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Paving the Way for Autonomous Vehicles—the Future of Mobility Is Here

Mario Loyola

It is imperative that the United States maintain its technological edge in the autonomous vehicle (AV) sector. Legislators and regulators must continue to pursue policies that pave the way for the safe and efficient deployment and commercialization of AV technology. Other countries, both friends and foes, are adopting future-focused approaches, and the U.S. is starting to fall behind. America must move quickly to develop and implement a regulatory framework that allows great innovations to be developed the American way—through a decentralized economy that protects the privacy and safety of all citizens.

On April 24, 2025, Secretary of Transportation Sean Duffy announced a new Automated Vehicle Framework as part of the Department's Innovation Agenda, saying, "American is in the middle of an innovation race with China, and the stakes couldn't be higher."[1] The Department's announcements—streamlining reporting requirements, facilitating research and protype testing, and clearing the way for rapid commercialization of AV technologies,—signals a renewed commitment to winning the innovation race in autonomous vehicles (AVs). And as Secretary Duffy said, the stakes couldn't be higher.

Fully autonomous vehicles (AVs) promise to transform everyday life for the better, liberating Americans to spend more time on productive work and leisure activities through a transportation mode that will almost certainly be much safer than the manually driven cars of today.

If America is able to lead the AV revolution in the decades ahead, the implications for America's standing in the world will be immense. Just as Ford's Model T helped to make America the world's superpower in the 20th century, so can AVs help to maintain that status in the 21st century.

But America's ability to lead the AV revolution faces significant challenges. The policy innovation at the Department of Transportation during President Donald Trump's first term stopped under President Joe Biden, as the Biden Administration sought to accommodate powerful anti-innovation pressures from key political constituencies. The disjointed regulatory framework that has evolved as a result does not reflect sound policy and is not favorable to innovation. China is advancing much faster than the U.S. in its development of a transportation policy framework that is favorable to AVs.

As in other areas, America needs to embrace a regulatory framework that prioritizes freedom, privacy, and safety, while facilitating investment, innovation, and competition.

The data collection and transmission entailed in AVs pose a considerable risk to privacy that must be addressed by robust privacy protections. AVs also pose risks to traditional models of car ownership that must be addressed by protecting the right to own and operate manual vehicles. As a classic disruptive innovation, AVs are sure to bring enormous social benefits in the aggregate—and are also likely to entail concentrated losses for specific groups, such as workers who may be displaced by innovation. Such groups could benefit greatly from innovative ways of supporting their transition to new business models and modes of employment.

Most emerging technologies are accompanied by a drive toward centralization to increase efficiencies, solidify market leadership, and mitigate risks. It is important to preserve, in the AV sector, the decentralized and permissionless innovation ecosystem that has helped to make America the global leader in high technology for decades. Decentralizing policies should be an overriding priority, from ensuring continued low barriers to entry to protecting the right to manually drive and repair one's vehicle, whether personally or through mechanics unaffiliated with the manufacturers.

The right regulatory framework will encourage innovation by helping to foster a national market for the development of economies of scale within a competitive ecosystem that remains favorable for start-ups and elevates consumer choice.

Automated Vehicles: What Are They?

The Society of Automotive Engineers (SAE) has established a comprehensive framework for classifying vehicle automation.[2] This widely adopted classification system delineates the progressive capabilities of automated driving technologies and the extent to which human control is needed. It outlines six levels of automation.

- **Level 0: No Automation.** This is the conventional vehicle of more than a century. The human driver is fully responsible for all driving tasks. The vehicle may have features like basic cruise control and forward collision warnings that provide momentary assistance, but no sustained control.

- **Level 1: Driver Assistance.** In Level 1, vehicles can assist with either steering or acceleration and deceleration, but not both simultaneously. Technologies such as adaptive cruise control and lane-keeping assistance exemplify this level, where the driver must remain engaged and monitor the driving environment continuously.

- **Level 2: Partial Driving Automation.** Level 2 automation allows the vehicle to control both steering and acceleration and deceleration under certain conditions. Drivers, however, must stay attentive and be prepared to take over at any moment. Examples include Tesla's Autopilot and the General Motors Super Cruise, which offer advanced driving assistance on highways.

- **Level 3: Conditional Driving Automation.** Vehicles at Level 3 can handle all driving tasks within specific conditions but require the human driver to intervene upon request. It is the lowest level of what most people would consider real automation. The system actively monitors the environment and manages tasks like lane changes and speed adjustments. Audi's Traffic Jam Pilot is one example, designed for use in limited scenarios such as congested highway traffic. Tesla's Full Self-Driving (FSD) feature is certified as Level 3 in a few cities. One variant of Level 3 that may become prominent is the use of a Level 3 vehicle for data gathering both on roads and conditions and how humans respond to them when taking over on the autonomous driving system's request.

- **Level 4: High Driving Automation.** This is where true automation of driving functions begins. Level 4 vehicles can operate entirely autonomously without human intervention in defined areas (geofenced zones) or conditions. (Depending on the vehicle's design, a human driver may still take over driving functions.) An AV that can travel on most roads but not in all driving conditions may also be considered Level 4. Autonomous trucks operating on defined routes[3] and autonomous shuttles operating in specific urban or campus areas fall into this category. Examples of Level 4 vehicles already in operation include Waymo taxis in Austin, Los Angeles, Phoenix, and San Francisco[4] and Nuro delivery services in Mountain View, California, Palo Alto, California, and Houston.[5] Uber, Lyft, Zoox (owned by Amazon), and Tesla are planning to launch new robotaxi services in the U.S. in 2025.[6] These offerings will all be Level 4 autonomous.

- **Level 5: Full Driving Automation.** Level 5 vehicles are capable of performing all driving tasks under any conditions that a human driver could handle, with no need for human intervention. These vehicles will not need traditional controls like steering wheels or pedals, as seen in some futuristic concept cars. A Level 5 autonomous vehicle is theorized essentially as a robot vehicle that would not need to be connected to a network or to any human control. Level 5 is not expected to be available for at least another decade.[7]

Though the term "autonomous vehicle" is often used loosely to refer to any level of automation, in this *Special Report* the term refers to Levels 3 and higher, where most driving functions are automated. The main difference among the three levels of higher automation is the human interface, which depends on the extent to which the AV can perform driving tasks in various driving scenarios. In Level 3, the human is still necessary; in Level 4, a human operator is not necessary but may still be able to take over driving functions if the vehicle is designed with that functionality; and in Level 5, the vehicle can perform all driving tasks on any road and in any circumstances without a human driver, and passengers direct the vehicles where to go. It is generally assumed that Level 5 vehicles will not allow human drivers to take over driving functions.

Dynamic Driving Tasks. AVs need to perform key driving functions, including localization, perception, planning, control, and management. SAE defines "dynamic driving tasks" as:

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, and including, without limitation, the following subtasks:

1. Lateral vehicle motion control via steering (operational)

2. Longitudinal vehicle motion control via acceleration and deceleration (operational)

3. Monitoring the driving environment via object and event detection, recognition, classification, and response preparation (operational and tactical)

4. Object and event response execution (operational and tactical)

5. Maneuver planning (tactical)

6. Enhancing conspicuity via lighting, sounding the horn, signaling, gesturing, etc. (tactical).[8]

Communication. Some development pathways would allow all these functions to be performed fully by the AV without having to communicate with other vehicles or any network. Level 5 AVs will be capable of that level of automation. Other development pathways contemplate that one or more of those functions would depend on the AVs being able to communicate. Such AVs are called connected autonomous vehicles (CAVs). CAVs will be able to communicate from vehicle to vehicle (V2V), from vehicle to infrastructure (V2I), or from vehicle to "everything" (V2X).

The Promise of AVs

The AV revolution could transform society as much as the original automobile did. The frenetic morning commute could become a thing of the past, as residents step out of their homes and into sleek, driverless cars summoned by a simple voice command or a tap on their smartphones. Streets will be safer, with far fewer accidents due to human error—the cause of 94 percent of crashes.[9] Streets will also be quieter, and traffic jams may become a thing of the past, due to such benefits of large-scale AV adoption as optimized traffic flow and intersection management, platooning, and reduced accidents.[10] Autonomous freight vehicles will transport goods more swiftly and efficiently. In this future city, the integration of AI and autonomous technology will provide mobility for many more Americans and facilitate access to things they need, helping to free up more time for productive work and enjoyable leisure.

Indeed, the way private cars are used is likely to be profoundly transformed. Unlike traditional cars, an AV will be able to transport different family members to various destinations sequentially throughout the day: The AV can drop a parent off at work, then return home to pick up the kids and drop them off at school, optimizing the vehicle's capacity use and reducing the need for multiple vehicles. This will not only cut down on parking requirements and associated costs, such as maintenance and insurance, but will enhance mobility for all family members, including those unable to drive themselves, such as children, the elderly, and those with special needs.

By operating at a higher use rate, AVs promise to be far more economical, with a substantially reduced environmental and social footprint per mile traveled. Currently, the car is a family's second-most expensive asset, yet its use rate is typically less than 10 percent. As a privately owned AV, the family car will be in service far more often, able to do the work of two or three traditional cars. On the other hand, with a Mobility as a Service (MaaS) business model, such as robotaxis, use rates will soar, resulting in enormous economic savings that will likely prompt new models of ownership, just as smartphones revolutionized ride-hailing services. Assuming a competitive marketplace, robotaxis could make ride-hailing so economical that it could become the predominant model of transit for most people, surpassing private car ownership.

Lengthy commutes will be far more manageable. AVs are likely to boost productivity and may reduce the length of the workday for commuting workers, who might find it easier to live further from their workplace. That could lead to more people moving to rural areas and suburbs, lowering housing costs while enhancing choice and increasing quality of life. Additionally, autonomous driving could enhance mobility for the elderly and others with reduced mobility, offering them transportation options beyond public transit or car-sharing services.

The logistics and delivery sectors will also be revolutionized by autonomous technology. Autonomous trucks will be able to operate virtually around the clock, ensuring that goods are delivered efficiently and on time. This will streamline supply chains, reduce emissions and fuel costs, and cut costs for businesses, ultimately benefiting consumers with faster service and lower prices.

As a result, autonomous trucking will almost certainly boost revenue and growth in the trucking industry. While autonomous trucks may reduce the demand for traditional long-haul driving roles, it will also create opportunities for new positions in technology maintenance, remote vehicle monitoring, and logistics management. This shift could lead to a transformation in the workforce, with a focus on more technologically advanced roles. It will also alleviate the severe shortage of truck drivers, which the American Trucking Association currently estimates at 60,000 vacancies.[11]

TEXT BOX 1

Autonomous Trucks Could Improve Life for Truckers

Autonomous trucks could eventually revolutionize the freight industry. Trends point to significant productivity gains in a sector characterized by persistent underemployment, with an estimated 60,000 vacant trucking jobs. E-commerce, with same-day delivery increasingly common, continues to exert relentless pressure on shippers to devise ever-more efficient logistics. Supply-chain automation enhances the ability to handle peak demand and heavier cargo. The asset-sharing models that have proven successful in other sectors, such as Airbnb and Uber, are emerging in the shipping and logistics sectors, increasing the use of trucks, warehouses, and other resources. Advanced data and analytics, now accelerated by AI, are helping shippers to forecast demand and optimize routes, leading to significant cost savings.

Ryder Systems and Georgia Tech's Socially Aware Mobility Lab studied a futuristic Autonomous Transfer Hub Network, where self-driving trucks handle long-haul routes between hubs, and human drivers take over for the shorter, more complex, first and last miles.[1] Using real-world data from Ryder's southeastern U.S. operations, the study found that implementing such a system could cut costs by up to 40 percent, potentially generating more than $80 billion in savings.

The cost savings come from autonomous trucks' ability to operate without breaks, cutting labor expenses and increasing overall efficiency. By optimizing routes and schedules, automation can significantly improve the flexibility and speed of freight networks. Integrating autonomous trucks into hub-and-spoke networks holds enormous potential to transform the freight industry, delivering not only cost savings but greater operational efficiency.

Autonomous trucks also mitigate environmental concerns. The trucks could use roadways much more efficiently, such as by platooning—when trucks drive closely behind each other, reducing air resistance—increasing roadway capacity. Increased capacity and less congestion would result in fewer crashes, as well as reduced fuel consumption and lower emissions.[2] AV technology could also allow remote operation through secure communication links. The improvement in truck drivers' quality of life would help to attract badly needed drivers.

Autonomous trucks would create new, higher-paying jobs in the trucking industry. As Chairman Rick Crawford (R–AR) told the House Highways and Transit Subcommittee:

> We need to incorporate employee development and training programs to upskill our workforce so they can take advantage of new jobs that AVs will create. And while I remain confident about the potential for this technology, I also am confident that if you choose to become a truck driver today, you will have the ability to retire as a truck driver.[3]

The autonomous trucking industry still has a long way to go before full commercial deployment. It is crucial for innovation to continue.

1. Ryder Systems, Inc., and the Socially Aware Mobility Lab, "The Impact of Autonomous Trucking: A Case-Study of Ryder's Dedicated Transportation Network," October 27, 2021, https://www.ai4opt.org/sites/default/files/docs/2021-10-27-ryder-white-paper.pdf (accessed April 5, 2025).
2. U.S. House of Representatives, Committee on Transportation and Infrastructure, "The Future of Automated Commercial Motor Vehicles: Impacts on Society, the Supply Chain, and U.S. Economic Leadership," hearing, September 13, 2023, https://transportation.house.gov/calendar/eventsingle.aspx?EventID=406848 (accessed March 28, 2025).
3. Ibid.

Most important, the AV transformation will save countless lives. Currently, U.S. roadway fatalities exceed 40,000 per year, constituting the eighth-leading cause of death in America, with 2.6 million emergency room visits due to motor vehicle crashes in 2022.[12] As noted, human error is the cause of car crashes in almost all cases.[13] With AV technology those deaths are largely avoidable. When fully automated passenger and freight transport reach a critical level of adoption, roadway fatalities and injuries will almost certainly be a tiny fraction of what they are today.

Full automation may still be decades away. But intermediate levels of automation are already appearing on our streets. Level 3 vehicles, including Tesla and Mercedes-Benz, are operating in some cities. Level 4 vehicles have made their first appearance, including driverless taxis in Austin, Los Angeles, Phoenix, and San Francisco. And whatever challenges loom, the future could be closer than appears. Long-range freight transport, commercial delivery, public transport, and taxis all have the potential for full automation technology in the next decade. The AV revolution is well underway.

A successful transition to AVs will have enormous economic and social consequences. These benefits will come mostly in the form of productivity gains and improved quality of life from hands-free travel and reduced collisions.

Effects will be felt throughout the economy. AVs will reduce the need for human-driven taxis. Automated trucks will improve efficiency and safety, potentially saving the freight industry hundreds of billions of dollars per year. AVs are also expected to be a significant driver of the tech sector, as just the software component of AV systems is expected to account for 45 percent of total production costs for a passenger AV.[14]

Liability is likely to shift from drivers to manufacturers, according to the study, reducing the need for personal auto insurance.[15] The auto insurance industry could shrink significantly, and fewer accidents will decrease the need for personal injury lawyers. Fewer traffic violations will also reduce government revenue from fines, while also reducing the need for traffic police.

Not all effects of AV deployment will be positive. One study by a group of Norwegian and Dutch scholars suggests that while AVs may enhance productivity by allowing occupants to engage in other activities during travel, they could also contribute to increased land use and decreased population density by making longer trips more convenient.[16] That could encourage shifts away from current urban transit modes such as public transport, cycling, and walking, while the increased automobile dependence could increase congestion in urban areas, exacerbating traffic problems rather than alleviating them. The authors of that study conclude that the environmental benefits of AV deployment may not be clear cut. Many Americans, though, already prefer to live in suburbs and use personal mobility rather than living in urban areas and relying on public transit and bicycles.

Some commentators have taken this study as a point of departure to advocate policies that would discourage private ownership of AVs in favor of public–private partnerships that would manage AV fleets for ride-sharing. Two Princeton University researchers argue that the deployment of AVs could either benefit or harm the environment, depending on factors like fuel efficiency standards and whether AVs are owned as personal vehicles or fleets of shared-ride vehicles.[17] The authors suggest that managed fleets with rigorous fuel-efficiency standards are more likely to yield positive environmental outcomes. They propose public policies that discourage private AV ownership and encourage ride-sharing, including through public–private partnerships that would partly displace today's public transit.

Similarly, in their book, *Autonomous Vehicles: The Road to Economic Growth?*, Clifford Winston and Quentin Karpilow acknowledge the potential to boost economic growth significantly but also argue that AVs could have negative effects on land use, employment, public finance, and the environment. Winston and Karpilow propose a robust set of public policies to mitigate these factors, some of which could also discourage private AV ownership.

Such policies are often a halfway house to socializing some part of the private economy and regulating it as a public utility. As with climate change, the gravest danger that AVs pose in terms of economy, safety, and environment may well be the misguided policies that government regulators adopt to command and control the sector.

AVs will also help to foster more economical and resilient supply chains. During the COVID-19 pandemic the U.S. faced serious challenges moving goods through ports and across the country. Partly because of the hours-of-service limitations on driving times, it often takes several days for a product to get from point A to point B, while continuous driving would take less than a full day. By using AV technology, vehicle and truck technology can be used for more hours in a day. As well as the expanded return on capital investment from greater use, products are able to move faster, a particular benefit for agriculture and other industries that need to get their products to market quickly.

There is little doubt that the AV revolution will cause a significant disruption if it occurs suddenly, both in the transportation sector and for society as whole. A shift of passengers from public transport to AVs would reduce revenue for public transit systems and affect local budgets.[18] Additionally, the rise of AVs could result in job losses in certain sectors, including those that are almost certain to enjoy significant economic benefits from AVs in the aggregate, such as taxi services, delivery services, and freight logistics. Despite growth in these sectors, the automation of driving tasks could displace a substantial number of drivers. For instance, the logistics industry, which is already experiencing labor shortages, might adopt AV technology rapidly, leading to contraction in some job categories even as the sector expands—leading to *overall* job growth in the industry.

However, the AV revolution will likely be gradual rather than sudden and will thus be less disruptive, with the new technology displacing the old gradually. The labor force participation rate has not recovered to pre-pandemic levels. With older Americans retiring and younger Americans investing in more education AVs could play a major role in filling gaps and complementing the skills of the existing workforce. Truck driver vacancies are forecast to increase as global supply chains continue to be intertwined and shipments that arrive at ports need to be transferred to final destinations.[19]

The transition to AVs will also create new job opportunities in areas such as AV maintenance, remote monitoring, and software development, requiring workers to acquire new skills.[20] Software and high-tech components will account for a much larger part of the cost of manufacturing and operating an AV, leading to growth in those sectors.

Consumer demand could expand quickly for AVs once they become readily available in local markets. It would then not take long for American leadership in AVs to become linked to American power and prestige. Just as the U.S. took the lead with Ford's Model T, Bell's telephones, personal computers, and smartphones, it could take the lead with AVs.

U.S. Faces Fierce Competition for AV Leadership—China Poised to Take Lead

The current leaders of the AV revolution are China, Germany, South Korea, Singapore, the U.K., and the U.S. The competition among leading industrial economies for leadership in the AV race will be one of the central determinants of global power in the 21st century. Among the key factors that position countries as leaders in AV deployment are technological innovation and regulatory frameworks.

Japan already has comprehensive legislation that supports AV testing and deployment. Japan allows AVs on public roads, which has accelerated their development and integration, whereas in the United States, AVs are allowed on public roads only under limited test exemptions from the antiquated Federal Motor Vehicle Safety Standards (FMVSS), which were developed for manually operated vehicles and require every car to have a steering wheel, manual break pedals, and rearview mirrors.

For all the challenges facing AV development in the United States, the U.S. is still well positioned to continue to lead the AV revolution. But other countries are catching up quickly, as can be seen in the annual "Global Guide to Autonomous Vehicles" report by Dentons law firm.[21] Notable in the 2024 Dentons report is progress made by China, Germany, and the U.K.

The U.S. Remains in the Lead—for Now. AVs have gradually become more common on U.S. roads through companies' aggressive use of testing exemptions from FMVSS, but progress toward a pro-innovation regulatory framework has stalled. In technological innovation, the U.S. is arguably the leader in the AV race—with China and Germany the closest competitors. North America hosts some 400 AV companies, of which more than 150 have reached venture capital Series A funding.[22] The U.S. leads with an estimated 136,000 AV-related patents, followed closely by China.[23]

Arizona, California, Nevada, and Texas have become hubs for testing and deployment, but at the federal level, significant legislation has not advanced since 2017, when bills such as the Safely Ensuring Lives Future Deployment and Research In Vehicle Evolution (SELF DRIVE) Act and the American Vision for Safer Transportation through Advancement of Revolutionary Technologies (AV START) Act, faltered due to unresolved issues concerning federal preemption of state AV design regulations and arbitration requirements as well as autonomous trucking. Deployment of Level 4 AVs remains in very early stages, with just a few thousand on the road today, mainly Waymo robotaxis.

Germany Has Acted Quickly. Germany's auto industry is facing historic challenges in the form of competition from Chinese electric vehicle (EV) manufacturers and high energy prices.[24] Despite these headwinds, Germany has moved quickly to develop a regulatory framework favorable to the development of autonomous vehicles.[25]

In the Autonomous Driving Act of 2021, Germany became the first country to create a fully comprehensive legal framework for Level 4 autonomous driving.[26] This law allows Level 4 vehicles to operate in specified areas, such as logistics terminals, with technical supervision. The framework was further bolstered in 2022 with the Ordinance on Autonomous Vehicles, which detailed technical and procedural requirements for vehicles with autonomous driving functions, including approval processes, data storage standards, and compliance.[27] U.S. policymakers should study both carefully.

On the testing front, Germany has established more than 20 urban-scale AV test sites nationwide, including initiatives such as the ALIKE project in Hamburg. This project plans to integrate up to 10,000 autonomous shuttles into a ride-pooling service by 2030.[28] The service is set to begin passenger operations in 2025. Mercedes–Benz and Bosch obtained government approval to introduce a fully automated parking system at the airport in Stuttgart.[29] This system allows compatible Mercedes–Benz vehicles to autonomously park themselves in designated areas of the garage. Drivers can then summon their vehicles via a smartphone app, and the cars will drive themselves back to the designated pick-up points.

Germany's automotive industry, which remains a leader in automotive technology, has been at the forefront of developing autonomous technology. Mercedes–Benz's Drive Pilot was the first commercially available Level 3 system in the world. In addition to supporting research, the German government has funded more than 100 projects in autonomous driving, focusing on real-world applications.

Developments in the U.K. The United Kingdom has taken significant steps in developing a regulatory framework that is favorable to AV innovation. The Automated Vehicles Act 2024 establishes a comprehensive legal framework to support the deployment of self-driving vehicles.[30] Key provisions include a new regulatory and liability scheme for AVs, requirements for AV safety information, and measures for data sharing between authorized self-driving entities and insurers. The act also introduces immunity for drivers in incidents where the vehicle was autonomously driving, marketing restrictions, and a permit system for automated passenger services, such as driverless shuttles.

Departing from the United States model, with its significant division of labor between federal and state authorities (see "Technological Challenges and Policy Issues" below), the U.K. Automated Vehicles Act, passed under Conservative leadership, establishes an overall national framework, with more detailed regulations to follow in the course of experience and further study. It remains to be seen whether the new Labour government will pass the additional regulations that were planned under the prior government.

China Poised to Take the Lead. The country doing the most to pave the way for AVs' long-term future—Level 5, fully autonomous—is perhaps China. Committed to a national goal of leadership in both AVs and EVs, the Chinese Communist Part (CCP) has invested aggressively in infrastructure and research, pushing progress in policy, technology, and deployment with increasing success.

In 2023 and 2024, China's AV industry advanced markedly in the development of its regulatory framework, expanded testing programs, and commercialization.[31] The CCP introduced a range of policies to support AV development, such as authorizing the testing and deployment of Level 3 and Level 4 AVs and issuing guidelines for vehicle standards, transportation safety, and highway infrastructure tailored to automated driving.[32] Nine Chinese automakers, including BYD, Nio, and Changan Auto, based in Beijing, Shanghai, and Shenzhen, respectively, have been granted approval by the Ministry of Industry and Information Technology to operate Level 3 autonomous driving systems on restricted roads, enabling conditional self-driving without human intervention except in emergencies.[33]

Testing and deployment activities have also expanded significantly. China has established 17 national-level test zones for intelligent connected vehicles, opening more than 3,200 kilometers of test roads, and issuing more than 16,000 test licenses.[34] Key milestones include the removal of the requirement for safety officers in some testing scenarios, the operation of high-level autonomous buses in public transport systems, and the deployment of unmanned sanitation vehicles in Beijing and Shenzhen.[35] Xinhua News reports that Beijing plans to significantly expand its high-level autonomous driving area.[36]

Despite these advances, and despite accelerating private investment in the sector,[37] significant challenges persist. Technological barriers, particularly in the development of domestic chips for autonomous vehicles, remain a critical hurdle. While companies such as Horizon and Black Sesame Technologies have made strides in improving computational power, Chinese chips remain behind American standards of innovation.[38] Additionally, regulatory constraints will continue to pose challenges. For example, fully autonomous vehicles are required to have remote drivers or safety officers in many cases.[39]

The commercial application of autonomous driving technologies has begun to take shape across various sectors. The government recently announced that 32,000 kilometers of roads had been established for AV testing and that 16,000 test licenses had been issued nationwide.[40] At least 19 cities are testing robotaxis and autonomous buses.

Artificial intelligence (AI) remains at the core of China's AV work. Companies such as Haomo AI and Geely Auto have heavily invested in AI technologies, including self-supervised learning models and advanced computing systems. Major technology firms such as Huawei and Baidu have helped to build out a fully capable AV ecosystem by developing large AI models with AV applications.[41]

The rapid deployment of 5G technology further supports the AV ecosystem in China, particularly by facilitating precise vehicle control and the efficient high-data-transfer bandwidths necessary for connected vehicles. China is outpacing the world in 5G, with about 4.2 million 5G base stations deployed—a staggering 40 times as many as in the U.S.—and that number is expected to double in 2025.[42] In 2023, the first 5G intelligent connected vehicle testing ground was launched in Shangrao.[43]

Major industry players such as Pony.ai, WeRide, and Mogo Auto continue to drive innovation in the AV sector.[44] Pony.ai expanded its robotaxi operations across major cities. WeRide achieved global milestones in licensing and certification, positioning itself as a leader in autonomous driving safety. Mogo Auto showcased its cutting-edge vehicle-road-cloud integration systems, setting industry benchmarks for intelligent transportation solutions.

AVs include both electric and traditional combustion engine vehicles. But both AVs and EVs are nascent industries, and China is clearly pursuing a strategy of fomenting their development in tandem. The CCP sees AVs as the future of EVs, and EVs as the future of personal mobility. There are compelling geostrategic reasons for this. The CCP is notably sensitive about its dependence on oil imports, which could be interdicted with relative ease by a foreign navy in the event of conflict over Taiwan. Indeed, perhaps the greatest deterrent to Chinese aggression against Taiwan is the threat of a foreign adversary interdicting China's oil supply. That could explain the ferocious speed with which China is moving to electrify its transport sector while also completing construction on one or two new coal power plants every week.[45] China has no significant domestic oil supply but is self-sufficient in coal. Hence, if China manages to transition to EVs, relying on AVs to increase use and reduce costs, while successfully electrifying its entire transport sector, its dependence on vulnerable foreign energy supply will be greatly reduced.

The CCP's increasingly sophisticated regulatory framework, coupled with technological advancements and infrastructure investments, positions China to potentially dominate the global AV market in the near future.

The National Security Imperative of American AV Dominance

The AV revolution is a critical domain in the race for pre-eminent power in the 21st century and is a central front in the geopolitical competition between the U.S. and China. This technology promises substantial benefits for both economic growth and military capabilities. It also introduces significant risks, particularly in cybersecurity.[46]

As with other critical sectors of industry and technology, the country that succeeds most in the economic domain of the AV race is also most likely to lead in the military domain. AVs can improve logistics, provide greater operational flexibility, and reduce the risk to human soldiers in dangerous environments. The integration of AVs in logistics and combat operations can streamline supply chains, ensure timely deliveries, and enhance the overall efficiency and effectiveness of military operations.

Like drone technology, AV technology is quickly revolutionizing military operations.[47] This technology enables autonomous execution of hazardous tasks, such as surveillance, resupply,[48] route clearance, explosive ordnance disposal, and casualty evacuation.[49] AV technology has dramatically enhanced the reconnaissance and surveillance capabilities of even the most rudimentary armed forces and have allowed sophisticated militaries to increase lethality and intelligence gathering while lowering the risk to personnel.[50] AV technology is making possible entirely new kinds of operations, such as swarm tactics and the integration of advanced weapon systems and large-impact strikes into small-unit operations, thus transforming the battlefield and expanding the spectrum of military capabilities. The world has seen harrowing demonstrations of AVs' military potential in the Ukraine war, where Ukraine has used AV technology to help to blunt Russia's overwhelming advantage in terms of men and matériel.[51]

Nor are the military advantages of AV technology limited to the tactical domain. At the strategic level, as noted in the previous section, China has been heavily investing in AV technology and infrastructure, aiming to become the global leader in this sector. China dominates many global standard-setting bodies, and China could set global standards and norms for AV technology, potentially undermining U.S. economic and strategic leadership. This is another reason why the U.S. must develop a regulatory framework that is second to none in fostering innovation and competition in the AV sector.

The adoption of AVs also brings considerable cybersecurity challenges. AVs rely heavily on navigation technologies, many linked to the Global Positioning System, as well as complex software and interconnected systems, making them targets for cyberattacks. These vulnerabilities can be exploited by adversaries to disrupt civilian life and military operations, steal sensitive data, or even weaponize autonomous systems. Ensuring robust cybersecurity measures for AVs is therefore paramount to safeguard national security and protect critical infrastructure. AV systems should be considered part of "transportation systems" for the purpose of critical infrastructure planning by federal authorities.[52]

The U.S. government should ensure that regulations encourage innovation in dual-use technologies, while safeguarding national security. The U.S. should collaborate with partners and allies to ensure the widest-possible adoption of the U.S. model for AV development. Simply put, for both economic and military purposes, it is critical that America's framework for development and deployment of AV technologies be recognized as "best in class."

Technological Challenges and Policy Issues

Road accidents are a leading cause of death in America, claiming more than 40,000 lives in 2022. There are an average of about eight injuries per 10 million vehicle miles traveled.[53] AV technology will eventually eliminate the greatest source of serious car accidents, which is human error. Yet fear of the unknown remains a significant barrier to innovation and development for AVs. One incident involving injury to a pedestrian led California to suspend Cruise LLC's license to operate fully autonomous vehicles in San Francisco, though human error was the initial cause of the accident.[54] Nevertheless, Cruise pulled its promising Level 4 line of AV development soon after the incident.

AVs promise a future with dramatically fewer accidents, especially as Levels 4 and 5 fully autonomous vehicles gain widespread adoption. In the meantime, the U.S. will have to overcome significant technological, policy, and political challenges.

Technological Challenges. According to M. Saquib Sarfraz, PhD, the head of Deep Learning at Mercedes–Benz's Autonomous Systems Unit, the development of Level 5 vehicles is still potentially decades away, and even the widespread adoption of Level 4 could take a long time.[55] It is important to understand the difference between these two levels. Level 4 can be programmed to operate on specific routes but does not have anything resembling artificial general intelligence (AGI). Level 5 on the other hand is essentially a robot vehicle with the ability to perform any driving task that a human could accomplish on any roadway.

The toughest challenge might be human-AV interaction. The AI systems that control AVs will need to be capable of understanding what humans in the surrounding environment are doing in real time, predicting what each of them might do in the next few seconds, and responding appropriately, even as the AV navigates an ever-changing landscape.[56]

The development of fully autonomous Level 5 vehicles presents a fascinating and complex set of technological challenges. Each of the core driving functions—localization, perception, planning, control, and management—must work together at least as well as performed by a human, both to ensure that vehicles meet consumer expectations and to ensure that the vehicles operate safely and efficiently.

- **Localization.** At the heart of AV technology lies the challenge of localization, the process by which a vehicle determines its precise position within an environment.[57] This task is critical for navigation and relies on a blend of technologies, such as GPS, Simultaneous Localization and Mapping (SLAM), high-definition maps, and sensors including Light Detection and Ranging (LIDAR), a crucial AV technology. GPS provides general location data, but its accuracy can be compromised in urban settings where tall buildings interfere with signals. A number of technologies have been developed to counter loss of GPS from interference with outside objects, hacking, and spoofing. For instance, SLAM uses data from sensors like LIDAR and cameras to create dynamic, real-time maps, allowing the vehicle to track its position accurately.[58] High-definition maps, such as those maintained without GPS by Tern.ai,[59] which developed the Independently Derived Positioning System (IDPS), can further enhance this process by providing detailed road information that AVs can use to cross-reference their sensor data against known landmarks, but maintaining these maps is a significant logistical challenge. Companies such as NextNav purchase spectrum and use beacons to send location signals to subscribers. Other companies use subscriptions to Low Earth Orbit (LEO) satellite data from Starlink or Irridium to provide backup to GPS satellites. Other technologies use AM or FM radio waves for location or bounce signals off LEO satellites without subscriptions.

- **Perception.** Perception is another crucial function of AVs, enabling them to interpret and understand their surroundings.[60] Through the use of cameras, LIDAR, radar, and ultrasonic sensors, AVs can detect and classify objects such as other vehicles, pedestrians, cyclists, and road signs. This involves not only identifying the presence of these objects but understanding the environment, such as assessing road conditions, detecting lane markings, and recognizing potential hazards. Advanced machine-learning algorithms, particularly neural networks, are employed to improve the accuracy and reliability of these perception systems.[61] However, the variability of environments, the difficulty of distinguishing between animate and inanimate objects, and the need for these systems to function reliably in diverse weather conditions and lighting scenarios present significant challenges.

- **Planning.** The decision-making process of an AV, known as planning, determines the optimal path and actions the vehicle should take.

This function is divided into path planning, behavioral planning, and trajectory planning. Path planning involves calculating the safest and most efficient route to a destination, considering dynamic factors like traffic and road conditions. For example, an AV might reroute to avoid congestion based on real-time data. Behavioral planning requires the vehicle to decide how to react to dynamic elements, such as pedestrians crossing the road or vehicles merging into traffic.[62] This involves predictive models that anticipate the actions of other road users. Finally, trajectory planning generates precise, time-optimized paths that account for the vehicle's physical constraints, ensuring safety and comfort throughout the journey.

- **Control.** The execution of these plans falls under the control function, which involves sending appropriate commands to the vehicle's actuators.[63] Control is divided into longitudinal and lateral aspects. Longitudinal control manages acceleration and braking, maintaining desired speeds and safe distances from other vehicles, which is vital for smooth traffic flow and safety. Lateral control, on the other hand, governs steering to keep the vehicle within its lane and execute turns accurately. To ensure that these controls work as intended, feedback loops continuously monitor the vehicle's actions, allowing the system to make real-time adjustments as needed.[64]

- **Management.** Finally, the management of AVs involves overseeing the integration and coordination of all components and systems. System coordination ensures that localization, perception, planning, and control functions communicate effectively and function as a cohesive unit. Monitoring of system health is critical, as it involves tracking the performance and status of all vehicle systems to detect and address any malfunctions that could compromise safety.[65] Data management is another key aspect, dealing with the vast amounts of information generated by AVs, ensuring that it is collected, stored, and processed securely. In the context of multiple AVs, fleet management becomes essential, involving the scheduling and optimization of vehicle use to meet demand efficiently, particularly in commercial applications, such as ride-sharing and logistics.

AI, planning, and decision-making are at the core of AV functionality. AVs must process vast amounts of data from their sensors to make real-time decisions. This involves complex AI algorithms that can predict potential hazards and plan safe routes. Additionally, communication between AVs and infrastructure (V2I communication) is essential for coordinating traffic and enhancing safety.[66] Policymakers must address these technological challenges to ensure the safe and efficient deployment of Levels 4 and 5 autonomous vehicles.

Major Policy Issues. AVs raise novel and difficult policy challenges.

Testing and Deployment. Under current law, AVs need a testing exemption from Federal Motor Vehicle Safety Standards that require design features incompatible with AVs, such as steering wheels. (See "The Regulatory Framework for AVs" below). Consequently, most AV policy development currently focuses on testing, where states have taken the lead—in contrast to other countries leading the development of AVs, such as Germany and China, which have adopted national standards for testing, safety, and other issues. The patchwork of inconsistent approaches in the U.S. may exceed the states' traditional role as primary regulators of roadways and may be an obstacle to innovation. State testing standards vary greatly with respect to where vehicles can test (on "test tracks" vs. public highways and roads) and requirements for testing authorization, such as safety drivers, liability insurance, and incident reporting. Arizona, California, and Texas are among the leaders in testing.

Insurance. Fully autonomous vehicles will shift the focus of liability and insurance from the driver to the manufacturer and any operator of the vehicle. But the intermediate levels (2 and 3), in which human drivers are able or required to take over basic driving functions in certain scenarios, will present complicated issues for liability and insurance. The proper assignment of responsibility to drivers of partially automated vehicles will depend on a proper understanding of the inherent technical dangers of shared operation and transfer of control, driver consent to the obligation to assume control at a moment's notice under certain situations, and driver training for specific levels of automation. These challenges will be made more complicated by the anticipated rapid evolution through intermediate levels of automation to full automation, as well as by the high probability that, at least for the foreseeable future, fully automated vehicles will share the road with manually operated traditional vehicles.

If and when most vehicles on the road are at Levels 4 and 5 fully autonomous, some key issues of liability and insurance would become simplified. Products liability law will assume central importance, except to the extent that remote operators are involved in supervising the AVs and expected to intervene under certain circumstances.[67] If and until then, liability and insurance regimes will have to evolve to accommodate difficult and novel scenarios, such as the situation where an accident might have been avoided had the driver taken over operations from a Level 3 (or remote supervisor in the case of a Level 4 vehicle), but did not do so quickly enough because, for instance, he was distracted or dozing off.[68]

Cybersecurity and Privacy. As AV technologies advance, the cybersecurity of data collected by vehicle computers and the protection of on-board systems against unauthorized access will become increasingly critical concerns. Modern vehicles, equipped with a range of sensors and automated components, generate significant data about the vehicle, its location, driver behavior, and overall performance. While these data are essential for the operation of AVs, they also present significant cybersecurity risks. With vehicles becoming more connected—capable of communicating with each other, roadside infrastructure, and manufacturers for software updates—there are increased opportunities for hackers to exploit these systems and access sensitive data, as explained above under "Localization." To combat these vulnerabilities, modern vehicles are designed to accept remote software updates, enabling manufacturers to promptly patch security weaknesses without requiring the vehicle owner's intervention or permission.

To bolster cybersecurity further, motor vehicle manufacturers have established the Automotive Information Sharing and Analysis Center (Auto-ISAC). This organization, which released a set of cybersecurity principles in 2016, serves as a central hub for manufacturers to share reports of cybersecurity incidents, threats, and violations within the industry. Beyond the threat of hacking, numerous legitimate entities—including manufacturers, technology suppliers, vehicle owners, urban planners, insurance companies, law enforcement, and first responders—are interested in accessing vehicle data. Critical issues related to vehicle data collection involve crash data storage and accessibility, data ownership, and consumer privacy. No laws prevent manufacturers and software providers from selling data about individual vehicles and drivers to third parties. As the automotive industry continues to integrate more advanced technologies, addressing these data privacy and security concerns will be crucial to ensuring consumer trust and the safe deployment of autonomous vehicles.[69] It may be necessary to establish legal protections for data privacy, such as data minimization.[70]

As vehicles become more connected, they can collect and misuse sensitive information. Some hardware and software in these vehicles can gather data about locations and important infrastructure, which malicious actors could exploit to disrupt operations. Technologies from China and Russia in connected vehicles could be used for surveillance and sabotage. On

September 26, 2024, the U.S. Department of Commerce proposed a rule to prohibit transactions involving vehicle-connectivity-system (VCS) hardware and covered software designed, developed, manufactured, or supplied by companies controlled by China, including Hong Kong, or Russia.[71]

Ethical Issues. A consultative committee on ethics established by the French government was charged with studying ethical questions surrounding AVs. The outcome document delved into several critical areas, including safety, liability, privacy, and social consequences. Of particular concern is which principles should be used in programming vehicles to make life-and-death decisions.[72] Among the committee's recommendations are to allow remote control for public and shared vehicles, to ensure that both manual and automated modes are incorporated into AV designs, to protect personal data, and to ensure user control of vehicle locking and movement.

The Regulatory Framework for AVs

With a regulatory framework that was developed for manually operated vehicles, America is facing major challenges in updating its regulations for the age of AVs.

The Vehicle Safety Act and the Federal Motor Vehicle Safety Standards. The regulatory framework for AVs starts from the existing regulatory framework for conventional vehicles. At the federal level, the National Traffic and Motor Vehicle Safety Act (MVSA)[73] requires the U.S. Department of Transportation to establish safety standards for motor vehicles and to guide research and development to support such standards. Meanwhile, state governments handle vehicle licensing, insurance, liability, and similar matters. For several reasons, that division of labor between federal and state authorities may not be optimal for AVs. Moreover, stakeholders consistently report that the lack of needed action at the federal level is compelling states to take legislative and regulatory measures that result in a regulatory patchwork lacking the uniformity and consistency necessary for efficient development and deployment of AVs.

The MVSA itself does not explicitly prohibit AVs. It defines a "motor vehicle" as "any vehicle driven or drawn by mechanical power manufactured primarily for use on the public streets, roads, and highways, except any vehicle operated exclusively on a rail or rails."[74] The definition is technology neutral and focuses on the vehicle's power source and intended use without specifying who or what operates the vehicle. The term "driven" might imply a human operator, but the purpose and policy of the act, as well as the evolving nature of automotive technology, strongly imply a more inclusive interpretation.

TABLE 1

FMVSS Need to Be Updated for AVs

Category	FMVSS Number	Not Needed/ Incompatible with AVs	Description
CRASH AVOIDANCE	101		Controls and displays
	102	✗	Transmission shift position sequence, starter interlock, and transmission braking effect
	103		Windshield defrosting and defogging systems
	104		Windshield wiping and washing systems
	108	✗	Lamps, reflective devices, and associated equipment
	110		Tire selection and rims and motor home/recreation vehicle trailer load carrying capacity information
	111		Rear visibility
	113		Hood latch system
	114	✗	Theft protection and rollaway prevention
	118	✗	Power-operated window, partition, and roof panel systems
	124		Accelerator control systems
	125		Warming devices
	126		Electronic stability control systems for light vehicles
	138	✗	Tire pressure monitoring systems
	141	✗	Minimum sound requirements for hybrid and electric vehicles
CRASHWORTHINESS AND OCCUPANT PROTECTION	201	✗	Occupant protection in interior impact
	202a	✗	Head restraints
	203	✗	Impact protection for the driver from the steering control system
	204	✗	Steering control rearward displacement
	205	✗	Glazing materials
	206	✗	Door locks and door retention components
	207		Seating systems
	208		Occupant crash protection
	210		Seat belt assembly anchorages
	214		Side impact protection
	216a		Roof crush resistance
	219		Windshield zone intrusion
	222		School bus passenger seating and crash protection
	225		Child restraint anchorage systems
	226		Ejection mitigation

SOURCE: U.S. Department of Transportation, "FMVSS Considerations for Vehicles with Automated Driving Systems: Volume 2," https://rosap.ntl.bts.gov/view/dot/54442 (accessed April 23, 2025).

As required by the MVSA, the National Highway Transportation Safety Administration (NHTSA) has established Federal Motor Vehicle Safety Standards (FMVSS).[75] These FMVSS establish minimum safety performance requirements for motor vehicles and related equipment. Key areas covered include controls and displays, braking systems, crash avoidance, and occupant protection.

The NHTSA has identified several FVMSS that may need "technical translation" for AVs because the required or referenced feature may not exist in an AV. These include steering columns, steering wheels, driver's seats, and rearview mirror, which are not needed in an AV. Those standards are highlighted in Table 1.[76]

The Department of Transportation and the NHTSA have developed principles and a proposed framework for widespread adoption of AVs while refraining from imposing mandatory design features and performance standards specific to AVs. However, FMVSS apply to all vehicles, even those without drivers. Manufacturers must self-certify compliance with these standards unless they receive a specific exemption. Although the NHTSA cannot pre-approve new vehicle designs, vehicles that do not comply with FMVSS are subject to recall, and manufacturers who do not comply with the NHTSA recall orders are subject to significant penalties.

A related issue is that the MVSA prohibits making "inoperative any part of a device or element of design installed on or in a motor vehicle" in compliance with FMVSS.[77] Exemptions are available on a company-by-company basis, but this is another irrational legal hoop through which AV companies must jump as a result of a statutory provision that was not intended to exclude AVs.

In the absence of a comprehensive national framework for AV regulation, state and federal officials are starting to confront challenging new policy issues, such as data collection, liability, and guidelines for how vehicles should react to dangerous situations.

Without a clear regulator taking the lead, various regulatory authorities are pushing various and often inconsistent regulatory schemes for balancing safety, innovation, and ethical considerations. The result has been an unfavorable regulatory environment that risks hampering innovation and commercialization.

The NHTSA's Proposed Regulatory Framework for Automated Driving System Safety. In December 2020, under the Trump Administration, the NHTSA took a significant step toward shaping the future of AVs by seeking public input for a new Framework for Automated Driving System Safety.[78] This was the federal government's first proposal of a regulatory framework specific to AVs and focuses on the autonomous driving system (ADS), the system that executes driving tasks autonomously. The initiative reflects a recognition that existing standards, which are primarily designed for human-driven vehicles, are inadequate for the complex systems involved in autonomous driving. The NHTSA invited creative and innovative ideas to develop a regulatory framework that balances safety with the flexibility needed to foster innovation in this rapidly evolving field. The comment period for this proposal closed in early 2021. The Biden Administration did not see this effort as a priority, and according to the NHTSA's last report to the Unified Agenda on this docket, the agency is still analyzing comments.[79]

The 2020 advance notice of proposed rulemaking (ANPRM) recognized that existing legal authorities developed for traditional vehicles are inadequate and that a comprehensive new framework is needed. According to the ANPRM:

> Rather than elaborating and prescribing by rule specific design characteristics or other technical requirements for ADS, NHTSA envisions that a framework approach to safety for ADS developers would use performance-oriented approaches and metrics that would accommodate the design flexibility needed to ensure that manufacturers can pursue safety innovations and novel designs in these new technologies. This framework could involve a range of actions by NHTSA, including guidance documents addressing best industry practices, providing information to consumers, and describing different approaches to research and summarizing the results of research, as well as more formal regulation, from rules requiring reporting and disclosure of information to the adoption of ADS-specific FMVSS.[80]

The NHTSA emphasized performance-oriented approaches that accommodate design flexibility and innovation. It included potential voluntary measures, such as public safety assessments and industry best practices, alongside the development of new mandatory regulatory standards tailored for ADS technologies. To further refine the framework, the NHTSA is soliciting feedback on various elements, including engineering and process measures, implementation mechanisms, and the prioritization of safety standards. According to the NHTSA, the proposal would create a regulatory environment that is technology neutral, predictable, and efficient while encouraging market-based innovation. It recommends the following priorities. Policymakers and stakeholders should:

- **Focus** on core ADS functions like sensing, perception, and control that can be assessed through testing;

- **Include** standards, such as ISO 26262 for electrical system safety and UL 4600 for evaluating ADS safety through a safety case approach;

- **Encourage** transparency and public confidence through voluntary safety assessments and performance comparisons;

- **Propose** technology-neutral, performance-based standards that adapt to innovation and market changes; and

- **Suggest** a gradual implementation of mandatory standards to prevent stifling innovation, prioritizing critical safety measures first.

According to the Unified Agenda maintained by the Office of Information and Regulatory Affairs,[81] the NHTSA is considering a proposed rulemaking ("Exemption and Demonstration Framework for Automated Driving Systems") that would establish a framework for the review and assessment of ADS-equipped vehicles "in order to evaluate operations or requests for exemptions involving such technologies while also informing the agency's approach to future rulemaking and oversight."[82] The NHTSA is also considering a requirement for new FMVSS that would make lane-departure warning and lane-keeping assistant systems mandatory.[83]

The Federal Motor Carrier Safety Administration (FMSCA). In parallel with the NHTSA's AV framework, the FMSCA is developing a proposed regulatory framework for motor carriers, including autonomous trucks. On February 1, 2023, the FMSCA published a supplemental advanced notice of proposed rulemaking (SANPRM) titled, "Safe Integration of Automated Driving Systems (ADS)-Equipped Commercial Motor Vehicles (CMVs)."[84] Building on the precursor ANPRM,[85] the SANPRM focuses on Levels 4 and 5 automation. The FMCSA does not believe there is a need to revise the Federal Motor Carrier Safety Regulations (FMCSR) to address the integration of Levels-0-to-3 equipment because a licensed human CMV driver must be seated behind the wheel of these vehicles at all times to perform, or be ready to take over, dynamic driving tasks. Only at Levels 4 and 5 can an ADS control all aspects of the dynamic driving task without any expectation of intervention from a human driver. Accordingly, the FMSCA solicited public comment on the following topics: whether the FMCSR requires a human driver; commercial driver's license (CDL) endorsements; drivers' hours of service rules; medical qualification standards for human operators; distracted driving and monitoring; requirements to ensure safe driving; inspection, repair, and maintenance; roadside inspections; cybersecurity; and confidentiality of shared information. According to the Unified Agenda, the FMSCA is still studying comments on this proposal.

Effective regulation of these issues would foster innovation and adoption of AV technology. There was little movement on the regulatory front in the Biden Administration, likely because of effective opposition from special interest groups, such as labor unions and the trial lawyers' bar.

Second Standing General Order 2021-01. On June 29, 2021, the NHTSA issued Standing General Order 2021–01.[86] As amended in April 2023, the order[87] requires certain vehicle manufacturers and operators to report crashes involving vehicles equipped with ADS or advanced-driver-assistance systems (ADAS) to the NHTSA. The stated purpose of the order is to ensure timely and transparent reporting of real-world crashes, so that the NHTSA and Transportation Department are able to conduct investigations and address emerging safety issues related to the testing, development, and deployment of new driving-automation technologies.

However, members of the public complained about the onerous costs and privacy concerns of the required data-gathering. The order bypassed normal regulatory review processes by invoking "emergency clearance," raising concerns about its necessity given no evidence of increased AV accidents. Critics argued that the broad definitions of reportable crashes, which included accidents without any allegations of fault by the AV, and the steep penalties for non-compliance could burden companies and stifle innovation. Publicizing the data without context risked misleading perceptions of AV safety. This approach, critics argue, could hinder U.S. advancements in AV technology, giving global competitors an edge.

On April 24, 2025, the NHTSA published a revised Standing General Order, which significantly streamlines and simplifies reporting requirements.[88] This is expected to alleviate a significant regulatory burden for AV companies.

Proposed "AV STEP" Rule. On January 15, 2025, the NHTSA proposed a new "voluntary" reporting regime for vehicles that operate ADS (generally Levels 3, 4, or 5) on public roads, regardless of compliance with, or exemption from, FMVSS.[89] The program covers vehicles requiring human intervention during emergencies as well as fully autonomous systems capable of managing all driving tasks independently. Participants must periodically submit extensive safety and design data, including independently reviewed "safety cases" outlining safety protocols and decision-making frameworks, along with periodic operational reports. The NHTSA will use these data to evaluate ADS safety and guide future regulations; it also proposed to make relevant data about participants, their operations, and safety records publicly available.

The co-chairs of the Congressional Autonomous Vehicle Caucus, Representatives Bob Latta (R–OH) and Debbie Dingell (D–MI), took the unusual step of pointing out the proposed rule's insufficiency in a joint statement: "Today's proposed rule is not a substitute for Congress establishing a federal regulatory framework."[90] The proposed rule would create more paperwork on top of the already onerous burdens of the Standing General Order and should be viewed with skepticism by the Trump Administration. The comment period closed on March 17, 2025.

State Regulatory Developments. During the Biden Administration, most of the legislative and regulatory activity has occurred at the state level.[91] Nineteen states permit AVs so long as they are (1) in compliance with federal motor vehicle safety regulations; (2) able to operate in compliance with state safety and traffic laws within the AV's operational design domain without a human driver; and (3) able to achieve "minimal risk condition" when the ADS fails to operate properly, for example, by shutting down and illuminating hazard lights.[92] Twelve states, including California, permit only testing or piloting. However, since all Level 4 vehicles are currently operating pursuant to numerically restricted testing exemptions from FMVSS, there is little practical difference between the two groups.

State legislation is not uniformly supportive of AVs. Policymakers in California and Texas, states at the forefront of AV development, have introduced bills that suggest greater hesitancy, focusing on additional safety and operational requirements for AVs.[93] Some of these measures may be driven by concentrated special interest groups that oppose AV development generally. This underscores the need for industry to engage with policymakers and address their concerns proactively, while doing a better job of informing the public about the enormous potential benefits of AVs.

Legislative Proposals. Congress has considered several major pieces of legislation to address adoption of AVs, but none has achieved final passage thus far. The two main bills, the SELF DRIVE Act and AV START Act, would have laid the groundwork for a federal regulatory framework for AV design, construction, and performance. Both would have authorized the NHTSA to expand exemptions from existing FMVSS for the purpose of testing, from the current 2,500 exemptions per manufacturer per year to 100,000 per manufacturer per year. However, both bills would have maintained the current testing framework for establishing or revising vehicle design and performance rules, with the NHTSA's recall authority under the MVSA remaining unchanged. Neither bill has prospered. Other bills had narrower objectives but similarly failed.

The SELF DRIVE Act. The SELF DRIVE Act passed the House in 2017 but failed in the Senate the following year.[94] It would have required the NHTSA to issue a "rulemaking and safety priority plan" for potential technology-specific amendments to FMVSS. Key provisions included requiring the NHTSA to develop safety-assessment certifications for AV manufacturers and ensuring that manufacturers share critical safety data. The act also would have mandated the creation of a consumer-education program to inform the public about the capabilities and limitations of AVs. Additionally, it sought to enhance the cybersecurity of AVs and protect consumer privacy by establishing guidelines for data collection and usage. In the 115th Congress, the bill passed the House but died in the Senate.

The AV START Act. The AV START Act aimed to establish a federal framework for the regulation and deployment of highly automated vehicles (HAVs), defined as Levels 4 and 5.[95] The act would have pre-empted state laws regulating the design, construction, and performance of HAVs, while leaving states responsible for issues such as vehicle registration and traffic laws. This bifurcated approach aims to streamline the development and deployment of autonomous vehicles while ensuring safety and consistency across states. The bill would also have required a one-time set of recommendations from a "Highly Automated Vehicles Technical Committee" within five years, followed by the NHTSA's consideration of any necessary FMVSS amendments. The Senate Commerce Committee advanced the act in 2017, but it died the following year after the full chamber failed to take it up.

The AV Accessibility Act. This bill would have prohibited a state from regulating driver's licenses for Level 4 and Level 5 in a manner that discriminates on the basis of disability.[96] This prohibition would in effect pre-empt a "driver in seat" bill, as the requirement of a "driver" discriminates against, for example, blind people, on the basis of disability. AVs' promise of enhanced mobility for the disabled has generated significant pressure in favor of AV deployment from disability-rights groups.

Political Challenges. AV innovation faces major political obstacles. Powerful, concentrated special interest groups who feel vested in the current transportation paradigm have mounted fierce resistance.

Some national labor unions oppose regulations and legislation that pave the way for the deployment of fully autonomous vehicles. For example, the Teamsters Union's Autonomous Vehicle Federal Policy Principles call for specific standards for vehicle manufacturing and performance that include mandatory human operators for all autonomous vehicles, and comprehensive reporting and data-recording requirements.[97] The Policy Principles provide no rationale for requiring a human operator, and the implementation of that requirement would impair the AV sector and prevent creative and useful job growth. The Policy Principles also highlight the importance of addressing workforce effects and ensuring that any legislation prioritizes safety and does not compromise existing protections.

Other unions and trade associations are also opposed to pro-innovation AV legislation, including the National Society of Professional Engineers (NSPE).[98] The NSPE opposed the AV START Act, arguing that expanded exemptions from FMVSS undermine public safety.[99] The NSPE argued that the act fails to address critical safety, technological, and ethical challenges, leaving substantial gaps in consumer and public protections. Furthermore, the NSPE argues that the act would permit the premature deployment of AVs, potentially leading to unsafe conditions on public roads.

Trial lawyers have voiced similar concerns. The American Association for Justice, a prominent trial lawyers' association, has strongly opposed expansion of FMVSS exemptions, and any provision for forced arbitration clauses.[100]

Overcoming the opposition of concentrated special interest groups will require a widely felt demonstration of the enormous potential benefits of AVs.

Achieving American Dominance in AV Technology

As the regulatory framework for AVs is developed, there is likely to be pressure for regulations to favor "shared mobility" over private ownership of AVs for "equity" and "social justice" reasons.[101] To the extent this framing implies favoring public transit over private transit, and the regulation of private-sector ride-sharing companies as public utilities, the framing would be deeply mistaken. Regulations should avoid picking winners and losers. Instead, the right regulatory framework will be technology neutral and agnostic about the modes of ownership and operation, prioritizing consumer choice and the ability to maintain private ownership.

The principles articulated in the Transportation Department's 2018 and 2020 reports, "Preparing for the Future of Transportation: Automated Vehicles 3.0" and "Ensuring American Leadership in Automated Vehicle Technologies: Automated Vehicles 4.0," should be bedrock principles for future development of a pro-competitive, pro-innovation regulatory approach:[102]

Robust Protections for Safety, Cybersecurity, and Privacy. The AV 3.0 and AV 4.0 reports emphasize the importance of ensuring robust protections for physical safety, cybersecurity, and privacy. These include developing and enforcing safety standards that address the unique challenges posed by AV technology, such as preventing cyberattacks and safeguarding user data. The reports highlight the need for continuous monitoring and updating of these protections to keep pace with technological advancements and emerging threats.

Promoting Innovation and Competition. Another key principle outlined in the AV 3.0 and AV 4.0 reports is the promotion of innovation and competition within an efficient market for the AV industry. The Transportation Department advocates a flexible, technology-neutral approach that encourages diverse technological solutions and fosters innovation through competition. This principle aims to ensure that the best and most-effective AV technologies can emerge and thrive, ultimately benefiting consumers and enhancing transportation systems.

Facilitating Coordination and a National Market. The AV 3.0 report also stresses the importance of facilitating coordination, standard-setting, and the development of a national market for AV technologies. This includes pre-empting state and local regulations that discriminate against AV technologies or inhibit their development. By creating a cohesive regulatory framework, the Transportation Department aims to support the seamless integration of AVs across the country, ensuring that innovations can be implemented uniformly and efficiently.

Building on those principles, policymakers should commit to the following objectives:

Deploy Level 4 AVs as Widely and Rapidly as Possible. The overriding goal of AV regulation should be to achieve Level 4 driverless capabilities as rapidly as possible, while paving the way for Level 5. The rationale for this tiered approach is that there has already been substantial progress in technology, logistics, and operational efficiency toward Level 4 automation. The obstacles to Level 5 remain significant and inhere in the limits facing AI robotics across the board; achieving Level 5 will have to await a broader leap forward in AI robotics. But most of the benefits of AVs can be demonstrated, and most of the problems solved, in the deployment of Level 4.

Pave the Way for Economies of Scale in a National Market for AVs. Given the high costs associated with developing and commercializing AV technology, it is crucial to achieve economies of scale by developing affordable vehicles that can be deployed widely. By scaling production and deployment, manufacturers can reduce costs and make AVs more accessible to a broader market. The key is developing a national policy framework that is consistent with the basic division of regulatory authorities contemplated in the MVSA, which reserves design and safety regulation to federal regulation, while leaving most other matters to states. This approach not only supports the growth of the AV industry but also ensures that the benefits of autonomous technology are widely distributed, which will help to counter the political pressure of special interest groups opposed to AV development. This is as true for the autonomous trucking industry as it is for passenger mobility.

Avoid Excessive and Inconsistent Regulation. Relatedly, overregulation, regulatory uncertainty, and the entrenchment of an inconsistent regulatory patchwork are the most immediate obstacles to America's dominance of AV innovation and deployment. Congress and the relevant agencies should move quickly to establish a national regulatory framework that favors competition and innovation, pre-empting inconsistent and discriminatory state regulation while leaving to the states those issues that are optimally delt with at state level, such as licensing, registration, insurance, designation of permissible routes for AV use on non-federal roadways, and regulation of the MaaS (such as robotaxis) sector. To eliminate regulatory uncertainty and foster the development of AVs, it is essential to establish clear and consistent federal guidelines.

Foster Interstate Regulatory Competition without Overregulation. The right national regulatory framework will give states broad latitude to serve as "laboratories of democracy" without interfering with the development of an efficient national market. Federal preemption of state laws that could hinder the deployment of AVs may be necessary, but robust interstate competition should suffice to pressure states to achieve optimal levels of regulation.

Balance the Need for Data Collection with the Need for Data Privacy and Security. Data collection is another critical issue in AV development, and the issues arise both in the "training" of AVs on roadways as well as in their operation in dynamic driving environments. AVs must have information about roadways down to extremely precise details. They also need to be trained on traffic and pedestrian behavior data, much as large language models (LLMs, AI systems that can understand and generate human language) need to be trained on virtually the entire Internet. This implies that even in the training phase AV companies may need to collect enormous amounts of information about what people are doing as they go about their daily lives on sidewalks and roadways. This raises obvious data privacy and data security concerns. Regulators should ensure transparency about which data are being collected and how they are being used. Minimal standards of data minimization should ensure that only the data that are strictly necessary for AV operations are collected, and that AV operators delete such data once they are no longer needed. One drawback of "big data" analytics is the ease with which anonymized data can be re-identified. The way that LLMs are trained and used can perhaps point the way to some solutions. LLMs use vast amounts of training data to calibrate "model weights," which are the billions of parameters used by LLM algorithms in response to prompts. In that way, training data is reduced to mathematical abstractions; the LLM does not otherwise retain memory of its training data.

Establish Effective Liability and Insurance Regimes. Maintaining operator responsibility and strict liability for manufacturers will be essential to maintaining the safety of AVs. In its 2018 "Torts of the Future" report, the U.S. Chamber of Commerce recommends a mixed liability approach, tailored to assign responsibility based on the nature of the accident and the party at fault.[103] For instance, liability could fall on manufacturers if an accident results from a defect in the AV's software or design, while responsibility could shift to owners or operators in cases of misuse, improper maintenance, or failure to update software. The report also explores the potential benefits of no-fault insurance, particularly for Level 3 and lower AVs where fault attribution might be complex.

Recommendations for Policymakers

When it comes to regulation, the U.S. Department of Transportation should move quickly to continue building on its AV work that was begun in President Trump's first term:

- **The NHTSA should promptly propose a regulatory framework for AVs.** The NHTSA should publish a proposed rule based on the comments it received in response to its December 2020 ANPRM, "Framework for Automated Driving System Safety."[104]

- **The FMSCA should speedily propose a regulatory framework for autonomous trucks.** The FMSCA should publish a proposed rule based on the comments it received in response to its February 2023 SANPRM, "Safe Integration of Automated Driving Systems (ADS)-Equipped Commercial Motor Vehicles (CMVs)."[105] The FMSCA should reaffirm the position stated in the 2019 ANPRM that the FMCSR *do not* require the presence of a human driver in the vehicle.[106]

- **The NHTSA should reverse course on burdensome reporting requirements.** The NHTSA took a step in the right direction with its Third Amended Standing General Order on April 24, 2025. It should likewise reconsider the approach proposed in its "AV STEP" NPRM.[107]

- The Department of Transportation should prioritize:

  - Regulatory self-certification for compliance with safety standards.

  - Technical translation of FMVSS for AVs, taking a technology-neutral approach to passenger safety, recognizing that such translation will often yield equivalent or significantly improved safety (for example, occupant seat arrangement). The Transportation Department should use the April 2020 "FMVSS Considerations for Vehicles with Automated Driving Systems" as point of departure.[108]

For legislation, given the political opposition that emerged to defeat the SELF DRIVE and AV START Acts, Congress may want to start from scratch, combining key provisions of those bills with new approaches. At a minimum, legislation should include the following:

- **Expanded testing exemptions for AVs.** The simplest way to reach economies of scale in the AV industry may be to continually expand the testing "exemptions" system so that AVs can be demonstrated at increasingly larger scale until acceptance has reached a level where a comprehensive framework becomes politically feasible. To this end, Congress should expand the exemption authority in the MVSA and clarify that vehicle modifications necessary for safe operation of AVs do not violate the "make inoperative" provision of the MVSA.[109]

- **Data privacy and security.** Congress should require the Transportation Department, in conjunction with AV manufacturers, to develop policies and regulations to protect data privacy and cybersecurity, including transparency about which data are being collected and how they are being used, strictly limiting data collection to information that directly helps the product, a ban on selling AV data to third parties, and requiring data deletion after a specific period of time.

- **Passage of the AV Accessibility Act.** This act would prohibit states from using licensing requirements to deprive blind and otherwise disabled people from using AVs by themselves.

As for state regulatory activity, as contemplated in the MVSA, states should focus on doing what states do best: vehicle registration, operators licensing, insurance regulation, traffic regulation, and similar matters. The federal regulatory framework should give states ample room to compete for optimal levels of both safety and attractiveness as destinations for AV testing and deployment.

States should authorize the operation of autonomous vehicles on public roads, subject to meeting safety requirements. Such safety requirements could include the ability to operate in compliance with applicable traffic and motor vehicle safety laws and regulations. States should avoid "driver in seat" and similar mandates that would make most Levels 4 and 5 AVs essentially illegal; such mandates should be pre-empted by federal law, if necessary.

Conclusion

It is imperative for America to maintain its technological edge in the AV sector. In order for that to be possible, legislators and regulators must continue to pursue policies that pave the way for the safe and efficient deployment and commercialization of AV technology. Other countries, both friends and foes, are adopting future-focused approaches, and America is starting to fall behind. The United States needs a regulatory and legislative agenda that allows the greatest innovations—the American way—through a decentralized economy that protects the privacy and safety of all Americans.

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