fall-back systems (capable of transitioning the vehicle to a minimum risk condition or other safe state) in the event of an emergency or ODD excursion. In the early stages of development, this will involve intervention from a safety driver, but other measures such as teleoperation and minimum risk manoeuvres need to be considered at higher milestones
- Demonstrating that the AV platform is *acceptably safe* in the ODD for which the company wishes to deploy it. No AV will be completely risk-free, and AV developers will be unable to prove perfection
- Ongoing data collection during testing and post-deployment to ensure the relevance of the assessment and to address any missed scenarios or accidents that occur after deployment, improving the testing process over time

5.3 Objective of SafeDI framework

The Safe Drive Initiative seeks to establish a high-level framework to enable a regulator to implement an operational safety assessment; the end goal is to facilitate allowing AV companies to operate without a safety driver. The SafeDI framework will provide a synthesis of the core technical knowledge required to understand the validation process, and customize it to the specific jurisdiction by identifying key steps, design choices and policy levers.

This approach makes the following assumptions:

1. A regulator wishes to implement a more rigorous validation approach than self-certification or a code of practice
2. An AV provider has not conducted extensive testing in the deployment ODD within the regulator’s jurisdiction

3. The regulator is the sole party responsible for AV governance in its respective market or country
4. The regulator can assure AV companies that their intellectual property will be protected

While this framework cannot provide a universally prescriptive approach, it will offer high-level guidance that local regulators can use to inform their interactions with AV developers and policy decisions. Regulators will also need to consider the nuances of their political and geographic environments when applying this framework.

In the spirit of its organizational mission to Improve the state of the world, the World Economic Forum will continue to advocate for and encourage AV operators to share knowledge and learnings on AV safety, to benefit the broader industry and the public.

Contributors

The World Economic Forum's Safe Drive Initiative is a global, multistakeholder and cross-disciplinary initiative intended to help shape the development of successful autonomous vehicle policy and improve the safety of AV pilots. The project has engaged leaders from private companies, governments, civil society organizations and academia to understand AV policy, identify challenges and define principles to guide future policy solutions. The opinions expressed herein may not correspond with the opinions of all members and organizations involved in the project.

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Endnotes

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