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Report

Autonomous Now: Why We Need Self-Driving Technology and How We Can Get It Faster

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Executive Summary

Autonomous vehicles (AVs) are poised to improve roadway safety and lower transportation costs, yet policy barriers are delaying their adoption. This report focuses on the two AV applications—autonomous ride-hailing and autonomous freight trucking—that present the greatest near-term opportunities for welfare enhancement and offers policy reforms to accelerate their success.

Autonomous ride-hailing (ARH) is on-demand, point-to-point transportation via cars equipped with autonomous driving systems (ADS). ARH works largely within cities or other defined geographic areas and can therefore be regulated at the local and state levels. Autonomous freight trucking (AFT) refers to the use of large self-driving trucks to transport goods over long distances and is thus best regulated at the state and federal levels.

ADS are already safer than human drivers in many circumstances. Equipped with 360-degree vision, programmed to adhere to traffic laws, and immune to human distraction, they will soon surpass human driving competency in almost all circumstances.

In the U.S. alone, more than 40,000 people die annually as a result of motor-vehicle collisions. Because more than 90% of collisions are the result of human error, ADS technology presents an enormous opportunity for safety improvement. Early results with autonomous driving within cities indicate that AVs are 50% less likely to be involved in collisions.

Moreover, AVs promise savings on labor. When firms can scale ADS technology, they will be able to provide ride-hailing and freight trucking at lower prices than are currently economical, given the constraints of the labor market. Lowering transportation costs for people and goods facilitates economic activity and improves performance.

ADS may soon be able to cut ride-hailing fares in half and reduce trucking costs by 30%.

Both ARH and AFT are capable of delivering these benefits with what the Society of Automotive Engineers calls Level 4 automation—a designation meaning the vehicles can perform all aspects of driving autonomously within specific, defined environments. Level 4 is distinct from the utopian Level 5, wherein autonomous vehicles take people and goods anywhere at any time.

To foster AV development, this report gives three recommendations to city governments, three to state governments, and three to the federal government.

To support successful ARH, U.S. cities should: (1) allocate curb space to ride-hailing loading and unloading; (2) allow autonomous ride-hails to use preferred lanes; and (3) implement congestion pricing.

State governments should: (1) devote a state policy office to AVs; (2) license ADS similarly to the licensing of human drivers; and (3) invest in quality infrastructure that facilitates autonomous technology without prematurely committing to vehicle-to-infrastructure (V2I) technology.

The federal government should: (1) raise or eliminate AV manufacturing caps; (2) address problems as they arise, rather than before they arise; and (3) use the power of federal highway funding to induce state receptivity to autonomous trucks.

Introduction

Autonomous driving systems (ADS) use sensors to collect data on their surroundings and use artificial intelligence (AI) to direct vehicle movements. These sensors can be passive (detecting light, radiation, and heat, among other phenomena) or active (emitting signals and then detecting the interaction between those emitted signals and the vehicle's surroundings).

These sensors are the eyes, ears, and other sensory organs of the autonomous vehicle (AV). Whereas a human can look only in one direction at a time, ADS can scan in all directions simultaneously and with far more acuity than a human. Unlike a human driver, who must look away from the road to check a mirror, ADS can simultaneously see another car at the rear, the traffic signal ahead, and the bicyclist in what would be a human driver's blind spot. Sensors provide a more comprehensive picture to ADS than a human driver's senses provide to the brain.

Together, these systems supply the raw data that on-board AI systems (called "compute," in industry parlance) then synthesize, interpret, and utilize to command a vehicle's actions. The AI's output is the directions that it gives to the vehicle's actuator, the system that accelerates, brakes, and steers the vehicle.[1] An ADS AI is analogous to a human driver's decision-making process, but ADS AIs are trained on more data than any human could ever internalize because all the cars in a given system can share data from all the roadway scenarios that they have. As one AV company explains, its system is "the world's most experienced driver."[2].

Autonomous Driving Classification System

The Society of Automotive Engineers (SAE) separates AVs into six levels of autonomous capabilities.[3] While utopian visions of universal self-driving (Level 5) capture popular imagination, incremental capability improvements should be appreciated. Within the Level 4 parameters, autonomous ride-hailing (ARH) and autonomous freight trucking (AFT) can add immense benefits.

Level 0: Vehicles equipped with no automated features, requiring the driver to be in complete control of the vehicle.

Level 1: Vehicles equipped with one or more primary automated features, such as cruise control or lane centering, but requiring the driver to perform all other tasks; sometimes called "driver assistance."

Level 2: Vehicles equipped with two or more primary features, such as adaptive cruise control and lane-keeping, that work together to relieve the driver from controlling those functions; sometimes called "partial automation."

Level 3: Vehicles equipped with features that allow the driver to relinquish control of the vehicle's safety-critical functions depending on traffic and environmental conditions. However, human drivers are expected to take over control of vehicles in certain circumstances, given the constraints of the automated features. "Traffic jam chauffeur" is a hallmark feature of Level 3 vehicles, which is sometimes called "conditional automation."

Level 4: Vehicles equipped with features that allow drivers to become riders, relinquishing control of vehicles' safety-critical functions. Vehicles can perform all aspects of driving in defined environments; sometimes called "high automation."

Level 5: Vehicles equipped with features that allow drivers to become riders, relinquishing control of vehicles' safety-critical functions. Vehicles can perform all aspects of driving in any environment; sometimes called "full automation."

While Level 5 AVs might someday arrive at scale, Level 4 vehicles provide a monumental opportunity for improvements in human welfare in terms of roadway safety and economic efficiency. Both ARH and AFT can operate effectively today with Level 4 autonomous capabilities. Moreover, on the fleet model, the safety standards of ARH and AFT can be more effectively monitored than the safety standards of personally owned AVs. Level 4 ARH and AFT is an achievable step in widespread adoption of autonomous driving, which will provide safety and economic benefits.

The Safety Imperative

Human Error

Human drivers fail with disturbing frequency. When they fail, people are frequently injured or killed. In the five years spanning 2015 through 2019, motor-vehicle collisions resulted in an annual average of 36,791 deaths in the United States.[4] In the aftermath of the Covid-19 pandemic,

roadways have become even deadlier. In the three years spanning 2020 through 2022, motor-vehicle collisions resulted in an annual average of 41,471 deaths in the United States.[5] With the recent surge, motor-vehicle deaths in the U.S. now tally more than 4 million since cars took to the roadways en masse a century ago.

The World Health Organization estimates that more than 1.3 million people are killed on roadways globally each year. According to one estimate, bodily injuries from vehicular collisions will cost the world economy $1.8 trillion between 2015 and 2030.[6] Relative to its peers, the U.S. bears a heavy burden from collisions. According to an analysis from the Centers for Disease Control and Prevention, motor-vehicle deaths are 2.3 times higher in the U.S. than the average rate for 28 other high-income countries.[7]

While vehicle safety features, roadway rules, and roadway design can improve these figures, the key factor in fatal collisions is most commonly the human operator of the vehicle. Intoxication, fatigue, distraction, and simple carelessness cause human beings to lose control of the vehicles that they are driving, often injuring themselves and others as a result.

According to a 2015 National Highway Traffic Safety Administration (NHTSA) collision-causation survey, in 94% of collisions the "immediate reason for the critical pre-crash event" was the vehicle's human driver.[8] This corroborates a 1977 NHTSA-commissioned study, which found that "conservatively stated,…human errors and deficiencies were a cause in at least 64% of accidents, and were probably causes in about 90–93% of accidents investigated," and that "human factors were possibly a cause in up to 97.9% of accidents."[9]

To reduce the incidence of collisions and avoid the bodily and economic harm that they cause, there is no more powerful lever available than to remove human drivers from vehicles. McKinsey's Michele Bertoncello and Dominik Wee find that the U.S. could save up to $190 billion annually if AVs were to supplant human drivers and prevent the tens of thousands of deaths and millions of injuries that they cause each year.[10]

Autonomous Driving Safety

No comprehensive studies have yet been published on the collision risks involving Level 4 AVs. To fill this data void, AV companies have tracked and published their own on-road statistics in keeping with Department of Transportation guidance recommending Voluntary Safety Self-Assessment (VSSA).

Waymo and Cruise are ARH companies that are already offering driverless rides with customers on board. Their Level 4 vehicles provide transportation in San Francisco and Phoenix, and their data suggest that the technology is already driving more safely than humans.

In February 2023, Waymo reported on the first million miles that its ADS operated without a human driver aboard.[11] In the evaluation period, Waymo AVs were involved in 20 "contact events."[12] No injuries were reported in any of these events. Only two collisions met the criteria for NHTSA's collision database, which requires at least one vehicle to be towed. The more severe of the two cases involved a Waymo vehicle being hit from behind by a distracted human driver. Over half the incidents involved a stationary Waymo vehicle hit by a human driver. None of these incidents happened at intersections or involved vulnerable road users such as pedestrians and cyclists.

In November 2022, Cruise released a similar report on its first million miles. The results were similarly impressive, with Cruise reporting just 36 incidents.[13] In only one incident was an injury recorded. Cruise's account of the collision—which was corroborated by independent investigations—explains:

> This particular collision took place while our AV was making an unprotected left turn. At the time of collision, the other party was driving straight in a turn-only lane, and was traveling at more than 40 mph on a road with a posted speed limit of 25 mph. Although the police assigned responsibility for this incident to the other driver, Cruise chose to improve its software to avoid recurrence of this one-time event by building in additional defensive driving behaviors. We issued a voluntary recall to notify regulators and the public of this change.

The Cruise report tries to assess the performance of its AVs relative to human drivers in comparable environments—something inherently difficult because of the limited availability of data on both human drivers and AVs at this juncture. Data on the leading indicators of human-driver risk (such as frequency of hard braking) are growing but still scant. Data on the lagging indicators of ADS risk (such as observed collisions) are too limited in scope.

Cruise attempted to bridge this gap with a study conducted in conjunction with the University of Michigan Transportation Research Institute and the Virginia Tech Transportation Institute. The analysis suggests that Cruise's AVs have thus far performed significantly better than human-driven ride-hails in San Francisco, recording 53% fewer collisions, 92% fewer collisions in which its vehicles were primarily responsible, and 73% fewer collisions with a meaningful risk of injury. Of course, self-reported data must be corroborated, but if the reports from Waymo and Cruise stand up to scrutiny, they show that a safer roadway experience is within reach for the cities where ARH will be most viable.[14]

In America's five largest cities—New York,[15] Los Angeles,[16] Chicago,[17] Houston,[18] and Phoenix[19]—more than 1,200 people were killed in motor-vehicle collisions in 2022. Many of these vehicular deaths could potentially have been prevented through widespread AV deployment. Encouragingly, Cruise is expected to expand its services to Houston and Dallas in late 2023.

The same Level 4 technologies that power ARH can be used for freight trucking. Given the smaller number of variables that affect driving on limited-access highways, AFT is likely even more viable at scale than ARH.

Replacing human-driven freight trucks with AVs has the potential to improve roadway safety significantly, even though large freight trucks account for a much smaller portion of roadway fatalities than common vehicular collisions. Between 1975 and 2020, 231,575 fatalities were recorded in the U.S. from collisions involving large trucks, an average of more than 5,000 per year.[20] That figure constitutes less than 15% of total average annual roadway fatalities in an average year. In most of these collisions, however, large trucks are the cause. A Federal Motor Carrier Safety Administration analysis of 963 fatal collisions found that 55% of the time, a truck was the "critical reason" for the crash.[21] In 87% of the instances in which a large truck was the "critical reason" for the crash, the driver of the truck was deemed responsible. This means that truck-driver error accounts for about 2,400 fatalities each year in the United States. While companies are testing their technology on public roads in Arizona, California, Texas, Pennsylvania, and in several southeastern states, meaningful data on driverless miles operated by autonomous freight trucks are not yet available. Given the fundamental overlap in technology, driverless ARH operation suggests that AFT will also be a safety success. While the kinetic energy of a truck far surpasses that of a passenger car, the simpler operational domain means that risks can be managed effectively.

By facilitating the adoption of Level 4 AVs for ride-hailing and freight trucking, policymakers can begin the long journey to safer and more efficient roadways.

Status Quo Bias

With the technology ready, the main hurdle standing between ADS and U.S. roadways is fear of the unknown. As the RAND Corporation explains in *Safe Enough: Approaches to Assessing Acceptable Safety for Autonomous Vehicles*,[22] status quo bias leaves popular judgment of AVs clouded.[23] People are accustomed to human drivers, so they take existing roadway risks as given. In light of the advances we have seen in ADS technology, however, the human-driver norm looks suspect. Though people feel that AVs entail unjustified risk to public safety, the status quo poses a deadly risk to us each day. Early data suggest that Level 4 autonomous driving is safe enough for deployment in metro areas across the country. Each year that we artificially delay the development and deployment of ADS, we are condemning people to a higher probability of vehicular injury or death.

In order to win over public opinion, RAND recommends that AV developers should "forge uniform and transparent approaches to presenting evidence for meeting safety thresholds," "collaborate with state and local leaders to bring their vehicles into communities," and hold "[public] demonstrations of how AVs operate" and of "things AVs can do that might improve on human perception and reaction capabilities."[24]

In 2021, Manhattan Institute senior fellow James B. Meigs offered similar insights in a *Commentary* article, which argued that integrating AVs into the transportation mix is less of a technical challenge than it is a psychological challenge.[25] Pew survey data support that view, showing that barely 25% of Americans think that widespread use of driverless cars would be a good idea.[26] A 2023 survey conducted by the American Automobile Association delivered similar results, finding that 68% of Americans are afraid of AVs.[27]

"Today, we accept that human drivers are fallible," Meigs observes. "While we don't excuse accidents caused by driver error, our society has come to tolerate them as a cost of our car-oriented lifestyle. We see machines differently. Riding in a fully autonomous car means putting our faith in hardware and algorithms we don't fully understand. That requires a much higher level of trust."[28]

By familiarizing as many people as possible with this new, paradigm-altering technology, developers stand the best chance of overcoming the expected hurdle of popular fear. Autonomous driving technology will never remove all roadway risk, but it presents a way to mitigate it.

Autonomous Ride-Hailing

Autonomous ride-hailing will improve public welfare by displacing riskier human drivers, including, perhaps most important, drivers who are under the influence of alcohol. Each year, more than 10,000 people are killed in the U.S. in vehicle collisions involving alcohol impairment.[29] In 2021, the total was 13,384—more than one-third of all U.S. roadway fatalities. If not for the availability of existing, app-based ride-hailing services like Uber, these figures would be higher still. Ride-hailing offers an alternative to driving one's own vehicle with much lower friction than hailing a traditional taxi. By lowering the barriers to hailing a ride, app-based options induce safer behavior and reduce risk for the general public.

Christopher Morrison, assistant professor of epidemiology at Columbia University's Mailman School of Public Health, conducted a 2022 meta-analysis of 20 papers on ride-hailing and impaired driving, concluding that "the collective evidence suggests, with some exceptions, that the technology likely reduces alcohol-involved crashes." Moreover, ride-hailing options "reduce crashes in areas with underfunded public transit access."[30]

A 2021 study by Christopher R. Conner et al. concluded that the introduction of Uber to Houston in 2014 was associated with a 24% reduction in motor-vehicle crash trauma at city hospitals during peak trauma periods (Friday and Saturday nights) between 2014 and 2019. Ride-share use was also associated with "a significant, geographically linked reduction in impaired driving convictions."[31] Also in 2021, a study by Michael L. Anderson and Lucas W. Davis found that the presence of just one ride-hailing company, Uber, prevented 214 alcohol-related traffic fatalities in 2019 nationally.[32]

As the Cruise joint study indicates, ARH will improve upon the safe operation of hailed vehicles. More crucially, however, ARH will *lower the cost* of hailing a ride by eliminating the expense of driver pay. In so doing, ARH will induce greater adoption of ride-hailing, taking even more risky human drivers off the road.

According to a 2018 analysis by the Economic Policy Institute, "the share of passengers' fares that Uber claims in fees and commissions and that do not go to drivers" is only 33.2% of what riders pay—meaning that drivers receive more than 66% of the fare.[33] UBS reports that an even higher percentage, 70%–80% of gross revenue, goes to drivers.[34]

Company-owned, -maintained, and -operated fleet vehicles present a sizeable opportunity for autonomous ride-hailing to outcompete human driver ride-hailing, even as the industry flips from an asset-light model to an asset-heavy model. McKinsey concluded in 2022:

> The cost per mile for a robo-taxi could drop by more than 50 percent between 2025 and 2030. The major drivers of this reduction include lower hardware costs due to declining costs of high-performance chips, operational improvements (such as lower maintenance needs and higher overall mileage), lower costs of mobility-services provisioning due to scale, a decrease in empty miles traveled, and greater economies of scale, which distribute development and validation costs across more vehicles.[35]

This cost improvement would put ride-hailing near parity with personal car ownership, potentially catalyzing a mobility revolution not seen since the advent of the automobile age itself. The economics for rides in autonomous shuttles (pooled with other people) are even more favorable, with McKinsey projecting that from 2030 such rides will cost 40% less than the current cost per mile of personal car ownership. Should anything approaching this cost-savings become possible, the positive effect on public safety would be profound.

In addition, low-cost ARH opens new opportunities for mobility and commerce. The elderly and the young, specifically, will be more mobile and less likely to operate motor vehicles themselves, thus reducing the risk imposed by two populations with higher-than-average collision probability. A further consideration is that reducing driver costs has added importance for the ride-hailing sector amid the ongoing political offensive to compel companies to classify drivers as employees and therefore entitle them to expensive employee benefits.[36] Thus, one policy threat, at least, is spurring, rather than retarding, autonomous development.

A similar application of this technology is in last-mile autonomous delivery. Delivery is the fastest-growing portion of Uber's business. This sector of the urban economy is now witnessing the emergence of autonomous delivery vehicles, some smaller than a Radio Flyer wagon.[37] These vehicles move things like groceries around cities without a rider involved. Because they are designed for goods rather than people, these vehicles do not need heavy internal safety components and can therefore be smaller and lighter—which means safer—for the general public.

The AV industry is raucous and fast-paced. Startups abound, while auto-industry incumbents vie for future market share as well. Which companies will eventually predominate is anyone's guess; as of mid-2023, some of the companies that appear primed for success in the U.S. are Waymo,

Cruise, Zoox, Nuro, AutoX, and Pony.ai.[38] Tesla, which is adding autonomous features to privately owned cars over the air, may prove more successful—and disruptive—than any of the companies angling for the ARH market.[39]

Autonomous Freight Trucking

Autonomous driving technology may also revolutionize the freight trucking industry, a vital part of the modern market economy. According to FreightWaves, an industry analysis firm, trucking accounts for 43% of total logistics costs globally, with a total value of $4.1 trillion, a sum projected to reach $5.5 trillion by 2027. Within the U.S., trucks move about 70% percent of freight.[40] As discussed earlier, autonomous trucks could improve safety by eliminating human error that results in 2,400 fatalities in the U.S. annually. However, because trucks are already relatively safe, the most enticing aspect of automating trucking is economic.

ADS technology will allow trucking companies to provide their services at a lower cost due to the labor savings. According to the American Transportation Research Institute, wages and benefits for drivers constituted 44% of the industry's total average marginal cost in 2021, up from 34% in 2013.[41]

The American Transportation Research Institute sees driver scarcity as a major inhibitor in the years to come, projecting an industry deficit of 160,000 drivers in 2030.[42] The more acute this deficit becomes, the higher the cost of moving freight, ceteris paribus. For the trucking industry, autonomous technology is thus a compelling option.

AFT can produce savings not only by eliminating wages and benefits for drivers but also by improved efficiency. For instance, autonomous trucks will not be subject to federally mandated driver rest requirements, meaning that they can travel farther in less time, perhaps as far as double the distance in a 24-hour span. In March 2022, an autonomous Kodiak Robotics truck operating in partnership with the freight company U.S. Xpress shuttled goods between Dallas and Atlanta for five straight days, traveling more than 6,300 miles on four round trips and delivering eight loads—a task that would take a human-operated truck 10 days.[43]

Moreover, ADS technology will be more efficient than humans in vehicle operations—especially in acceleration and braking, which will lead to lower fuel consumption per mile. Boston Consulting Group estimates that even after accounting for the cost of adopting ADS technology (which could be as high as $100,000 per unit), the reduction in driver costs and improved efficiency will yield savings of 30% on the total cost of ownership.[44]

According to McKinsey, operating costs with full trucking autonomy would decline by about 45%, saving the U.S. industry $85 billion–$125 billion annually.[45] For the wider economy, AFT would provide a modest but meaningful boost by reducing the cost of moving goods. Robert Waschik, Daniel Friedman, and Catherine Taylor find in a 2021 study commissioned by the U.S. Deptartment of Transportation that under a "fast adoption" scenario, AFT at Levels 4 and 5 could lift U.S. GDP by 0.34% above baseline in 30 years, or the equivalent of $68 billion in current dollars.[46] Fast adoption would also reduce medical costs associated with truck collisions by almost $100 million annually.

Importantly, these researchers conclude that autonomous trucks will not decrease overall employment but will increase the number of U.S. jobs by as many 35,000, as more economic activity is generated. The losses in driving jobs that autonomous trucks cause will be offset by

gains elsewhere. In no scenario do the researchers find that trucking job losses would amount to more than 1.7% of driving jobs in any given year, with the largest impact being felt a decade after autonomous trucks are introduced.

Automating driving also presents the opportunity to reallocate labor to more productive tasks that would suit many erstwhile drivers while allowing them to stay closer to home and avoid roadway risks. In Singapore, for instance, truck drivers have been trained to operate logistical hubs. Another idea is for drivers to become dispatchers and responders when autonomous trucks experience problems on the road.

Autonomous trucks will facilitate growth in digital platform–based freight shipping services, such as Uber Freight, a platform that connects shippers and carriers to facilitate the transportation of goods. Uber's freight division pairs retailers, manufacturers, and other shippers with truckers, using dynamic pricing that recalibrates every 15 minutes. The platform, which launched in 2017, earned Uber $7 billion in revenue in 2022 and is considered a candidate, according to Bloomberg, for an independent initial public offering.[47] J. B. Hunt's 360 digital brokerage platform is a similar product that reportedly earned the company $1.5 billion in 2022.[48]

In the near term, however, many companies are hesitant to adopt AFT because, given the current state of the technology, they face the prospect of having to pay for expensive technology *and* labor to provide the safety of redundancy. In the Kodiak Xpress demonstration, for example, the *New York Times* reported that humans on board the truck as "safety drivers" had to grab the wheel "multiple times."[49] That has cast a pall over industry expectations. In April 2023, Axios reported that several autonomous truck startups "have stalled in recent months, leaving only a handful of players aiming to deliver on a huge promise."[50]

Rising interest rates have stifled the industry, amid a broad tech pullback. Embark Trucks, which went public through a SPAC deal in 2021, is currently in the process of liquidation. TuSimple, formerly a front-runner in the industry, is making efforts to reorganize following a period of internal discord that adversely affected its partnership with Navistar[51] and a 2022 noninjury crash that harmed its reputation.[52] Moreover, links between TuSimple and China have raised concerns among U.S. regulators. Waymo has postponed the deployment of its autonomous trucks to focus on ride-hailing. Only a few companies, including Aurora Innovation, Torc Robotics (a branch of Daimler Truck), and Gatik, are still committed to their timelines of launching autonomous trucks within the next one or two years, according to Axios.[53] Even among this group, though, not all is well. Aurora lost $1.7 billion in 2022 and is short on cash. "People have become jaded about the industry and whether they can believe it," cofounder Sterling Anderson told Axios in April. "[S]teps [like a quarter-by-quarter road map to commercialization] have to happen for this to reach the market because until now, it's been a bit of a black box."[54]

An important and achievable aim is to establish hub-to-hub autonomous trucking routes. On this model, autonomous fleet operators focus on moving trucks in a more controlled interstate highway environment while leaving loading and delivery in more congested and complicated conditions to human drivers. With the hub-to-hub approach, trucks are loaded outside cities at mass warehouse facilities or "inland ports" and moved to analogous facilities outside other cities. One such "inland port" that could serve as a leading base for hub-to-hub autonomous trucking is under construction in California's Kern County, 70 miles north of Los Angeles.[55] Uber's freight division has identified "an immediate addressable market of 25 billion miles of long-distance dry van freight on the interstate system."[56] Hub-to-hub AFT is a target around which the industry and policymakers should coalesce.

A noteworthy, if slightly less dramatic, weigh station on the path to freight automation is truck platooning, in which vehicles are "tethered" by automation at a safe distance from one another and move efficiently in the slipstream of the vehicle ahead. Prior to true Level 4 autonomous

truck platooning, a human driver would still control the platoon of trucks from the lead vehicle. According to the company Locomotion, its platooning technology has a driverless follower truck that "uses its own perception and information exchanged over dedicated short-range inter-vehicle communication (DSRC) to follow the human-driven leader truck." Locomotion claims that this technology will deliver 8% fuel cost-savings and began testing it in 2021 in Idaho and Oregon.[57]

Public Policy

Because roads are publicly owned, governments will be important in creating conditions for AVs to proliferate. Unfortunately, in a 2021 McKinsey survey of 75 executives from automotive, transportation, and software companies working on autonomous driving worldwide, most said that regulation is the biggest barrier to AV deployment, rather than technology or consumer sentiment.[58] In North America, 52% of the executives picked regulation as the "main bottleneck," compared with 29% who named technology as the bottleneck.

City Policy

Some U.S. cities are already beginning to reap the benefits of AV adoption, while others lag behind.[59] For the most part, the difference can be explained by factors outside the control of city governments, such as state policies, weather, and proximity to technology hubs.

States have primary authority in regulating the testing and deployment of AVs, which has provided a boost to some cities and proved a hindrance to others. Weather, which also affects the proficiency of human drivers, can challenge ADS by reducing the effectiveness of lidar and other technologies. This creates headwinds for northern cities that more regularly experience snow and ice. Economically and technologically advanced regions also have the advantage of drawing top talent. This confluence of nonlocal government factors has put San Francisco and Phoenix at the frontier of ARH as private companies have selected them for the earliest rollouts.[60]

Given these constraints and the primacy of the market in determining which metro areas get a crack at AVs first, what can U.S. cities do to facilitate adoption of this welfare-enhancing technology? This report offers American cities three recommendations:

1. *Allocate curb space to ride-hailing loading and unloading.*

While cabdrivers and human ride-hail drivers have no compunctions about stopping in busy urban traffic, turning on the flashers, and picking up or dropping off a rider, ARH vehicles do. Desiring to remain in compliance with traffic laws and procedures, ARH companies program vehicles not to double-park, even if only to enable a rider to hop into or out of the vehicle. The result is that riders will often be dropped off blocks away from their intended destinations or asked to meet a car blocks away from their real origin points. Compliance with the letter of the law thus puts ARH at a disadvantage relative to human-driven vehicles.

This disadvantage could slow ARH adoption. To remedy the problem, cities could allocate more curb space to loading and unloading passenger vehicles, creating safe, legal places at short intervals where people can grab a ride. Like any policy decision, there would be a trade-off—namely, a loss of street parking. One market mechanism that could allocate space fairly to different road users and other interested parties would be to auction off such space, allowing ARH companies, perhaps in consortium, to purchase scarce curb access. Alternatively, cities could expressly permit double-parking for the brief loading and unloading period. Another idea would be to charge companies

for permission to double-park for such brief periods. Loading and unloading of passengers should not be as big of a challenge as it is for ride-hailing companies that wish to remain in compliance with the rules of the road.

2. *Add autonomous ride-hails to the categories of vehicles that qualify for use of some special-access roads.*

Level 4 ARH is currently barred from some areas where riskier human-driven taxis are permitted. In January 2020, San Francisco converted one of the most important public thoroughfares in the city, Market Street, to a private-car-free zone. East of Van Ness, Market Street is now accessible only to buses, licensed taxis, and motorcycles. App-based ride-hailing services are prohibited, as are all other transportation network companies.[61] Unlike app-based ride-hailing with human drivers, however, ARH will be fleet-based, not relying on a vehicle owned by an individual. It is, in that sense, distinct from the current app-based ride-hailing model. Authorizing ARH is safe and efficient, and it enhances public welfare; adding this category of vehicle to restricted lanes would encourage adoption. Market Street and others like it across the country should include ARH, particularly in the case of multi-rider shuttle vehicles.

Another related recommendation to encourage adoption is to permit ARH to use high-occupancy vehicle (HOV) lanes even when only one rider is aboard. HOV lanes tend to allow human-driver ride-hails. Allowing ARH will prevent the perverse incentive to choose human-driver ride-hail over ARH to reach a destination faster via the HOV option.

3. *Implement congestion pricing.*

One potential pitfall with ARH is that it might create a "zombie car" problem, with driverless vehicles continually plodding through cities while they await their next fare, causing congestion.[62] Though companies are incentivized to find fares quickly by the revenues they generate and to save energy by the cost of fuel, unpriced road space artificially increases the number of cars on the road at a given time.

By pricing road usage through a vehicle tracking system, cities can align ARH deployment with market dynamics. With roads (and parking spaces) credibly priced, companies will have to reckon with the cost of using a shared resource before deploying vehicles. Singapore is a model here. Since 1979, Singapore has used Electronic Road Pricing (ERP) to control traffic flows within the city. ERP has bolstered the city's reputation for safety, livability, cleanliness, and efficiency. U.S. cities would benefit from such an approach to the scarce resource of road space irrespective of AVs, but the "zombie car" problem adds urgency.

State Policy

America's federal system puts state governments in the proverbial driver's seat on AVs. Each state has the opportunity to be a catalyst for AV adoption, but not all states are logical entry points for competitors in the AV industry. Two states that are logical entry points are California and Texas. They merit special attention, particularly with respect to AFT.

California vs. Texas

California and Texas are the two largest states by area in the contiguous U.S., the two largest by population, and the two largest in terms of GDP, together making up almost a quarter of U.S. economic output. Moreover, both have several key economic and logistic hubs. According to the 2020 census, California and Texas hold six of the top 10 U.S. cities by population (Los Angeles, Houston, San Antonio, San Diego, Dallas, and San Jose)[63] and four of the top eight combined

statistical areas (Los Angeles, Dallas, Houston, and the San Francisco Bay Area). Both states have leading agricultural economies in their sparsely populated regions and both abut Mexico, America's top trading partner.[64]

Freight connections between these economic nodes are critical to American commerce, and autonomous trucks can strengthen them. On autonomous trucking—as on many other policy issues—the two states are charting divergent courses, with Texas creating the more welcoming environment for deployment of the new technology, despite California's global leadership in technological development.

Texas is a hotbed for AFT testing. Aurora has been hauling freight for FedEx between Houston and Dallas since 2021 and between El Paso and Fort Worth since 2022.[65] Trucks on these routes have so far had safety drivers aboard; but in April 2023, Aurora announced that its technology is "feature complete" and that it has a plan to operate driverless in Texas, beginning next year. Alongside the ADS completion, Aurora announced that it has a commerce terminal ready for its autonomous trucks. According to the *Dallas Morning News*, the terminal, located south of Dallas in Palmer, already deploys trucks pulling freight for pilot customers such as FedEx, Schneider, and Uber Freight between Dallas and Houston.[66] The terminal, according to Aurora Vice President Kendra Phillips, "has all of the tools, features, functionalities, processes, people, to ensure that we can perform all of the autonomous activities at the terminal, perform all the traditional transportation activities at the terminal and allow customers to run their load as they normally would in their supply chain through our terminal network with our autonomous trucks."[67]

Aurora expects a second terminal in Houston to be ready by late 2023, positioning the company for its driverless hub-to-hub launch next year. Gatik, Waymo, Kodiak, and TuSimple also have operations testing and transporting goods in the Dallas area.

Underpinning Texas's adoption of autonomous trucking is alignment between public policy and technology progress. In 2017, Texas passed an AV bill permitting the testing and deployment of driverless vehicles without the need for special registration, data-sharing, or additional insurance requirements. The law prevents local cities from imposing additional requirements.[68]

The bill amended the state's transportation law with a new subchapter stipulating:

> When an automated driving system installed on a motor vehicle is engaged the owner of the automated driving system is considered the operator of the automated motor vehicle solely for the purpose of assessing compliance with applicable traffic or motor-vehicle laws, regardless of whether the person is physically present in the vehicle while the vehicle is operating; and the automated driving system is considered to be licensed to operate the vehicle.

This abiding openness to technology, what policy scholar Adam Thierer calls "permissionless innovation," is what has made the Lone Star State the national leader in AFT. "Permissionless innovation," as Thierer describes it, refers to the idea that "experimentation with new technologies and business models should generally be permitted by default. Unless a compelling case can be made that a new invention will bring serious harm to society, innovation should be allowed to continue unabated and problems, if they develop at all, can be addressed later."[69]

In what can only be interpreted as a swipe at California—Texas's West Coast rival—Waymo's state policy manager, Aidan Ali-Sullivan, told Reuters in 2022 that "there are other states that have really great ports or connections, but they don't have the same regulatory environment that Texas has."[70]

Though California has been an early adopter of ARH, the state's autonomous trucking future is stuck in neutral. While Texas already allows ADS to operate trucks as if they are licensed drivers with no human aboard, California's Department of Motor Vehicles expressly forbids the testing of ADS on vehicles with a gross weight greater than 10,000 pounds on public roads even *with* a human aboard. This effectively rules out testing any vehicle affixed with autonomous technology larger than a pickup truck.

Autonomous freight trucking's prospects in the Golden State could soon get even worse. A bill backed by the Teamsters' union, AB316, was filed in January 2023 and is now under consideration in the California Senate after passing the Assembly and the Senate Transportation Committee in July.[71] The bill would prohibit the operation of all autonomous trucks over 10,000 pounds for testing purposes, for the transportation of goods, or for the transportation of passengers without a human operator physically present in the vehicle.[72] The cost of ADS on top of the cost of labor for a human aboard makes this arrangement uneconomical and could prevent the state from achieving the supply-chain improvements that would push its economy forward.

Even the possibility of such a bill is inhibiting autonomous freight development in the state. "Despite the fact that many of the leading companies are based in California [and] are providing a lot of economic value in California, Californians themselves don't get the benefit of AV trucks, because some in the state legislature are threatening to disrupt it," Jeff Farrah, executive director of the Autonomous Vehicle Industry Association, told *Bloomberg Law* in March.[73]

A 2021 report from the Silicon Valley Leadership Group analyzes the effects that autonomous trucks could have on California's economy. In the report's fast-adoption scenario, autonomous trucks would spark a 0.35% increase in California's real GDP relative to baseline growth, the equivalent of almost $8 billion relative to 2019 GDP. It would also boost the for-hire trucking industry's California output by 4%, improve fuel efficiency, and reduce fatalities and safety costs. In the fast-adoption scenario, the report finds that—contra the labor movement's insinuations—California's total employment would increase by approximately 2,400 jobs.[74] Indeed, the effect on employment is estimated to be positive under all adoption timelines.

Looking Abroad

Due to the nature of the American federal system, some national governments abroad are more akin to our state governments vis-à-vis transportation policy than to our federal government. U.S. states can learn from the policies that some of these countries—especially Singapore and Japan—have set for autonomous vehicles.

The Southeast Asian city-state of Singapore, by dint of its geography and governance, has both advantages and limitations that U.S. jurisdictions do not, but it nevertheless can serve as a policy North Star. KPMG, a consulting firm, recognized Singapore in 2020 as the top country in the world in its Autonomous Vehicles Readiness Index.[75] The index takes into account four categories: policy, technology, infrastructure, and public receptivity. In these categories, Singapore ranks 1st, 11th, 5th, and 1st, respectively.

The index divides policy, where Singapore is at the forefront, into seven subcategories: AV regulations, government AV funding, AV-focused agencies, the "future orientation" of government, legal-system efficiency, government readiness for change, and the data-sharing environment. Richard Threlfall, KPMG's global head of infrastructure, states: "Singapore has embedded AVs into wider goals, including greater use of public transport, wider use of EVs and economic development from research-focused jobs."[76]

AVs are one of three prongs of Singapore's "Strategic National Project" on "Smart Urban Mobility," alongside contactless transit fare payment and open data and analytics.[77] Singapore's Land Transport Authority (LTA) oversees AV programs and actively champions their development. LTA guidelines require companies to obtain a permit from LTA, demonstrate the competency of their AVs, and meet specific insurance requirements. "Singapore is increasingly facing urban mobility challenges such as land and manpower constraints, an ageing population, and rising expectations for a comprehensive and efficient public transport system," LTA states. "Innovative mobility solutions, through technology such as AVs, can help us overcome these challenges and needs effectively and sustainably."[78]

LTA's support for AVs goes beyond endorsement on paper. In 2016, the government announced a $100 million fund to support R&D in intelligent transportation systems, including AV technology. That year, nuTonomy began the first ARH tests on public roads.

The Singaporean government certifies vehicles in concert with the Centre of Excellence for Testing and Research of Autonomous Vehicles–Nanyang Technology University, which features a two-kilometer test circuit replicating urban road conditions. Singapore has now approved more than 40 AVs for on-road testing and is in the process of rolling out autonomous ride-hails, multi-rider shuttles, street sweepers, and baggage-handling vehicles at Changi Airport. All public roads in western Singapore are now open to AV testing. In 2021, autonomous buses were opened to commuters at Science Park II and Jurong Island, reflecting Singapore's goal of integrating AVs into its wider transportation ecosystem.[79]

Beyond direct AV policy, Singapore gets top marks for the quality of its roads (which rank first, globally) and national technology infrastructure (which ranks third, globally). These two advantages prime it for vehicle-to-infrastructure (V2I) connectivity.

The city-state also has an advantage in public acceptance due to the visibility of AV testing in the urban environment. As explained in the KPMG report, "The more people see AVs on the road, the more comfortable that they are likely to use them when they become available, so countries with a higher proportion of population that live in cities where AV pilots and testing are underway scored the highest."[80] While there may be an impulse to test AVs away from population centers to avoid risk, siting tests out of the public eye may hinder the commercial viability of the technology.

Singapore's only ranking outside the global top five is on technology, a by-product of its small market size relative to other countries. Remaining uncertainty around technological progress has, as of mid-2023, precluded rapid commercialization in Singapore. Combining large U.S. markets and tech with Singapore-like policies could be the ideal recipe for AV development.

For AFT, Japan is an international bright spot. Suffering from long-term demographic decline and its labor effects, Japan is especially keen to incorporate autonomous technologies into its economy wherever possible. In transportation, this has engendered an exemplary openness to AFT.

Japan has designated a lane for autonomous trucks on its most heavily trafficked highway. *Nikkei Asia* reports that this special lane on the Shin-Tomei Expressway will span about 60 miles from Numazu to Hamamatsu, south of Mount Fuji. The segment's lengthy straightaways should provide optimal conditions for the deployment of autonomous trucks when the lane opens in 2024.[81]

Beyond the special designation, this development is intriguing because it will involve the use of V2I technology that enables communication between AVs and signals from the roadway infrastructure itself. V2I can coordinate traffic, or, as KPMG puts it, "orchestrate how vehicles operate for the benefit of all users."[82] The technology could be an important complement to ADS, further improving safety and efficiency on limited access highways and city streets.

State Policy Recommendations

1. *Devote a state policy office to AVs.*

States should devote regulatory resources to this technology so that a lack of state attention to applications and emerging conflicts does not become the bottleneck that stops it from rolling out at scale. A good way for states to start is to devote an office to AVs and to amply staff it. Marc Scribner, senior transportation analyst at Reason Foundation, describes such an office as "a clearinghouse and coordinating body for the variety of policy decisions that must be made across a number of agencies."[83] Such an office could serve as an umpire if a state's agencies diverge in their guidance to companies or judgments on various matters. Texas has such an office, the Connected and Autonomous Vehicle (CAV) Task Force. The Texas Department of Transportation launched the CAV Task Force "to provide the state with a single, unified resource for information regarding the coordination and advancement of CAV technologies across the state. Members include representatives from other state agencies and public entities, as well as key industry stakeholders."[84]

For large states such as California, avoiding regulatory diversity among their major cities is important. To provide the best access to their citizens, these large states should unify their internal regulations and preempt cities from locking out innovation. States such as California are ripe for AV investment, given the number of economically important cities that they encompass, and should set policy to leverage this advantage.

2. *Treat ADS more like human drivers.*

In addition to mimicking Texas's CAV Task Force, other states should adopt its treatment of ADS. The Texas model considers the owner of an autonomous driving system the operator of the vehicle engaging autonomous technology for the purpose of assessing compliance with existing traffic and motor-vehicle laws. This approach establishes an achievable baseline for ADS roadway performance and facilitates permissionless innovation as developers compete for incremental performance improvements.

3. *Invest in quality infrastructure, but avoid committing to V2I too early.*

While AVs can operate in isolation, they will be even safer and more efficient when connected via communications technology. This creates the temptation to invest not only in basic infrastructure but also in vehicle-to-infrastructure technology. V2I may someday be viable, but with competing technologies still emerging from infancy, it is too early to lock in a certain set of standards on public infrastructure.

The federal Department of Transportation is working closely with the Intelligent Transportation Society of America (ITSA), an industry consortium, to craft vehicle-to-everything (V2X) standards. In April, ITSA published its National V2X Deployment Plan.[85] According to the department, it has conducted spectrum interference testing with its industry partners and made the test data publicly available, and it has coordinated with the National Telecommunications and Information Administration and the Federal Communications Commission on issues such as granting waivers to permit immediate deployment of equipment that operates on the Cellular-V2X communications protocol. As we have seen with the evolution of electric vehicle charging stations, technical standards evolve over time and can be best driven by the private market. Committing to one form of V2I technology could prove wasteful or wholly unnecessary.

States should monitor communications developments that could facilitate V2I and V2X; but for the time being, they should focus on maintaining and improving standard roadway infrastructure. One reason for Singapore's place at the top of the KPMG rankings is the quality of its roads. Prosaic as it seems, managing the surface on which AVs operate is a baseline requirement for making a state attractive in the marketplace.

Federal Policy Recommendations

The federal government has thus far taken a backseat on AVs. Gary Marchant, professor of law and director of the Center for Law, Science and Innovation at Arizona State University, described the nature of the federal government's current approach as "soft law," meaning "measures that are not directly legally enforceable but that can, nonetheless, sometimes create substantive obligations," as opposed to "hard law" such as statutes and regulations. According to Marchant, "soft law has many advantages over hard law. It is more flexible and adaptable. It is easier to experiment with soft law, seeing what works and abandoning what doesn't." For AVs, Marchant writes, "[s]oft law, such as private standards being established by various standard-setting organizations, has a chance of working effectively in cases like this because companies want to avoid the government moving on to formal regulations, which could impose more costs and constraints."[86]

Proactive actions from Washington could contribute in important ways to Americans' access to ADS.

1. *Remove the cap on the manufacturing of vehicles designed for autonomous driving.*

The existing federal approval process for vehicle manufacturing creates a dilemma for the makers of AVs. Zoox and Cruise, two companies that have designed autonomous-only vehicles, have taken divergent approval paths; both have run into problems.

Zoox has opted to "self-certify" and has been met with an NHTSA challenge to such an approach. NHTSA stated in March 2023 that it is opening an audit query to determine whether the Zoox "certification basis depended upon unilaterally developed test procedures or determinations that certain standards were inapplicable due to the unique configuration of the vehicle."[87]

Cruise, on the other hand, has applied for a Federal Motor Vehicle Safety Standards (FMVSS) exemption rather than "self-certifying." FMVSS are developed and enforced by NHTSA pursuant to the National Traffic and Motor Vehicle Safety Act of 1966, which is now codified in 49 U.S.C. Chap. 301.[88]

Existing FMVSS require that vehicles sold to the public have such features as steering wheels and windshield wipers. The Cruise Origin, a multi-rider shuttle vehicle, designed solely for autonomous operation, has no use for such features and thus requires an FMVSS exemption. Current law, however, unreasonably restricts the number of vehicles that a manufacturer may produce if granted an exemption.

Even if granted an exemption, manufacturers are limited to 2,500 units annually for two years. This cap strains the economics of vehicle manufacturing. Without the ability to produce at scale, manufacturers will not make the autonomous-only vehicles that existing technology enables.

These are the very vehicles that will enhance urban connectivity, safety, and efficiency, if given the regulatory go-ahead. McKinsey, as noted earlier, projects that riding in shuttle vehicles could prove well more affordable than personal car ownership by the 2030s. A first step is to lift the cap. In the long run, the entire body of FMVSS regulation will need to be remade for the autonomous paradigm. In the meantime, Congress should raise the cap significantly or eliminate it altogether.

The SELF Drive Act[89] and the AV START Act[90] are two bills that address the FMVSS exemption cap, the former raising it from 2,500 to 100,000 and the latter to at least 80,000. Both bills have languished on Capitol Hill for five years.

2. *Address problems with AVs in an ex post rather than ex ante manner.*

Federal agencies have important authorities for preserving a reasonable level of safety on public roads, but rather than prescribing the way in which manufacturers should produce AVs, it should address the effects of AVs if and when problems arise. The National Transportation Safety Board (NTSB) and NHTSA are two agencies that have valuable ex post roles.

NTSB is the lead investigator of transportation mishaps. Congress should increase the budget for NTSB to investigate collisions involving AVs. Providing more information on the dynamics of AV-related crashes will shed light on their strengths and weaknesses and is likely to bend public opinion in their favor. Well-resourced investigations will improve public and private understanding of AV capabilities. Corroborating, or perhaps contradicting, the safety recordkeeping of companies with AVs on the roads is decidedly in the public interest.

Similarly, NHTSA should continue to utilize its recall authority when merited. In 2023, NHTSA issued a recall on vehicles with Tesla's Full Self-Driving technology. NHTSA argued that the software update allowed vehicles to "exceed speed limits or travel through intersections in an unlawful or unpredictable manner increases the risk of a crash."[91] Recalling an autonomous driving system that enables such violations is appropriate, provided that the agency leaves open a viable path to compliance.

Addressing problems ex post preserves the freedom for companies to think creatively about solving transportation quandaries and keeps them within guardrails where needed. An ex post orientation allows companies to optimize for outcomes rather than government-preferred processes.

3. *Use the power of federal highway funding to induce state receptivity to autonomous trucks.*

The interstate commerce that freight trucking makes possible is vital to America's economic success, and Congress should use its authority to bring states into the age of autonomous connectivity. One way to do so is to condition highway funding on autonomous trucking receptivity.

As early as 1934, Congress used this technique to encourage states to address federal concerns, reducing state highway apportionment by up to one-third if states excessively diverted gasoline tax receipts to non-highway purposes.[92] Likewise in 1978, Congress bolstered the national speed limit by requiring that up to 5% of a state's base apportionments be forfeited if more than some portion—as determined by the Secretary of Transportation—of the traffic in the state was traveling faster than 55 mph.[93] Since then, the penalties have been alcohol-related, starting with the federal push for states to adopt a drinking age of 21. The Supreme Court upheld this specific use of the spending power in *South Dakota v. Dole*.[94]

The commercial ramifications, in addition to the safety benefits, provide ample justification for Congress to induce states to welcome autonomous trucks. One objective way to gauge receptivity to AFT is by testing permitting standards. States need not follow identical playbooks, but permitting autonomous truck testing on public roads should be standard. To speed development and adoption of this high-leverage supply-chain technology, Congress should condition federal funds on test permitting.

Conclusion

This report highlights the value of AVs and demonstrates that their benefits can be attained in the near future, policy willing. Someday the vision of personal cars that can take us anywhere at the push of a button may be reality, but ARH and AFT are realistic and ready-to-deploy improvements over the status quo.

The most significant advantages that AVs will bring are enhanced roadway safety and reduced transportation costs, leading to economic benefits. ADS are rapidly surpassing the safety performance of human drivers. With their 360-degree vision, adherence to traffic laws, and immunity to human distractions, AVs already outperform human drivers in many situations.

In the U.S., more than 40,000 people die annually in motor-vehicle accidents, mostly due to human error. Eliminating human error provides a substantial opportunity for improving safety. Initial results from autonomous driving in cities indicate that AVs are 50% less likely to be involved in collisions. Furthermore, AVs offer the potential for significant cost-savings. As companies scale autonomous technology, they will be able to offer ride-hailing and freight trucking services at lower prices compared with the current labor-constrained market. ADS have the potential to reduce ride-hailing fares and freight trucking costs significantly. ARH and AFT can bring about these improvements within the framework of Level 4 automation, wherein vehicles can perform all driving functions in defined environments.

Local governments can be better hosts for ARH by resolving loading and unloading problems, granting ARH access to special roads, and implementing congestion pricing that will smooth demand for scarce road space.

State governments can accelerate autonomous developments by devoting an office to the many issues that will arise with this new, paradigm-shifting technology, treating ADS more like human drivers, and investing in quality infrastructure that will facilitate autonomous freight on limited-access highways without "locking in" technology that is still in its nascent stages.

The federal government can move the country toward a safer, more prosperous autonomous driving future by raising the manufacturer cap on AVs, addressing problems in an ex post manner, and incentivizing states to join the race for next-generation transportation.

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MI collegiate associates Will Hanna and Michael Oved assisted with research for this report.

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