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IS AI A BETTER DRIVER? A SPECIAL LOOK ON WAYMO ACCIDENT HISTORY WITH THE REGULATORY AND POTENTIAL LIABILITY FRAMEWORKS FOR DRIVERLESS CARS IN MIND

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Abstract
The locus of liability has begun to settle on the manufacturers and designers of autonomous vehicles. It is unsurprising, as driverless cars completely unattended by a human driver are now legally allowed on the road in many states. When a human driver is no longer at the wheel to make mistakes, the fault may rest with the programmers of the vehicle's software. AVs like those used by Cruise or Waymo (Google's robotaxi service) can make any mistake that the humans drivers do, but the robotaxi companies argue, they do so at far smaller rates than humas drove vehicles. AVs are even immune from fatigue, intoxication and the number one cause of traffic accidents: distracted driving. But regardless of their safety compared to human drivers, autonomous vehicles pose a unique issue for someone injured by one. If there is no driver, who is liable? And to what extent is liability affected by the lack of a human driver?
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1. WAYMO'S SAFETY MILESTONE AFTER 50 MILLION AUTONOMOUS MILES

Waymo's autonomous driving system has surpassed an important milestone, having accumulated over 50 million miles in fully autonomous operation. According to a recent report from Ars Technica, these vehicles demonstrate a notably strong safety record, with crash rates significantly lower than those of human drivers (Lee, 2025). This achievement represents a critical benchmark for the long-term viability and public acceptance of self-driving technology.

A significant discovery indicates that over 44 million autonomous miles, Waymo estimates human drivers would have been involved in approximately 190 injury-causing collisions, a markedly higher rate compared to incidents involving Waymo vehicles. Moreover, insurance-claim data reveals that property damage

claims for Waymo vehicles are 88% lower than those for conventional human-driven vehicles (Di Lillo, 2024).

Peer-reviewed research provides robust support for Waymo's safety assertions: an analysis encompassing 56.7 million "rider-only" miles demonstrated a notable decrease in crash rates across multiple categories (Kusano, *et al.,* 2025). Intersection-related crashes, recognized as high-risk, were reduced by 96% for incidents involving any injury and by 91% for those requiring airbag deployment. Other crash types, including collisions with pedestrians, cyclists, motorcycles, or those leading to secondary accidents, also experienced statistically significant declines. Importantly, no crash category reported higher rates for Waymo vehicles relative to human drivers, indicating comprehensive safety improvements.

These results represent a significant advancement in the capabilities of autonomous vehicles. Waymo's performance demonstrates consistent improvements in safety relative to human drivers, even in complex environments such as intersections; Comprehensive validation utilizing both real-world data (including insurance claims) and rigorous statistical analysis; Emphasis on operational design, as Waymo generally restricts autonomous operation to mapped urban areas and favorable conditions. Notably, within these parameters, Waymo consistently surpasses human driver performance, indicating substantial progress towards safer, scalable deployment (Kropka, 2023).

Nonetheless, researchers and policymakers advocate for continued caution. Despite the promising nature of Waymo's results, "edge cases", rare or unpredictable events, remain critical challenges, especially in highly complex or extreme scenarios. Waymo has achieved over 50 million autonomous miles with significantly lower crash rates compared to human drivers, representing a pivotal development in the advancement of autonomous vehicle safety. The consistency observed across various crash types, coupled with rigorous analysis, provides substantial evidence that autonomous vehicles can outperform human drivers in numerous real-world scenarios. Looking ahead, the primary challenge for both industry stakeholders and regulators will be facilitating the integration of autonomous technology into increasingly diverse environments and effectively managing rare but critical edge cases. While Waymo's accomplishment demonstrates considerable promise, addressing these remaining challenges will be essential for fully realizing the long-term potential of autonomous vehicles.

To prepare for the future, this article will try to explain the emergence, development and legal implications of autonomous vehicles in the direction of clarifying the stage of knowledge and the prospects that unfold before us.

2. EMERGENCE AND DEVELOPMENT OF SELF-DRIVING CAR LEGISLATION WORLDWIDE

Autonomous vehicles (AVs), also referred to as self-driving cars, have progressed from conceptual ideas to active areas of technological development and legal consideration. Governments internationally are formulating regulatory frameworks intended to manage innovation alongside issues related to public safety and ethical standards. Initial trials of self-driving technology identified both possible benefits, such as decreasing human error in accidents and improving mobility for individuals unable to drive, as well as challenges involving liability, data governance, and public acceptance. Consequently, the legal context for AVs has changed over the past decade, evolving from local policies to broader national strategies. We will examine the emergence and advancement of self-driving car legislation across different regions. It includes a historical review of early regulatory efforts, assesses current legislative approaches in key regions (including the United States, Europe – with a focus on Germany and the UK – Asia's leaders like China and Japan, and early adopters such as the UAE), considers central legal, ethical, and technical issues, and outlines potential future regulatory developments.

The initial regulatory approaches to self-driving vehicles were characterized by caution and inconsistency, mirroring the experimental phase of technology during the early 2010s. In the United States, regulation was primarily initiated at the state level. Notably, Nevada became the first jurisdiction globally to permit autonomous vehicles on public roads in 2011 (NCSL, 2023).

This significant development, which established a licensing and testing framework for autonomous vehicles (AVs), was soon followed by Florida's 2012 legislation that affirmed its intent to promote the safe advancement and evaluation of AVs, explicitly stating that such testing was not prohibited under existing law (Norton Rose Fulbright, 2016). In subsequent years, numerous states enacted their own statutes or executive orders regarding AVs. By the mid-2010s, many U.S. states had adopted laws pertaining to AV testing or operation, each with varying requirements and definitions. Typically, these initial state laws mandated the presence of a human safety driver, required specific vehicle identification or permits, and addressed preliminary insurance and liability considerations on a trial basis.

This combination of state actions addressed the lack of binding federal regulations: at the federal level, the U.S. Department of Transportation and National Highway Traffic Safety Administration (NHTSA) provided non-binding guidance instead of formal regulations. In 2013, NHTSA released a preliminary policy statement outlining levels of vehicle automation and recommending that states restrict full self-driving operation to testing phases. In 2016, the Obama Administration introduced the first Federal Automated Vehicles Policy, indicating an interest in creating safety assessment standards; however, comprehensive

federal legislation had not been enacted (Norton Rose Fulbright, 2016). As a result, initial U.S. regulatory activity consisted mostly of state-level measures and federal guidelines that supported testing with a human driver as a fallback.

International regulations faced challenges with autonomous vehicles due to the 1968 Vienna Convention, which required a driver to control the vehicle. In March 2016, the UN amended the Convention to permit automated driving systems if they can be overridden by a human or meet UN standards. This change enabled countries to update their laws for driverless technology, and some nations had already started pilot programs under strict controls before the amendment (UNECE, 2016).

In Europe, individual nations began updating national laws and guidelines by the mid-2010s. For example, Germany adopted a proactive stance. The German government released a national strategy on automated driving in 2015, and in June 2017 it amended the German Road Traffic Act to legally permit drivers to cede control to highly or fully automated systems under certain conditions (Gesley, 2021). The 2017 amendment, one of the first of its kind, permitted Level 3 automated driving features on public roads, provided that a human driver could intervene and remained ultimately responsible. In the same year, Germany established an Ethics Commission to examine the moral considerations associated with autonomous vehicle decision-making, demonstrating an early legislative awareness of ethical concerns. For example, legislation aimed to ensure that unavoidable accident scenarios did not involve discrimination based on personal characteristics of potential victims (Gesley, 2021).

The United Kingdom adopted an early approach involving guidance rather than legislative changes. In 2015, the UK government issued a Code of Practice for testing automated vehicles ("The Pathway to Driverless Cars"), which permitted trials on public roads without additional legislation, provided that a safety driver was present and requirements such as roadworthiness and insurance were met (UK Dept. for Transport, 2015). This approach allowed initial pilot projects for automated vehicles in UK cities while postponing the resolution of more complex legal issues. In 2018, the UK enacted the Automated and Electric Vehicles Act 2018, which primarily addressed insurance for automated vehicles by requiring insurers to cover incidents involving a vehicle operating in automated mode, treating the vehicle as the driver for insurance purposes. During this time, other countries such as France, Sweden, and Singapore also granted special permissions for pilot testing, typically through regulatory sandboxes or exemptions within existing traffic laws.

Within the Asia-Pacific region, Japan established itself as a regulatory leader in autonomous vehicle (AV) policy during the late 2010s. Confronted with demographic challenges such as an aging population and driver shortages, Japan identified AV technology as a viable mobility solution. The government consequently prioritized the creation of a legal framework to enable higher levels

of automation in both personal and public transportation. By 2019, amendments to Japan's Road Traffic Act facilitated the limited deployment of Level 3 autonomous vehicles on highways. In 2020, Japan became the first country to officially permit Level 3 self-driving cars – under specified conditions – for production vehicles, leading to Honda's introduction of a Level 3-capable sedan, the Legend, on Japanese roads in 2021. This progressive approach continued in April 2023 with another significant legislative development: a revision to the Road Traffic Act permitting Level 4 autonomous driving on public roads under defined circumstances (ITA, 2023). Initially this Level 4 permission is limited to defined areas and use-cases such as unmanned autonomous shuttle services in sparsely populated towns, reflecting a cautious roll-out. Nevertheless, Japan's legal amendments in 2023 explicitly enable fully self-driving vehicles (without a human driver onboard) in designated zones, making it one of the first countries to legalize Level 4 operation (Japan Road Traffic Act, 2023). These early Japanese regulations also impose requirements such as remote monitoring and emergency override systems for unmanned vehicles, illustrating how early legislation tied technical safeguards to permissions.

China in the 2010s approached autonomous vehicle regulation through government directives and city-led pilot regulations rather than immediate national legislation. The Chinese government identified autonomous and connected vehicles as a strategic emerging industry and issued high-level guidance (e.g. the "Made in China 2025" plan and subsequent innovation strategies). By 2017–2018, China's Ministry of Industry and Information Technology (MIIT) and Ministry of Public Security jointly released national guidelines for intelligent connected vehicle road testing, which set basic conditions for cities to authorize trials (such as requiring a qualified safety driver and test permits). Major cities including Beijing, Shanghai, and Shenzhen established dedicated test zones and licensing schemes for companies like Baidu, Pony.ai, and others. For example, Shanghai opened up an expansive Intelligent Vehicle test area and issued some of the first batch of licenses for unmanned vehicle testing on certain roads. By 2020, over a dozen Chinese cities had published local rules to manage AV pilot projects. These early rules were often promulgated as municipal orders or interim measures, focusing on safety driver qualifications, vehicle equipment requirements, data reporting, and gradual expansion from testing to passenger-carrying pilot service. A notable development in China's early regulatory timeline is the creation of national pilot demonstration zones: by 2023 China had 17 national-level Intelligent Connected Vehicle (ICV) test zones with over 3,200 km of roads designated for AV testing, and more than 700 test licenses issued to companies (Dentons, 2025). This indicates that even without a single blanket law on AVs, China's early approach combined central policy support with local regulatory innovation to facilitate large-scale testing.

Other regions also saw initial steps during the 2010s. In the Middle East, the United Arab Emirates (especially the Emirate of Dubai) declared ambitious goals for AV integration (targeting 25% of trips to be autonomous by 2030) and began issuing regulations for testing. Dubai in 2017 and 2019 released guidelines for AV trials, and Executive Council Resolution No. 3 of 2019 set out safety requirements for testing autonomous cars on Dubai's roads – always including mandatory police supervision during tests and the presence of a human safety driver (Sadek, 2021). By 2020, Dubai had established a process for companies to apply to the Roads and Transport Authority (RTA) for AV testing permits and had partnered with industry (notably an agreement with the U.S. company Cruise to deploy autonomous taxis) to accelerate adoption (Sadek, 2021). Similarly, Singapore issued its first AV test permits in 2015 and passed an amendment to its Road Traffic Act in 2017 to allow the transport minister to exempt autonomous vehicle trials from certain rules, thereby legalizing on-road pilots. Australia and Canada also launched consultations and trial regulations around 2016–2018 at state/provincial levels. These early global efforts shared a common thread: they were mostly focused on enabling testing and research, often through temporary measures, and universally required a human supervisor (either inside the vehicle or remotely) during any automated driving trials.

In summary, the development of self-driving car legislation evolved incrementally. Early regulatory strategies worldwide were marked by prudence and experimentation, employing special permits, executive orders, and targeted legal adjustments to facilitate the testing of autonomous vehicles on public roads. Between approximately 2010 and 2016, the focus was placed on data collection and demonstrating safety through controlled trials, rather than establishing comprehensive legal frameworks for consumer deployment. However, by the late 2010s, insights from numerous pilot programs, alongside emerging concerns regarding safety, liability, and standardization, prompted the transition toward more robust and comprehensive legislative measures in subsequent phases.

3. THE PRESENT GLOBAL STATE OF AUTONOMOUS VEHICLE LEGISLATION

As of 2025, the regulatory landscape for autonomous vehicles is markedly more robust and structured than a decade prior. Many countries and regions have progressed from tentative pilots to formal laws or regulations governing the deployment of self-driving cars. However, approaches still vary widely, reflecting different legal systems, traffic conditions, and policy priorities.

In the United States, the regulatory framework for autonomous vehicles is characterized by a constellation of state statutes, underpinned by federal oversight. As of 2025, there is no comprehensive national legislation directly addressing the operation of autonomous vehicles; federal law has yet to establish an overarching Autonomous Vehicle Act. Federal initiatives have instead centered on modifying

vehicle safety standards and issuing voluntary guidelines. Legislative efforts in Congress, such as the SELF DRIVE Act and AV START Act (circa 2017–2018), did not advance due to ongoing debates concerning safety protocols and liability frameworks. In this legislative vacuum, the U.S. Department of Transportation (DOT) and the National Highway Traffic Safety Administration (NHTSA) have introduced incremental reforms. Notably, in 2022, NHTSA revised select Federal Motor Vehicle Safety Standards to permit vehicles lacking traditional controls – such as steering wheels or pedals – thus facilitating the deployment of fully driverless vehicles that need not comply with requirements designed for human-operated vehicles (Reuters, 2022). Additionally, NHTSA has exercised its authority to grant exemptions for limited deployments of experimental vehicles without conventional features, exemplified by approvals granted to GM's Cruise and Nuro for small fleets of autonomous shuttles. Federal agencies have also published successive guidance documents – AV Policy 2.0: A Vision for Safety (2017), AV 3.0 (2018), and AV 4.0 (2020) – which articulate best practices and cross-modal integration strategies. While these policy statements lack binding force, they convey federal expectations on critical matters such as safety assessment, cybersecurity, and data management. For instance, DOT guidance recommends manufacturers submit a voluntary safety self-assessment addressing twelve key safety domains, including object recognition and fallback performance, and reaffirms the applicability of existing federal safety standards and state traffic laws absent AV-specific federal legislation. The prevailing federal approach remains permissive and industry-oriented, enabling autonomous vehicle testing and deployment within existing regulatory structures, supplemented by case-specific exemptions and reactive enforcement measures when necessary. This absence of uniform federal regulation has shifted significant responsibility to individual states, resulting in operational uncertainties for interstate vehicle deployment, but has concurrently afforded the industry considerable latitude to innovate within receptive legal environments.

State legislation in the U.S. is the primary source of rules for self-driving car operations. As of 2025, most states have addressed autonomous vehicles in some form – either through statutes or gubernatorial executive orders. The scope of these state laws varies. Many states now explicitly authorize fully driverless operation (i.e. a vehicle with no human onboard) under certain conditions. For example, California – which hosts extensive AV testing – established a detailed regulatory process through its Department of Motor Vehicles: companies must obtain a testing permit (with a safety driver) and, separately, a permit for driverless testing and another for deployment for commercial service. California's rules mandate annual public reports of any disengagements (incidents where the human driver had to take over) and any crashes, providing a level of transparency. In contrast, states like Arizona took a very business-friendly approach: via executive order and legislation, Arizona allowed driverless testing and operations with

relatively fewer procedural hurdles, which attracted companies like Waymo to launch early robotaxi services in Phoenix. States such as Florida and Texas have passed laws explicitly allowing autonomous vehicles to operate without a human driver or even without a human occupant, as long as certain insurance and safety requirements are met. For instance, Florida's 2019 law removed the requirement that a licensed driver be present in the vehicle, making it legal for a car to drive itself with no person inside on Florida roads (Farah and Farah, 2023). By 2022–2023, new states continued to join the trend: the National Conference of State Legislatures notes that 29 states have enacted legislation related to AVs (as of early 2023), and several others have active executive orders (NCSL, 2023). Common elements in state laws include: definitions of "automated driving system" and levels of driving automation (often referencing the SAE Level 0–5 taxonomy), requirements for an AV to comply with traffic laws and safely stop if it fails, mandatory insurance or surety bonds, and designation of the automated driving system as the "driver" for purposes of traffic law when it is engaged. Liability rules are beginning to be addressed as well: some states (e.g. Illinois, Tennessee) clarify that the original manufacturer is not liable for after-market automated driving systems installed by third parties, whereas others assert product liability theories can apply to software failures. There is also growing attention to trucking: states like Texas have authorized autonomous trucks to operate on highways without a human, spurring pilot projects in freight transport.

The U.S. has a complex but generally permissive legal landscape for autonomous vehicles, allowing companies to test and operate ride-hailing AVs under various state regulations. While efforts are underway to coordinate rules, crossing state lines can mean navigating differing laws. The U.S. leads in real-world AV deployment due to supportive policies in some states, with fully autonomous robotaxis operating in cities like San Francisco and Phoenix as of 2025.

Germany has established itself as a pioneer in autonomous vehicle legislation within Europe, while working in tandem with evolving European Union regulations. German law not only permits advanced levels of vehicle automation but also frames specific requirements for their safe operation, influenced by ethical considerations and technical standards. Meanwhile, the EU has been developing a harmonized framework to ensure uniform safety across member states, particularly through type-approval regulations and United Nations Economic Commission for Europe (UNECE) standards. Germany's 2017 amendment to the Road Traffic Act, mentioned earlier, was an initial step that allowed Level 3 automated driving features (highly automated, but with a human fallback). Building on that, Germany enacted a groundbreaking Autonomous Driving Act in July 2021, which made it the first country to broadly legalize Level 4 autonomous vehicles in defined public traffic areas. Under this law, vehicles with "autonomous driving capabilities" (SAE Level 4) are permitted on public

roads nationwide, without a human driver on board, so long as they operate within an approved defined operating area (Gesley, 2021). These operating areas are specific zones or routes approved by local authorities – for example, a city might approve an autonomous shuttle service on a particular bus route or a logistics company might get approval for driverless forklifts on set paths. A critical aspect of the German approach is the requirement of a technical supervisor: even when no human is in the vehicle, a remote human operator must be designated who can monitor the vehicle and intervene or deactivate it if necessary (Gesley, 2021). The law also imposed robust safety and cybersecurity requirements. Vehicles must have an "accident-avoidance system" that prioritizes protection of human life and never makes choices based on personal attributes like age or gender – a direct incorporation of the Ethics Commission's guidelines into law (Gesley, 2021). Additionally, a form of "black box" data recorder is mandated: the vehicle must log detailed operational data (e.g. sensor inputs, control actions, incidents) to aid in accident investigations and continuous safety evaluation. Another element is compulsory insurance covering the autonomous operation and the technical supervisor's liability (Gesley, 2021). Taken together, Germany's 2021 law provides one of the most comprehensive legal frameworks for AVs in the world, covering definitions, technical standards, oversight mechanisms, and liability. It has enabled pilot deployments such as driverless shuttle buses ("people movers") on certain city routes and autonomous parking systems in Stuttgart's airport garage – all under strict regulatory approval and supervision.

As an EU member, national regulations on vehicles must align with EU rules, especially regarding vehicle safety certification. The EU's approach has centered on updating type-approval regulations and endorsing international (UNECE) standards that facilitate automated driving. A major development was the revised EU General Safety Regulation (EU) 2019/2144, which took effect in July 2022. This regulation not only made a suite of advanced driver-assistance systems mandatory in new cars (such as intelligent speed assistance, lane-keeping, event data recorders, and driver monitoring), but also explicitly created a legal framework to approve "fully automated vehicles" in the EU (European Commission, 2019).

Pursuant to this, the European Commission in 2022 adopted technical implementing rules for Level 4 vehicles – the first such regional regulations globally. These rules allow for EU type-approval of fully driverless vehicles (like robotaxis or automated shuttles) in limited numbers (initially under a small-series type approval scheme). They set stringent requirements for safety validation, including comprehensive test procedures, cybersecurity measures, software update compliance, data recording of incidents, and oversight of manufacturers' safety management practices. In essence, an automaker or operator can now seek approval to sell or deploy a Level 4 vehicle across EU countries, provided it meets these new standards – a significant step toward scaling AV deployment beyond

isolated pilots. For Level 3 automation (where the car drives itself under certain conditions, but a human might need to take over upon request), the EU has aligned with UNECE regulations, specifically UNECE Regulation No. 157 on Automated Lane Keeping Systems. UNECE R157 was initially limited to low-speed (up to 60 km/h) traffic jam scenarios but was updated in 2022 to allow operation up to 130 km/h with more stringent safety requirements (Mercedes-Benz notably used this to offer a Level 3 "Drive Pilot" system in Germany). The EU automatically incorporates such UNECE regs, enabling vehicles with approved ALKS systems to be sold across member statessingle-market-economy.ec.europa.eu. Thus, a German or French consumer can buy a car with a certified Level 3 system and legally use it on highways because the underlying international regulation has been agreed and adopted.

Following its departure from the EU, the United Kingdom has enacted a comprehensive law governing autonomous vehicles. Initially, the UK issued limited reforms like the 2015 Code of Practice for AV testing and the 2018 Automated & Electric Vehicles Act focused on insurance and definitions. To create a broader regulatory framework, the government commissioned a review (2018–2021) by the Law Commissions, resulting in a January 2022 report that recommended an entirely new system to address automation across vehicle approval, legal responsibilities, and insurance.

The Law Commissions proposed a legal distinction between "driver assistance" and "self-driving" features, holding that once a vehicle is classed as self-driving (requiring no human monitoring), responsibility shifts from the human user to new entities like manufacturers or operators. They defined roles such as the "User-in-Charge" – a person present to take over when prompted – and "No-User-in-Charge" vehicles, which are fully autonomous. An "Authorized Self-Driving Entity," typically the manufacturer or software provider, would be legally accountable for the vehicle's actions during automated operation, with safety assured both at approval and through ongoing monitoring. These proposals have been enacted in the Automated Vehicles Act 2024.

The Automated Vehicles Act 2024, which received Royal Assent on 20 May 2024, establishes the core of the UK's AV legal framework (Gupta, 2023). Under this Act, it is lawful for an "authorized automated vehicle" to drive itself on public roads in Great Britain without a human driver in control – a radical departure from previous law, which always assumed a human driver. To achieve authorization, a vehicle must pass a specified self-driving test that evaluates whether it can drive autonomously, safely, and legally in each operational design domain. In essence, the vehicle must demonstrate that it is at least as safe as a competent human driver in that environment and complies with traffic rules to an acceptable degree. The Act empowers the Secretary of State for Transport to set safety performance criteria (a "Statement of Safety Principles") that guide this assessment.

The UK Act formalizes the roles of User-in-Charge (UiC) and No-User-in-Charge (NUiC) features. If a vehicle's autonomous feature requires a fallback user (UiC), that person is not criminally liable for the vehicle's motions while automated but must take over when alerted (akin to Level 3 scenarios). If the feature is NUiC, the vehicle can operate with no person on board or no active driver at all (Yaros et al., 2024mayerbrown.commayerbrown.com). The Act creates the concept of an Authorized Self-Driving Entity (ASDE) – typically the company that puts the vehicle on the market – which is responsible for the vehicle's behavior in self-driving mode and can be held liable for failures (UK Government, 2025gov.ukgov.uk). For vehicles with no user in charge, a licensed NUiC Operator must oversee the journey (perhaps remotely), handling non-driving duties like maintenance and incident response (UK Government, 2025gov.uk). These operators and entities will be subject to regulatory approval and ongoing requirements, ensuring they have the necessary integrity, financial stability, and monitoring capabilities.

In terms of liability and insurance, the UK's approach continues to ensure that victims are covered by insurance regardless of whether a human or an automated system was driving. The 2018 Act's insurance provisions remain, but now the manufacturer/operator accountability is strengthened: if a crash occurs due to the automated driving system, the insurer can in turn recover costs from the ASDE if the vehicle was defective or misrepresented safety. The Act also includes provisions to prevent misleading marketing of vehicles as "self-driving" before they are truly authorized as such – addressing concerns that overzealous marketing could lead to unsafe use of driver-assist systems by consumers.

China's regulatory framework for self-driving vehicles involves government oversight, the development of pilot zones, and the introduction of national-level guidelines. Instead of enacting a single law through the national legislature, China has implemented administrative regulations and policies that allow for local trials, which may later be expanded. As technology develops, these measures are evolving into more standardized regulations and laws.

In recent years, China has selected key cities for AV testing and deployment. Beijing launched its first comprehensive AV test zone in 2018, progressing to fully driverless tests in select suburbs by 2022 with operators like Baidu's Apollo Go. Shanghai issued 2021 regulations enabling not just testing but early commercial pilot services in Pudong, and in 2023 passed rules requiring permits for robotaxis and freight vehicles, legally allowing driverless passenger transport in specific areas. Shenzhen enacted a 2022 law defining automation levels and permitting L4 vehicles on public roads under license, assigning liability to the vehicle owner or operator in fully autonomous mode. These local laws position automated driving systems as new legal subjects.

Since 2020, China's central ministries have developed regulations for intelligent connected vehicles (ICVs). The Ministry of Public Security issued road

testing guidelines, while the State Council's roadmap targets large-scale autonomous car production by 2035 and a regulatory system by 2025. By 2023, over 30 industry standards addressed issues like vehicle cybersecurity and communication protocols, guiding manufacturers and local governments on safety. At the end of 2021, the Ministry of Industry and Information Technology released draft rules for smart car data security and software updates, requiring automakers and AV operators to safeguard user privacy and national security, especially in response to concerns over mapping data. By linking data regulations to autonomous vehicle deployment, China maintains oversight of data flows and aims to prevent misuse as vehicles become more autonomous.

China has rapidly expanded autonomous vehicle (AV) services, with pilot driverless robotaxi operations in at least seven cities by 2023, including Beijing, Shenzhen, Wuhan, and Chongqing (Dentons, 2024). For instance, Baidu and Pony.ai were the first to receive permits for paid, fully driverless robotaxis in Beijing, while autonomous buses are also running in cities like Guangzhou and Suzhou. Major tech companies, such as JD.com and Meituan, have introduced driverless delivery carts for last-mile logistics (Dentons, 2024). These initiatives rely on local approvals supported by national policies. A draft law to unify AV regulation was under review in 2022 to clarify testing, liability, and market entry rules. In early 2023, the government released new policies encouraging commercialization and streamlined approvals for AVs. By mid-2023, Chinese AV test vehicles had driven tens of millions of kilometers. China’s approach remains “centrally coordinated, locally implemented,” accelerating AV development under strong regulatory oversight and minimal public resistance.

Japan’s current autonomous vehicle legislation builds upon the early initiatives described previously, placing the country among the leaders in legalizing higher levels of vehicle autonomy. Japanese regulators have focused on incremental expansion of permitted automation levels, tied to specific use cases like highway driving and low-speed community transport, all under a strict safety regime.

A fundamental aspect of Japan’s regulatory strategy is the explicit incorporation of SAE automation levels into legal frameworks. In 2019, amendments to the Road Traffic Act and Road Transport Vehicle Act introduced definitions for “automated driving equipment” and formally legalized Level 3 conditional automation on expressways. As a result, Level 3 (conditional automation) became operational on Japanese highways in 2020, following the enactment of these legislative changes. Under this structure, drivers are permitted to allow vehicles to operate autonomously in specific situations – such as highway traffic congestion – without the obligation to monitor the driving environment during those periods. However, drivers must remain prepared to resume control upon system request.

Japan achieved a global milestone in 2021 by granting the first government certification of a Level 3 automated system for consumer vehicles: the Honda Legend equipped with "Traffic Jam Pilot," an automated driving system designed for congested highway traffic, received type-approval for commercial sale with this functionality. Regulatory requirements stipulate that all Level 3 vehicles be equipped with data recording devices to document usage of automated mode and any control handover prompts. Additionally, operation is confined to clearly defined scenarios, such as specified speeds and designated road segments. Drivers utilizing Level 3 systems must comply with established usage regulations. For example, while activities such as sleeping or vacating the driver's seat are prohibited, tasks like watching a video are permitted when the system is actively controlling the vehicle – activities ordinarily forbidden during manual driving. This comprehensive regulatory approach has positioned Japan as the first nation to legally enable drivers to disengage from active driving responsibilities within restricted settings, underpinned by clear legal protections.

Japan legalized Level 4 autonomous vehicles in specific settings with an April 2023 Road Traffic Act revision, allowing driverless shuttles on fixed rural routes under strict safety rules and special permissions. The first approval went to an autonomous shuttle in Eiheiji, Fukui Prefecture, which operates without human drivers or attendants. These vehicles must comply with MLIT's high safety standards, including system redundancy and remote monitoring, and their use is limited to controlled, fixed-route services – private cars aren't yet permitted Level 4 autonomy. Vehicle certification laws, such as the Road Transport Vehicle Act, have been updated to allow advanced driving features, aligning with UNECE regulations. Japan has also established technical guidelines for AV safety and security through METI. To promote public acceptance, Japan supports large-scale AV trials, like the "Road to the L4" project, conducting demonstrations in over 40 locations and aiming for 50 by 2025. These efforts, supported by special government permissions and targeted infrastructure adaptations, are part of a broader strategy to integrate autonomous vehicles into society.

The United Arab Emirates (UAE) has taken steps to develop regulations for autonomous vehicles (AVs), aiming to advance technological capabilities and enhance transportation services. While the UAE's road traffic laws are primarily federal, individual emirates like Dubai have led local regulatory efforts for AV deployment. Abu Dhabi and other emirates are also conducting trials, supported by federal standards initiatives. Dubai's regulatory framework includes the Autonomous Transportation Strategy announced in 2016, which set a target for 25% of trips to be made using self-driving modes by 2030. The government introduced several regulations to support this objective. Executive Council Resolution No. 3 of 2019 established requirements for AV testing in Dubai, including collaboration with police and the implementation of specific safety protocols (Sadek, 2021). This was followed by Administrative Decree No. 501 of

2020 by the RTA, which specifies application procedures for companies interested in conducting AV tests (Sadek, 2021). Entities seeking to test AVs must submit technical documentation, provide proof of insurance, and have each test vehicle inspected and approved by RTA officials. A human safety driver at least 25 years old with a valid UAE driver's license is required to be present during all tests (Sadek, 2021). For operational use beyond testing, Dubai implemented Law No. 9 of 2023, which regulates the operation of autonomous vehicles within the emirate. This legislation establishes legal grounds for the commercial deployment of AVs, setting out procedures for certification of vehicles and operators by the RTA (The National News, 2023). The law authorizes the RTA to define technical standards, issue operator licenses, and determine operating zones and conditions. Autonomous vehicles must be registered and display a special plate or marking. Regarding liability, if a vehicle is operating autonomously, responsibility for traffic violations or accidents lies with the permitted operator. Operators are required to maintain adequate insurance and may need to equip vehicles with data recorders, as outlined in subsequent RTA resolutions. Through Law 9/2023, Dubai is among the first jurisdictions in the Middle East to enact specific legislation for self-driving vehicle operations. As of late 2023, a limited pilot project involving Cruise autonomous taxis (without human drivers) was underway in Dubai's Jumeirah area, with future plans for expansion.

In Canada, the regulation of autonomous vehicles primarily falls within provincial jurisdiction. For instance, Ontario has implemented an AV testing program since 2016, utilizing a pilot permit system, and expanded its framework in 2019 to enable driverless testing – without a human operator in the vehicle, subject to stringent requirements. At the federal level, guidance for safe AV testing was issued in 2022, with ongoing efforts to modernize motor vehicle standards to align with UNECE regulations (Canada, Transport Canada AV Guidelines, 2021). Canada's regulatory model closely parallels that of the United States, seeking to foster provincial innovation while maintaining robust federal safety oversight.

Several Australian states have conducted automated shuttle bus trials in cities such as Perth and Adelaide. The National Transport Commission has established guidelines, and in 2020 proposed a national law to support the commercial deployment of automated vehicles. Australia is developing an Automated Vehicle Safety Law, which would establish a dedicated AV regulator and approval process, with implementation anticipated by 2026.

Singapore has introduced various autonomous vehicle (AV) initiatives over recent years. The Autonomous Vehicles Act 2022 consolidates existing regulations and introduces a licensing framework for AV operators, enabling driverless buses and robo-taxis to operate within designated areas. This legislation covers operator responsibilities, passenger safety requirements, and penalties for misuse of AVs.

South Korea enhanced its legal framework through the Autonomous Vehicle Act 2020, which established designated zones for testing and introduced a certification system for vehicles at Level 3 autonomy and above. In 2022, the government initiated a commercial self-driving taxi pilot in Seoul's Sangam district under a regulatory sandbox. Additionally, Korea continues to make substantial investments in smart road infrastructure, with legislation supporting the deployment of vehicle-to-everything (V2X) communication as a core component of autonomous vehicle integration.

Israel has emerged as a center for autonomous vehicle technology and enacted the Autonomous Vehicles (Trial) Law in 2019 to permit extensive public road testing. The government is currently considering additional legislation to enable commercialization, driven in part by innovative companies such as Mobileye (an Intel subsidiary), which are advancing autonomous ride-hailing pilots in Tel Aviv.

While each nation tailors its legal framework to suit local circumstances, a prevailing pattern emerges: an incremental approach to deployment, beginning with pilot testing, proceeding to restricted use, and eventually expanding as confidence in the technology grows, and adaptive legislation, which typically starts with provisional or experimental regulatory measures before transitioning to permanent statutes once the technology is sufficiently advanced. Additionally, international cooperation is becoming more prominent, exemplified by organizations such as UNECE's Working Party 29 on vehicle standards and Working Party 1 on road traffic rules. These forums facilitate harmonization of definitions and safety standards, even though specific legal frameworks may vary between jurisdictions.

4. LEGAL, ETHICAL, AND TECHNICAL ISSUES

Legislation regarding autonomous vehicles has advanced, but regulators and stakeholders continue to encounter several challenges. These include legal uncertainties, ethical considerations in machine decision-making, and technical issues related to safety and reliability.

Assigning responsibility in the event of an autonomous vehicle (AV) crash poses complex legal questions. Traditional traffic laws attribute accidents primarily to human driver negligence or, in some cases, mechanical failure by manufacturers. However, AVs complicate this framework, as the "driver" may be an algorithm. Regulatory responses vary internationally: for example, under the UK's 2018 legislation and Singapore's recent framework, insurers are initially liable when a self-driving vehicle is involved in an incident; insurers can later seek recourse from manufacturers or software providers if technological faults are identified. This approach aims to ensure timely compensation for victims but does not conclusively resolve questions about fault allocation between human users and vehicle makers. In Germany, for Level 3 automation, the law maintains the human

driver's liability, requiring intervention when prompted, whereas Level 4 shifts responsibility to the operator or vehicle keeper, mandating insurance coverage for autonomous operation.

In the United States, where there is no overarching federal law, courts and state statutes address liability, including product liability claims against AV companies concerning system failures. These cases examine whether an AV is "defective" or whether incidents resulted from unavoidable scenarios, with legal standards on what constitutes sufficient safety still under discussion, specifically, whether AVs should perform at the level of a reasonable human driver or achieve the highest possible technological safety. Liability apportionment is another point of consideration, especially for vehicles requiring human supervision (Level 2/3), where accidents may result from either user inattention or system design. Some jurisdictions, such as New York, require that drivers maintain hands on the wheel during partial automation, upholding the legal premise of human control. Insurance models are adapting accordingly, with new policies for AV fleets being developed and expanded mandatory coverage requirements introduced in countries like the UK and Germany, including protection against events such as hacking. Regulators are working to update insurance frameworks to remain effective and equitable in the context of AV adoption, possibly necessitating data sharing from vehicles to facilitate accident investigations (Kubica, 2022).

The regulation of autonomous vehicles (AVs) represents one of the most complex and multifaceted legal challenges of contemporary mobility governance. This essay examines the evolving global legislative landscape surrounding AV deployment, highlighting key legal, ethical, and policy issues. A central difficulty is definitional inconsistency across jurisdictions. Terms such as “autonomous,” “self-driving,” and “automated driving system” are not uniformly defined, and reliance on SAE levels (0–5) often leads to misinterpretation. Misleading marketing of partially automated systems as “self-driving” has already prompted legislative countermeasures, such as the United Kingdom’s restrictions on the use of autonomy-related claims. Harmonization remains essential, particularly in cross-border contexts like the European Union, where mutual recognition of vehicle approvals and driving permits is under development but not yet resolved.

Another major area of concern is data governance. AVs generate and process vast amounts of sensor, location, and environmental data, raising significant privacy challenges under strict regimes such as the EU’s General Data Protection Regulation (GDPR). Laws in countries such as Germany and the UAE attempt to balance road safety with personal data protection by limiting collection and regulating law enforcement access. Closely linked is cybersecurity, as AVs constitute connected digital platforms vulnerable to malicious attacks. Regulatory frameworks such as UNECE Regulations R155 and R156 now mandate cybersecurity management systems and secure software update protocols, shifting vehicle compliance from a one-time approval model to continuous oversight.

Liability for cyber incidents remains unresolved, particularly regarding whether manufacturers or third-party actors bear responsibility (NCSL, 2020).

An important topic is the integration of AVs into existing traffic systems. Mixed traffic conditions expose tensions between AVs' rule-abiding behavior and human drivers' less predictable conduct, with incidents of "bullying" AVs already observed. Legislators are adapting rules for platooning, right-of-way, and vehicle-to-infrastructure (V2I) communications, while cities explore new planning measures to accommodate robotaxi fleets. Enforcement of AV laws introduces novel challenges, as police and regulators must interact with vehicles lacking drivers. Some jurisdictions mandate remote disablement functions, though these create security risks. The UK's forthcoming "in-use regulator" represents a pioneering model of continuous safety assurance, including audits, testing, and the ability to revoke approvals.

Safety standards and testing methods remain unsettled. While traditional vehicle regulation assessed passive crashworthiness, AV approval requires evaluating AI driving competence through scenario testing, simulations, and frameworks such as ISO 26262, ISO 21448, and the EU's NATM. Defining acceptable levels of risk – whether AVs must merely match or exceed human safety performance – remains debated. Additional complexities arise from continuous software updates, which may alter vehicle functionality post-sale, requiring new regulatory oversight mechanisms.

Finally, the ethical and societal dimensions raise the questions of crash decision-making, social equity, accessibility, and employment displacement highlight the broader impacts of AV adoption. Bias in detection algorithms, privacy implications, and misleading consumer communication further complicate policymaking. Ethics commissions in countries such as Germany and France have influenced legal frameworks, yet global consensus is lacking. Public trust emerges as a decisive factor in AV adoption, shaped by transparent regulation, clear liability rules, and safeguards against misinformation.

Overall, the AV regulation requires unprecedented legal innovation, blending traditional type approval with continuous oversight, integrating data protection with cybersecurity, and embedding ethical considerations into technical standards. Achieving harmonization across jurisdictions while preserving public trust will be crucial for the safe and equitable global deployment of autonomous vehicles.

5. CONCLUSION

This article examines the global evolution of self-driving car legislation, tracing the trajectory from early experimental initiatives in the 2010s to the sophisticated frameworks now taking shape in major jurisdictions. It highlights how pioneering regions such as Nevada, Germany, and Japan established initial precedents, from authorizing on-road testing to formally recognizing Level 4 automation. Subsequent developments, including amendments to the Vienna

Convention and the UK's 2024 regulatory framework, underscore an emerging international consensus while revealing persistent differences in national approaches. The United States has pursued a decentralized, innovation-led model, Europe has emphasized centralized safety certification, and Asian countries display contrasting strategies, with Japan progressing gradually and China advancing through rapid pilot programs. The UAE and other emerging markets are also accelerating reforms to attract investment and modernize transport systems.

Key challenges addressed by legislation include liability, safety validation, cybersecurity, and data protection. Jurisdictions are exploring diverse liability models ranging from manufacturer responsibility to hybrid insurance schemes, while technical standards are evolving beyond traditional safety benchmarks to include AI-driven testing and continuous oversight. Ethical considerations remain central, particularly regarding fairness, equity, and the prioritization of human life in unavoidable crash scenarios. At the same time, public trust and transparent governance are recognized as prerequisites for widespread deployment.

Looking ahead, the article anticipates a decade of adaptive policy development and regulatory harmonization, shaped by technological progress, international cooperation, and societal values. Innovative governance tools, such as citizen panels, ethics boards, and sandboxing provisions, may enhance responsiveness and legitimacy. The scope of regulation is also expected to expand to autonomous trucks, drones, and other vehicles, requiring either unified or harmonized legal frameworks for integrated mobility systems. Ultimately, successful legislation will balance innovation with accountability, enabling safe, equitable, and future-ready transport ecosystems.

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