U.S. Chamber of Commerce
Technology
Engagement Center

# Innovation Highway:

## Unlocking the Social and Economic Benefits of Autonomous Vehicles

Robert Shapiro and Isaac Yoder

**July 2023**

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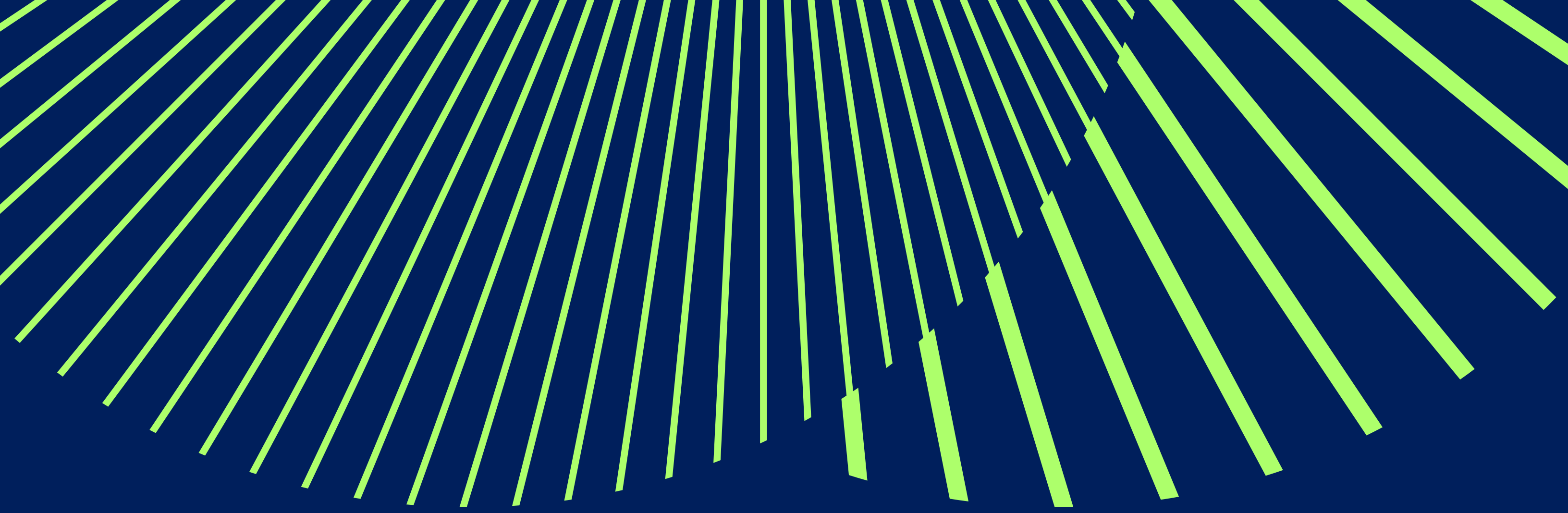

# Executive Summary

This report examines the potential social and economic benefits of autonomous vehicles (AVs). The U.S. and global markets for AVs will be extensive, and companies in the United States, China, Japan, and elsewhere are competing to develop and market them. The appeal and benefits of AVs rest on their potential to sharply reduce traffic accidents, enhance people's mobility and access (especially for those who have physical or visual limitations), reduce greenhouse gas emissions, and provide substantial economic benefits for the public. This report presents econometric models to estimate those potential benefits.

Estimates of when AVs will be widespread vary, depending on one's views about the pace of technological progress, consumer acceptance, the development of a conducive regulatory framework, and other factors. Most analysts expect high-level AVs (Levels 4 and 5) to enter the market in the next decade, and forecasts for widespread sale and adoption of these vehicles range from 2035 to the 2050s. Today, numerous companies across the United States are testing and deploying AVs on public roads. Because we cannot know precisely when and to what extent Americans will adopt AVs, our models project the likely effects when AVs constitute 25% or 50% of the U.S. motor vehicle fleet. We focus mainly on the nearest-term scenario, a 25% adoption rate. Because we also do not know the precise technologies of those AVs, our models project the likely effects for three stages of AV operations and technology based on the multimodal traffic flow model developed by the European Union's AV project.

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1. Here, the European Union project's terms for the three levels of AV technology are retitled as Basic in place of "Cautious," Standard in place of "Normal," and "Advanced in place of "All-Knowing."

1. Basic AVs:  Programmed to take a safe approach on braking distances, maintain sizable gaps for lane changes, and travel through intersections without signals.

2. Standard AVs:  Programmed to follow traffic laws and operate like an unimpaired human driver with sensors to determine distances and speeds of other vehicles.

3. Advanced AVs:  Programmed with high levels of sensor awareness and predictive capacity and the capability to cooperate with other AVs, resulting in smaller gaps in all maneuvers.

**Safety and Health Benefits:**

We found that accident rates would fall sharply (compared with accident rates in 2021) if AVs represented 25 percent of U.S. motor vehicles.

- With Basic AVs, we estimate 571,000 fewer accidents with 5,000 fewer fatalities and economic savings of $38 billion. With Standard AVs, we estimate 1,145,000 fewer accidents with 9,000 fewer fatalities and economic savings of $75 billion. With Advanced AVs, we estimate 1,442,000 fewer accidents, 12,000 fewer fatalities, and $94 billion in savings.

**Mobility and Access Benefits:**

We found that at a 25% adoption rate, Standard and Advanced AVs should markedly enhance mobility and access for elderly people and nondrivers, and Advanced AVs should also greatly enhance mobility for persons with disabilities.

- Although Basic AVs would not significantly enhance mobility, Standard AVs should increase annual vehicle miles traveled (VMT) by older people by a total of 2.5 billion miles and the VMT of nondrivers by 1.3 billion miles. Advanced AVs should increase the annual VMT of persons with disabilities by 4.6 billion miles, the annual VMT of older people by 4.9 billion miles, and the annual VMT of nondrivers by 2.4 billion miles.

**Climate and Environmental Benefits:**

We found that a 25% adoption of electric Advanced AVs should significantly reduce CO2 and NOx emissions, while also accounting for emissions associated with generating the electric power for AVs. Because electric vehicles produce no exhaust, the net benefits depend on those associated gains and the traffic and fuel efficiency of AV operations, less the emissions from the grid generating the electric power of AVs. We estimate the net benefits using three possible configurations for the grid based on the continued use of fossil fuels with greater or lesser use of substitutes:

1. Climate+: Grid with enhanced use of sustainable fuels and less use of fossil fuels.

2. Climate Neutral: Fossil fuels continue to dominate the grid without an enhanced role for sustainable energy.

3. Median Grid: The median between these alternatives.

We use motor vehicle CO2 and NOx emissions in 2021 as a baseline to estimate the net changes in emissions with a 25% adoption rate of electric-powered Advanced AVs.  (Notably, emission reductions would be greater with Standard AVs or Basic AVs because Advanced AV operations require more electrical power than Standard or Basic AV operations).

- With a 25% adoption of Advanced AVs and a Climate + grid, CO2 emissions related to motor vehicles would be 8.2% lower, and NOx emissions would be 8.9% lower.

- With a 25% adoption of Advanced AVs and a Climate Neutral grid, CO2 emissions should fall 5.9%, and NOx emissions should fall 6.4%.

- With a 25% adoption of Advanced AVs and a median grid, CO2 emissions should be 7.1% lower, and NOx emissions should be 7.7% lower.

**Economic Competitiveness:**

The report also examines the economic importance of U.S. competitiveness in the production and adoption of AVs. The U.S. motor vehicle industry is a vital source of jobs for Americans. In 2021, American motor vehicle and parts manufacturers and dealers directly employed 2,922,000 people. In addition, their suppliers employed 1,270,000 people creating the industry's intermediate inputs, for a total 4,192,000 jobs. With the introduction of AVs, these employment numbers will increase.

We also expect the composition of that employment to shift toward more highly paid, technologically related jobs in software, computers, and telecom equipment and services.

The adoption of AVs will have other economic benefits. At a 25% adoption rate, annual savings from fewer accidents should total up to $94 billion (in 2021 dollars). The mobility benefits of AVs include gains in jobs and income for nondrivers, people with disabilities, and people living in areas with little access to public transit.

Further, many technologies developed for AVs can be used in other areas, from mining to spacecraft, creating jobs to support those activities.

As U.S. and global markets for AVs grow, American producers will face strong competition from state-subsidized Chinese manufacturers and other foreign competitors. In this rivalry, the United States has a technological edge because U.S. companies dominate the world's top producers of software, computers, and telecom equipment and services. China's advantage comes from its extensive state subsidies for Chinese AV makers. U.S. policymakers can level the playing field by actively promoting the safe and secure deployment of AVs in the United States.

# Innovation Highway:

## Unlocking the Social and Economic Benefits of Autonomous Vehicles[2]

## I. Introduction and Summary of Results

This report explores the large potential social and economic benefits of autonomous vehicles (AVs). Investments in research and development and the initial commercialization of AVs and their underlying information and communications technologies have increased sharply over the past decade, and some automated driving technologies, such as lane-keeping assist systems and adaptive cruise control, are already common.[3] From extensive literature on the ways that automated driving could affect people's lives, we focus here on three areas: safety, mobility, and the environment. We also outline the economic importance of U.S. leadership in AVs.

Regarding safety, more than 90% of traffic-related deaths, injuries, and property damage arise from driver errors or failings, including driving under the influence of alcohol or drugs, distracted driving, excessive speed, and driver exhaustion. This report finds that AVs should dramatically reduce traffic accidents, fatalities, injuries, and property damage.

Regarding mobility, we found that shared-ride AVs linked to public transit systems should significantly expand access to employment, shopping, health care, and other activities for millions of nondrivers, persons with disabilities, older people, and people whose access to personal vehicles is limited by their incomes or location. Regarding the environment, adoption of electric-powered shared-ride AVs should substantially reduce greenhouse gas emissions and other pollutants.

To estimate the extent of these benefits, we also examine the potential costs associated with wide use of AVs. For example, as millions of mobility-impaired or restricted Americans gain greater mobility and access through AVs, their total vehicle miles traveled (VMT) will increase, resulting in more greenhouse gas and other emissions. Similarly, people traveling without the burdens of driving may find that they can relax during their trips and also increase their VMT.

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[2] We gratefully acknowledge the U.S. Chamber of Commerce's support of our research. The analysis and conclusions are solely those of the authors.

[3] Like, Chen, and Chen (2022).

Here, we assume the gradual acceptance and adoption of AVs over the next two to three decades. Public acceptance of AVs will also be helped by manufacturers that gradually introduce incremental automated driving features in conventional vehicles, a process now underway. Convincing many Americans that they can safely cede most or all their personal control over vehicles will depend on strict safety requirements and assurances, and the development of some of these features may require legislative and regulatory action. Similarly, the potential mobility benefits of AVs will be affected by local policies to route shared-ride AVs through areas now underserved by public transit and then intersect them with current transit routes. Another factor that increases the potential environmental benefits of AVs is providing incentives that favor shared-ride AVs and increased use of electric battery or other nonexhaust technologies in AV fleets.

We also consider the role of motor vehicle producers in employment. The manufacture and sale of motor vehicles and parts were responsible for nearly 4.2 million American jobs in 2021. Worldwide, 66 million vehicles were sold in 2022 for $4 trillion, and companies in China, Japan, the United States, Europe, and Korea dominated their manufacture.

The commercial introduction of AVs will quickly intensify competition among the United States, China, and others to lead the global market in AV production and sales, with large consequences for global leadership in many critical technologies.[4]

## Key Results

To estimate the net benefits that AV adoption in the United States could provide in terms of enhanced safety, greater mobility and access, and reduced emissions, we created models that incorporate the primary factors that affect outcomes in those areas, informed by the findings from previous studies. Because we do not know the pace at which AVs will be accepted and deployed, we created baselines in which 25%, 50%, 75%, and 100% of motor vehicles have AV technologies. Our analysis emphasizes the 25% adoption rate because the accuracy of econometric models diminishes as the forecast period increases.

Because AVs are under development and their technologies continue to evolve, we also cannot confidently predict their precise capabilities. Rather than assume an artificial standard, we adopt an approach used by other researchers and examine three modes or stages based on technology and driver behavior: (1) “basic” AVs programmed to drive like a cautious driver who obeys speed limits and always maintains safe distances from other vehicles, (2) “standard” AVs programmed to drive like people who obey traffic laws but do not make mistakes or drive in any impaired way, and (3) “advanced” AVs with programming that communicates with other vehicles and road infrastructure and uses artificial intelligence (AI) to assess what other drivers will do before responding. The key results from these simulations follow.

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4. Motor vehicle manufacturers and IT companies that develop AVs and their critical technologies include China, Japan, the United States, Germany, South Korea, Sweden, the United Kingdom, France, and Finland. See Nunno (2021).

## Safety and Health

- Our analysis found that 25% adoption of AVs should produce significant safety and health benefits with major economic and taxpayer savings under all three modes of AV operations.
- Using 2020 accident rates and cost estimates and a 25% adoption rate, Basic AV operations should result in 571,000 fewer accidents (down 11%) with 5,000 fewer fatalities, economic savings of $38 billion, and $3.3 billion in taxpayer savings. Standard AV operations should bolster these benefits through 1,145,000 fewer accidents (down 22%), 9,000 fewer fatalities, economic savings of $74.8 billion, and $6.6 billion in taxpayer savings.
- Similarly, Advanced AVs with the 25% adoption rate should reduce accidents by 1,442,000 (down 28%), with 12,000 fewer deaths, and should result in $94.2 billion in economic savings and $8.3 billion in taxpayer savings.

## Mobility

- At 25% adoption rates, Standard and Advanced AV technology and operations should produce meaningful mobility benefits for older people and nondrivers, and Advanced AV technology should produce those benefits for people with disabilities.
- Using 2017 population estimates for these groups and 2020 average VMT, access to Standard AVs should increase the total VMT of older people by 2.5 billion miles (2.4%) and the total VMT of nondrivers by 1.3 billion miles (1.7%).
- Similarly, access to Advanced AVs should increase the total VMT of people with disabilities by 4.6 billion miles (1.2 percent), the total VMT of older people by 4.9 billion miles (4.8%), and the total VMT of nondrivers by 2.4 billion miles (3.1%).

## Greenhouse Gas Emissions and the Environment

- Assuming that AVs will be electric vehicles that do not produce carbon dioxide (CO2) and nitrogen oxide (NOx) exhaust, their environmental benefits depend on the fuel efficiency of their operations and the gains from their electric powertrains, less the emissions produced generating the electric power. As a result, the environmental benefits depend on the grid's use of sustainable energy versus fossil fuels.
- Assuming a 25% adoption rate of Advanced AVs, the baseline of current motor vehicle emissions, and a grid that uses significantly more sustainable sources of energy, we estimate that CO2 emissions will be 8.2% less, and NOx emissions will be 8.9% less.
- With the same assumptions and a grid that uses the current mix of sustainable energy sources and fossil fuels, CO2 emissions should be 5.9% less, and NOx emissions should be 6.4% less.
- The median of these results would be 7.1% less CO2 and 7.7% less NOx emissions.

## AV Technology

Before examining the benefits of AV adoption in greater detail, we will review its basic features. The Society of Automotive Engineers and the National Highway and Traffic Safety Administration (NHTSA) distinguish five levels of automated vehicles, from cruise control to fully autonomous operations.[5] Today, Level 1 and Level 2 vehicles have automated features, as distinct from truly autonomous vehicles, and are on the roads in the United States and elsewhere. In addition, limited versions of Level 3 vehicles are becoming available, and more than 80 companies are testing and deploying AVs in 30 states and 120 cities across the United States.[6]

- Level 1: Vehicles with one or more automated basic features, such as cruise control, and the driver performs all other tasks.
- Level 2: Vehicles with two or more automated features that work together, such as lane keeping and adaptive cruise control, and the driver performs all other tasks.
- Level 3: Vehicles capable of driving themselves under certain traffic and other conditions, and the driver takes control when signaled to do so by the vehicle's systems.
- Level 4: Vehicles capable of driving themselves under certain traffic and environmental conditions and continue to operate if the driver does not intervene when signaled.
- Level 5: The vehicle is fully autonomous.

AVs need to account for variations in weather, natural light, geography, road conditions, and the placement and movements of other vehicles and pedestrians. To do so, Level 4 and Level 5 AVs use an array of sophisticated technologies to transmit, collect, and analyze large streams of data accurately. These technologies often include next-generation GPS to precisely triangulate a vehicle's positions; 360-degree radar and LiDAR sensor systems using radio waves and light beams to determine exact distances between obstacles and a vehicle's sensors; advanced camera systems that use algorithms to interpret image data; infrared sensors for objects difficult to detect under certain weather and nighttime conditions, including lane markings, pedestrians, bikes, and board-based personal transport; and systems that enable these sensor- and camera-based technologies to communicate between vehicles and road infrastructure. AVs also require AI technologies to accurately interpret these streams of data and to direct the vehicle's responses in an environment in which other vehicles also respond to their streams of data and some other vehicles are controlled by drivers.

AVs can also be equipped with advanced connectivity technologies to communicate with other vehicles on the same roads and with roadside infrastructure and other devices.[7] Vehicle-to-vehicle connectivity can determine their locations, headings, and speed. Vehicle-to-infrastructure connectivity can interpret traffic signals, lights, and signage. Vehicle-to-everything connectivity can ensure 360-degree coverage for at least 1.5 miles.[8] Extensive connectivity will be essential for the safe operations of Level 4 and Level 5 AVs. Such extensive communication also will need access to radio spectrum.

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[5] National Academy of Sciences, Engineering, and Medicine (2021-A).
[6] Engadget (2023); Alliance for Automotive Innovation (2022).
[7] Ibid.
[8] Ibid.

In 1999, the Federal Communications Commission set aside 75 MHz for intelligent transportation systems. In 2022, it reallocated 45 MHz for other purposes and added 45 MHz of lower spectrum for "intelligent transport."[9]

Through the development of Level 1, Level 2, and Level 3 AV technologies, many companies have accumulated considerable experience with these technical challenges. On this basis, some observers expect Level 4 and Level 5 AVs to become commercially viable in this decade and their widespread use to follow in the 2030s.[10]

### Forecasts of When People Will Adopt AVs

The timeline for widespread adoption of automated vehicle technologies is uncertain, and projections vary widely depending on the analysts' views of the pace of technological progress and consumer acceptance, regulatory frameworks, and other factors.[11]

Lux Research has forecast that by 2030, 92% of vehicles worldwide will have Level 2 technologies, and 8% will have Level 3 technologies.[12] Other analysts also expect Level 4 AVs to enter the market in the next decade, whereas Level 5 AVs may take longer to achieve broad adoption. However, the Victoria Transport Policy Institute has predicted that high-level AVs will be commercially available by 2030 with rapid increases in sales thereafter, and a study from the University of Texas projects that 5% of U.S. vehicles will be Level 4 AVs by 2030.[13]

The projected timelines of major automakers currently investing in AV technologies also cover a wide range.[14] Half a decade ago, most expected to introduce varying levels of autonomy in their vehicles by the mid-2020s,[15] but many AV companies have since pushed back their timelines. Similarly, the European Road Transport Research Advisory Council (ERTRAC) forecast in 2019 that initial deployment of Level 3 and Level 4 vehicles for highway driving, truck platooning, and low-speed transport in urban areas in Europe will start phasing in by 2025, with widespread adoption of Level 3 and Level 4 AVs in complex urban environments by 2030.[16] Beyond 2030, ERTRAC envisions continued development and deployment of Level 5 vehicles, assuming that the technical, legal, and societal challenges associated with fully autonomous driving are resolved.

Longer-term projections also vary widely, from estimates that Level 4 AVs will account for only 10% of the global vehicle fleet by 2040[17] to the forecast by the International Transport Forum that 70% of vehicles worldwide will be AVs by 2050.[18]

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[9] Intelligent Transportation Society of America *v*. Federal Communications Commission, August 12, 2022.

[10] For example, Litman (2023).

[11] The adoption rate of connected autonomous vehicles is likely to follow an S-shaped curve characteristic of the diffusion of many innovations, which makes predicting the timeline of mass adoption difficult. Initial adoption is predicted to be slow, followed by a rapid increase in uptake, and eventually leveling off as the technology reaches saturation (Talebian and Misra 2018).

[12] Laslau, Frangoul, and Robinson (2014).

[13] Litman (2021); Bansal and Kockelman (2017).

[14] Walker (2019).

[15] Some industry experts predict that automation will require a longer timeline for research, development, and testing. See Mervis (2017) and Ackerman (2017).

[16] European Road Transport Research Advisory Council (2019).

[17] Gartner (2020).

[18] International Transport Forum (2018).

A literature review of AV adoption scenarios found that predictions for 2050 vary from 5% to 40% of the worldwide fleet.[19] By contrast, IHS Automotive projected that the global fleet would be fully autonomous by 2051, and the Rand Corporation has estimated that Level 4 and Level 5 vehicles will become dominant after 2040.[20] Other analysts have predicted rates of future sales of Level 4 and Level 5 vehicles, ranging from 10% of sales by 2035 to 25% of sales by 2030 and 55% of sales by 2050.[21]

### Economic Benefits from Broader Application of New AV Technologies

AVs' enabling technologies will also likely generate significant benefits in many areas. As noted, their potential to sharply reduce traffic accidents will produce major economic savings and gains, including increased productivity of people spared injury or death and lower property damage, health care costs, and auto and health insurance premiums.

Also as noted, broad use of rideshare AVs will provide new access to jobs for people with disabilities who are unable to commute to find productive employment and will expand job opportunities for nondrivers and other people living in areas poorly served by public transit. And fleets of electric-powered AVs would reduce energy use, congestion, and the economic costs of responding to climate change.

Beyond those economic benefits, many technologies developed for AVs have other productive uses and create jobs to produce, operate, and maintain them.

For example, AVs will be equipped with 360-degree radar based on a network of multiple microwave radar systems at different places and orientations to provide narrow- and wide-beam and short- and long-range scans calibrated for any weather and lighting conditions.[22] The efficiency, resolution, and scope of these systems have many other applications. For example, the U.S. defense industrial base is applying these 360-degree radar technologies to develop the next generation of U.S. air defense systems.[23] These technologies can also be used to reduce workplace accidents by monitoring facilities where people work together with robots.

LiDAR, a remote sensing technology that emits infrared light beams from pulsed lasers, is another AV technology with broad applications. Working with other sensors, cameras, scanners, and specialized GPS receivers, LiDAR systems can produce millions of measurements in all directions that are combined to generate precise, three-dimensional information about the AV's environment, including the identities of objects such as pedestrians, other vehicles, and roadway abnormalities.[24] Current research and development (R&D) with LiDAR focuses on enabling AVs to see through, around, and beyond solid objects.

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19. Shiwakoti, Stasinopolous, and Fedele (2020).
20. IHS Automotive (2014); Rand Corporation (2021).
21. Mosquet et al. (2015); Litman (2022).
22. Murray (2019).
23. Eshel (2019).
24. American Geoscience Institute (2022); also, Lawrence-Berkeley (2019a).

Three-dimensional LiDAR imaging has many other uses that can generate substantial job and income benefits—for example, mapping crops and determining soil properties from topographic analysis; measuring concentrations of atmospheric gases and aerosols; gauging diversity of species in various habitats; and assessing damage after earthquakes, landslides, and other destructive natural events.[25] Scientists can also use the technology to produce shoreline maps and elevation models for geographic information systems, estimate carbon absorption rates in forests, and measure changes in glaciers and beaches.[26]

Law enforcement can use LiDAR to enforce speed limits, detect fingerprints, and collect detailed evidence for forensic analysis.[27]

The Pentagon can use it in advanced ground surveillance, air defense systems, and spacecraft.[28] Similarly, mining companies can use LiDAR technologies in oil and gas exploration and to calculate underground ore volumes. Architectural firms can use it in designing buildings, and construction companies can use it to detect small structural faults in structures.[29]

Cellular network companies also use LiDAR to determine lines of sight and viewsheds for antennae, hospitals use it to help locate tumors, and entertainment companies use it to create digital objects for films and games.[30]

Other next-generation sensor technologies under development for AVs also have other uses that translate into more employment and other economic benefits. These sensor technologies detect the movements and locations of nearby objects by emitting infrared radiation that strikes them and bounces back to the sensors Integrated with radar and AI, infrared sensors can be used to track objects ranging from missiles to nanoparticles in living organisms, study the weather, detect gas emissions, examine the properties of minerals, and enhance the security of access control systems.[31] Further, the cellular vehicle-to-everything systems (C-V2X) developed for AVs have many other uses. These technologies, which give AVs the capacity to see around obstructions and to communicate with other AVs, highway infrastructure, and the cloud, can also be applied to electronic toll collections and vehicle safety inspections, monitoring supply chains, and detecting equipment problems in factories.[32]

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25. Lawrence-Berkeley (2019b).
26. American Geoscience Institute (2022).
27. Ibid.
28. Ibid.
29. Lawrence-Berkeley (2019b).
30. Ibid.
31. Kisi (2022).
32. El Zorkany, Yasser, and Galal (2021).

# II. U.S. and Global Markets for AVs and the Looming U.S.–China Competition

Motor vehicle manufacturers and information and telecommunications companies in many countries are developing AVs and associated critical technologies. Based on current competition for global sales of motor vehicles, we should expect the United States and China along with Japan to vie for leadership in the production of AVs. China has announced its intention to lead the world in developing and deploying AI and its application to AVs.

In 2017, China's government released a national strategy to lead the world in AI[33] and three years later announced new goals that 50% of cars produced by China's state-owned and private manufacturers will have Level 3 AV technologies by 2025 and 30% will have Level 4 AV capacities by 2030, all equipped with AI.[34] In 2021, the government's new five-year plan included directives that China's national laboratories intensify their R&D efforts in AVs and AI.[35] Moreover, Chinese companies are reportedly dedicating large sums to AV R&D, with vehicle makers such as Baidu, Pony.ai, and WeRide spending $15 billion on such R&D in 2021.[36]

China has also taken steps to prepare for entering the U.S. market by conducting research and testing of their AVs in California and by collecting data on U.S. transportation infrastructure.[37]

In addition, European countries have been developing regulatory frameworks for fully AV operations. In 2022, the European Union adopted the first multinational Level 4 vehicle certification ("type-approval") framework, the most comprehensive AV requirements to date covering robotaxis, hub-to-hub freight, and automated valet parking.

In addition, France and Germany have enacted a suite of national rules to govern the commercial operation of transport-as-a-service use cases.

Many American vehicle and technology manufacturers have also accepted the challenge. By one recent account, major U.S. companies heavily invested in developing AVs include General Motors, Tesla, Alphabet's Waymo, Nissan, Ford, Toyota's Woven Planet, Hyundai's robotaxi, Amazon's Zoox, Rivian, Cruise, and Aurora.[38] In addition, U.S. companies, such as Lyft, Microsoft, and nuScenes, are developing the data sets that AVs will need to learn to make decisions about how to navigate; others, such as Luminar Technologies and Innoviz, are developing sensor technologies for AVs.[39] In 2021, equity funding for new AV-related technology companies exceeded $12 billion, up more than 50% from 2020.[40]

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[33] Roberts et al. (2021).
[34] Tabeta (2020).
[35] Murphy (2021).
[36] Kawakami and Shimizu (2023).
[37] Tabeta and Shiraishi (2019).
[38] Goncharov (2022); Fannin (2022).
[39] Goncharov (2022).
[40] Fannin (2022).

Given the Chinese government's aggressive steps to promote China's leadership in future AV markets, the U.S. government could respond with more support for the development and production of AVs by U.S. companies. Direct support has traditionally been limited. In 2020, for example, Congress called on the Department of Commerce and the Federal Trade Commission to report on how the United States can create the economic conditions needed to promote AV and other emerging technologies.[41] In 2022, Congress passed the CHIPS and Science Act that provides $53 billion to develop domestic capacity for semiconductors critical for the automotive industry and particularly AVs.[42]

## Global Market for Motor Vehicles

Although AVs will produce significant safety, mobility, and environmental benefits wherever their use is widespread, the extent of the U.S. employment and income benefits will also depend on AVs being developed and produced in the United States. The competition around AV production and sales, especially between the United States and China, will be intense and economically consequential.

The current U.S. and global markets for conventional motor vehicles can provide a baseline to gauge the likely dimensions of that competition.

Motor vehicles are sold and used in every country, with 2021 worldwide sales of more than 66 million units and revenues of nearly $4 trillion.[43] With the exception of China's vehicle manufacturers, other major producers maintain global production networks based on the locations of their important suppliers and markets.

As a result, major motor vehicle production facilities are located not only in countries with global vehicle brands—the United States, Japan, Korea, Germany, France, and Britain—but also in places such as India, Brazil, Spain, and Thailand.[44]

Despite China's small global footprint in the production of motor vehicles, one-third of all worldwide vehicle production in 2021 occurred in China. Chinese and foreign vehicle companies manufactured 22,225,242 units, compared with the 8,825,100 vehicles produced in the United States. Japan made 5,566,500, Germany made 3,353,200, and South Korea made 3,351,100.[45] Notably, automakers in China also sold 1,850,000 units abroad, including 60% of worldwide exports of electric vehicles[46] or twice the volume of all U.S. motor vehicle exports.[47]

China is also now the world's largest market for motor vehicles, with 2021 domestic sales of 21,413,700 units.[48] China's 14 state-owned automakers and 40 independent producers accounted for more than 45% of those sales. Japanese, German, and American vehicle companies accounted, respectively, for 21%,

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[41] The American Competitiveness of a More Productive Emerging Tech Economy Act (2020).

[42] The Creating Helpful Incentives to Produce Semiconductors (CHIPS) and Science Act (2022).

[43] International Organization of Motor Vehicle Manufacturers (2022).

[44] Ibid. All told, 50 countries produced passenger cars and commercial vehicles in 2021.

[45] Marklines (2022a) and Marklines (2022b). In the United States, the three major American producers (General Motors, Ford, and Tesla) accounted for about 40% of total production (3,519,344 units). This was followed by three major Japanese manufacturers (Toyota, Honda, and Nissan), with about 28% of U.S. vehicle production, and two major Korean manufacturers (Hyundai Kia and Subaru), with nearly 12%.

[46] Shen (2022).

[47] Federal Reserve Bank of St. Louis (2022).

[48] Marklines (2022c).

20%, and 10% of China's market.[49] The United States is the world's second largest market for motor vehicles, with Japanese and American producers accounting for nearly two-thirds of all U.S. new vehicle sales in 2021.[50] The Dutch group Stellantis (Chrysler, Dodge, Fiat, and Peugeot) was next, with nearly 12% of U.S. sales, followed by Korean producers with just under 9% and German manufacturers with less than 7%.[51] This global competition occurring principally among American, Chinese, European, and Japanese automakers will set the stage for the competition over AV production and sales.

### Impact of the Motor Vehicle Industry on the U.S. Economy

The stakes for the United States in that competition can be gauged by the motor vehicle manufacturing industry's current impact on the U.S. economy, including employment, contributions to U.S. gross domestic product, exports, and R&D. For example, motor vehicle and parts manufacturers (MVPMs) in the United States employed 957,000 people in 2021, produced a gross output of $733 billion, and contributed $158.5 billion in value added to the gross domestic product.[52] Those manufacturers also had fixed business assets of $300 billion,[53] invested $19.5 billion in R&D, and accounted for $144 billion in U.S. exports.[54]

The economic impact of MVPMs is even greater because their U.S. operations also support revenues and jobs for many other industries through the MVPMs' large purchases of goods and services as intermediate inputs. Those input purchases totaled $574.5 billion in 2021, accounting for the difference between the industry's gross output and its value added or contribution to the gross domestic product.

## Table 1. Motor Vehicle and Parts Manufacturing in the United States: Gross Output, Value Added, and Intermediate Inputs, 2021[55]

| Gross output | Value added (GDP) | Intermediate inputs |
|---|---|---|
| $732,951 M | $158,456 M | $574,495 M |

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[49] Wikipedia (2022). The big five state-owned automakers are SAIC Motors (2021, 5.4 million sales), FAW Group (3.5 million sales), Dongfeng Motors (3.3 million sales), Chang'an Group (2.3 million sales), and GAC Group (2.1 million sales).

[50] Japanese producers accounted for 34% and U.S. producers accounted for 29% of those sales.

[51] Marklines (2022d) and Marklines (2022e). In global sales outside China, Toyota led with sales of 10,496,000 units, followed by the VW Group with sales of 8,882,000 units, the Renault-Nissan-Mitsubishi Group with sales of 7,771,000 units, the Hyundai-Kia Group with sales of 6,668,000 units, General Motors with sales of 6,98,000 units, the Stellantis Group with sales of 6,41,000 units, Honda with sales of 4,121,000 units, and Ford with sales of 3,942,000 units.

[52] Bureau of Economic Analysis (2022a).

[53] Bureau of Economic Analysis (2022c).

[54] Bureau of Economic Analysis (2022b).

[55] Bureau of Economic Analysis (2022a).

The input purchases by MVPMs also have a disproportionate impact on other industries because they account for 76.5% of the motor vehicle industry's gross output, as compared with 59.6% for all manufacturing and 44.8% for all private industries.[56] These inputs also are dominated by goods and commodities rather than services. In 2021, material goods and commodities accounted for 92% of MVPM's inputs.[57]

We applied input–output analysis to identify the industries that most depend on their sales to MVPMs. For this analysis, we do not include inputs purchased from other companies in the MVPM industry, totaling $260.3 billion in 2021.

Apart from the intra-industry inputs, 23 industries sold at least $1 billion in inputs to MVPMs in 2021, with five industries accounting for nearly 72% of all of those inputs: $64.3 billion from primary metal producers, $55.1 billion from fabricated metal producers, $34.5 billion from plastic and rubber product makers, $33.5 billion from machinery manufacturers, and $32.7 billion from computer and electronic product makers. In addition, three industries are especially dependent on those input purchases because they accounted for more than 10% of their total output. MVPM purchases represented 24.5% of the total output of primary metals producers, 14% of the output of fabricated metal products manufacturers, and 14% of the output of plastic and rubber product producers. MVPM input purchases also constituted 8% to 9% of the total output of machinery manufacturers, computer and electronic product makers, nonmetallic mineral product producers, and apparel and leather product manufacturers. The economic impact of the U.S. motor vehicle industry also includes the dealers in its vehicles and parts. Those dealers directly employed an additional 1,965,000 people in 2021,[58] and like vehicle manufacturers, their input purchases supported growth and jobs in many other industries. In 2021, motor vehicle and parts dealers (MVPDs) purchased $99.8 billion in inputs from other industries, including purchases of $1 billion or more from 23 other industries.[59] Their largest suppliers were service companies, including $18.4 billion in purchases from professional, scientific, and technical service providers; $15.0 billion in real estate services; $7.7 billion for warehousing and storage services; $5.4 billion for administration and support services; and $4.3 billion for utility services.

MVPDs' purchases accounted for 1% to 5% of the output of four of its supplier industries: warehousing and storage service companies (4.2%); plastic and rubber product manufacturers (1.5%); miscellaneous professional, scientific, and technical services companies (1.0%); and real estate companies (1.0%).

The manufacture of AVs and their parts will draw on different combinations of inputs than current motor vehicle production. For example, MVPMs of AVs will likely purchase greater quantities and shares of inputs from computer and electronic manufacturers, computer system design service providers, and telecommunications companies. However, the motor vehicle and parts industry's dependence on inputs from other industries and the associated impact on jobs and demand in those industries will continue as MVPMs shift some production to AVs. And as U.S. and global motor vehicle sales gradually come to include AVs, the industry's significance for the American economy and employment should increase.

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[56] Ibid.

[57] Motor vehicle and parts manufacturing was relatively less energy dependent; its energy purchases accounted for 0.5% of its inputs compared with 2.2% for all manufacturing.

[58] Bureau of Economic Analysis (2022d).

[59] We exclude intra-sector inputs purchased by those dealers from MVPMs, totaling $7.6 billion in 2021, and focus on the $84.7 billion in purchases from those 23 other industries.

# III. AVs and Public Safety: Impact on Accidents and Related Deaths, Injuries, and Property Damage

The Pew Research Center reports that AV safety is a major concern for many people.[60] Yet, their greatest potential benefits lie in their capacity to sharply reduce traffic accidents and their accompanying injuries, deaths, and property damage. In contrast to many drivers, AVs cannot be distracted by conversations, cell phones, or other diversions, nor can they become sleepy, exhausted, or impaired by alcohol, drugs, or other causes. AV sensors and software have a broader view of a vehicle's environment regardless of weather or day or night and should be able to adapt to novel driving situations.[61]

A Department of Transportation study put it this way: "Automated vehicles that accurately detect, recognize, anticipate and respond to the movements of all transportation system users could lead to breakthrough gains in transportation safety."[62]

### Reducing the Human and Economic Costs of Motor Vehicle Accidents

Motor vehicle accidents entail enormous costs.[63] The NHTSA reports that 5,250,100 crashes were reported to police in 2020, and 31% involved serious personal costs, including nearly 35,800 fatalities and 1,594,000 injuries.

The remaining 69% or 3,621,700 accidents caused property damage, usually to the vehicles, without inflicting injury or death.[64]

The NHTSA further estimates that 94% of serious motor vehicle crashes resulting in injuries or deaths in 2018 involved driver-related factors, from impaired driving to speeding or illegal maneuvers.[65] Drivers are the dominant victims in fatal crashes, as 58% are single-car accidents:[66] In 2020, motor vehicle accidents killed 19,500 drivers and 5,800 motorcyclists, as well as 6,000 passengers, 6,500 pedestrians, and 940 bicyclists and other pedal cyclists.[67]

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[60] Rainie et al. (2022).

[61] U.S. Department of Transportation (2018).

[62] Ibid.

[63] Our use of the term "accidents" is interchangeable with the Department of Transportation's use of vehicle "collisions" and the NHTSA's use of "crash" statistics.

[64] National Highway Traffic Safety Administration (2022), Table 1.

[65] Ibid.

[66] Ibid., Table 28.

[67] Ibid., Table 1. Fatal crashes are as likely to involve SUVs and other light trucks versus passenger cars: 20,600 of those accidents involved SUVs and light trucks compared to 20,900 involving passenger cars, 4,840 involving large trucks, and 5,715 involving motorcyclists (Table 3).

About 30% of those fatalities, or 11,654 people, including 1,952 pedestrians, involved drivers who were impaired by alcohol or other intoxicants.[68] Drivers also are the most frequent victims of accidents that result in injuries short of death. Crashes in 2020 involved injuries to 1,545,700 drivers and 82,500 motorcyclists, as well 546,800 passengers, 54,800 pedestrians, and 37,900 pedal cyclists.[69]

These accidents involve substantial economic costs. The Centers for Disease Control and Prevention reports that the medical and work-related costs arising from fatal motor vehicle accidents totaled $55 billion in 2018.[70] Similarly, the National Safety Council estimates that medical and work-related costs averaged $1,750,000 per motor vehicle fatality in 2020.[71] Based on these estimates, traffic fatalities in 2020 imposed $62.7 billion in one-year economic costs. The National Safety Council also estimates that the average economic cost per injury caused by motor vehicle accidents in 2020 ranged from $29,200 for “evident injuries” (those evident at the time of the accident and neither fatal nor incapacitating) to $101,000 for “incapacitating injuries” (those that prevent the victim from continuing normal activities at the time of the accident).

Because incapacitating injuries accounted for 8.1% of all accident injuries, we can estimate that economic costs associated with injuries totaled $79.9 billion in 2020.[72]

Apart from fatalities and injuries, motor vehicle accidents also involve large-scale property damage, primarily damage to the vehicles involved in the accidents. Based on earlier NHTSA estimates of the property costs from motor vehicle crashes,[73] we calculate that in 2020, property damage costs averaged $13,012 per fatal accident, $12,883 per accident involving injuries, and $4,164 per accident involving only property damage.[74] On this basis, property damages associated with motor vehicle accidents in 2020 totaled $36.1 billion—$465.4 million in property damages arising from 35,766 fatal accidents, $20.5 billion in those damages arising from 1,593,390 accidents involving injuries, and $15.1 billion in those costs for 3,621,681 accidents with only property damage.

So, all told, the economic costs arising from police-reported motor vehicle accidents totaled $178.7 billion in 2020, including the costs of medical care, lost work, and direct property damages. That estimate does not include other costs associated with crashes, including the pain and suffering caused by accidents, increased insurance costs, legal costs, and costs arising from congestion related to accidents.

### AVs’ Potential Impact on Safety

AVs cannot eliminate all motor vehicle accidents and their resulting costs. For a time, AVs will share highways and roads with conventional vehicles driven by fallible drivers, and AVs can break down or malfunction.

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[68] National Highway Traffic Safety Administration (2022), Table 13 and Table 20. Notably, 83% of fatal accidents occur under normal weather conditions (Table 26).

[69] Unlike fatal accidents, these crashes were more likely to involve passenger cars (1,514,600) than SUVs and other light trucks (1,129,200); 107,000 large trucks and 79,700 motorcycles were also involved in accidents with injuries.

[70] Centers for Disease Control and Prevention (2020).

[71] National Safety Council (2022). The work-related costs include a victim’s projected lifetime work-related income.

[72] National Highway Traffic Safety Administration (2022). Table 54.

[73] National Highway Traffic Safety Administration (2015). Table 1-4.

[74] The inflation adjustment uses the Bureau of Economic Analysis GDP deflator.

Moreover, no technology can avoid crashes under anomalous conditions unanticipated by AV programming or situations in which all available responses result in accidents.[75] However, AVs could dramatically reduce the 30% of accident fatalities that today involve drunk drivers,[76] the 22% that involve high speeds,[77] and the 17.5% that involve collisions with fixed objects.[78] AVs would significantly reduce these types of errors by supplanting fallible drivers with advanced sensors and algorithms to detect and respond to road hazards, make decisions and take actions based on real-time data and inputs, and react quickly to changes in their environments.

Some analysts have already tried to evaluate the safety of AVs and to project their consequent impact on traffic accidents. Early studies did not produce a consensus. One 2016 study forecast that advanced AVs could reduce traffic accidents by 90%.[79] Another study published estimated that fatalities could fall by 25,000 per year, with annual benefits totaling more than $200 billion, if AVs represented 90% of all vehicles.[80] A third study suggested that AV crash rates could be comparable to conventional vehicles.[81]

A recent study, however, forecast that AVs could prevent or avert 34% of crashes,[82] and other analysts have argued that deployment of AVs would be justified if they can reduce crash rates by 10 percent.[83] Some recent evidence also suggests that AVs with current technologies are safer than human-operated vehicles. Waymo reports that its self-driving vehicles drove more than 10 million miles on public roads with only a handful of minor accidents, and all those accidents were caused by other human-operated vehicles.

The complete extent of AVs' impact on safety and health in the 2030s and 2040s will depend on their rate of uptake, the mode of their use and ownership, their engine types, and the extent to which AVs increase access. Under nearly all conditions, we find that the widespread use of AVs should make the roads safer. Beyond that, the deployment of fully electric shared AV fleets would also contribute to public health by reducing greenhouse gas emissions and other air pollution.

However, the widespread use of AVs may also entail some adverse health effects, such as possibly reducing physical activity, raising noise levels, and under certain conditions increasing congestion.[84]

Given AVs' potential to reduce accidents, their widespread adoption could reduce public perceptions of the risks associated with motor vehicles and could consequently lead to more risky behavior by some people, such as less seatbelt use, less attention to warnings from the AV's systems, or risky behavior by drivers in conventional vehicles who trust that AVs will prevent an accident.[85]

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75. Bailey and Erikson (2019).
76. National Highway Traffic Safety Administration (2022). Table 20.
77. Ibid., Table 33.
78. Ibid, Table 42.
79. Arbib and Seba (2017); Gao et al. (2016).
80. Lutrell (2015).
81. Sivak and Schoettle (2015).
82. Mueller, Cicchino, and Zuby (2020).
83. Groves and Kalra (2017).
84. Rojas-Rueda, Nieuwenhuijsen, and Frumkin (2020).
85. Millard-Ball (2016).

This overtrusting of technology[86] could also dampen the investment and use of conventional safety strategies such as driver education and training programs and vehicle safety features and investment in road infrastructure improvements.[87]

AV designers and programmers will need to consider technologies to address roadway risks to nonautomotive travelers who may be difficult to quickly detect, identify, and accurately predict their course, such as pedestrians, bicyclists, skateboarders, and motorcyclists.[88] Those designers and programmers will also need to account for how human drivers in conventional vehicles may interact with AVs in mixed-traffic situations, especially if drivers assume that AVs can offset their own risky behavior.[89] And if the adoption of AVs results in more VMT, those increases could lead to more accidents.[90] Even considering these other factors, given the current dimensions of deaths, injuries, and property damage arising from motor vehicle crashes, even modest improvements from the deployments of AVs could yield significant advances in safety and health.

### Risks Associated with Cybersecurity and Platooning

An AV's complex networks of sensors and algorithms raise safety issues based on the possible vulnerability of those systems to hacking or compromise from operational failures.[91] Given current technologies, interfering with the safe operations of AVs could be relatively simple. One study found that that graffiti-like markings on a roadside stop sign resulted in an AV's 2018 software misreading the stop sign as "Speed Limit 45."[92] To mitigate these risks, AV designers could create multiple levels of security and redundancy, although the rapid rate of change in AI and AV technologies complicates efforts to predict and prevent potential cyberthreats to those technologies.

The introduction of new AV driving modes such as platooning, in which a convoy of AVs travel closely together to reduce drag and improve fuel efficiency, may also introduce novel safety risks.[93]

Although platooning can improve safety by reducing the distance between vehicles and providing for more rapid reaction times, it may also worsen some accidents if one of the vehicles leaves the convoy, the convoy encounters an obstacle unanticipated by its programming, or simply the proximity of AVs in a platoon increases the prospect that a single vehicle failure could affect multiple vehicles.[94]

To address these and other technology-related risks, government regulators and AV developers and producers will have to collaborate on solutions that can minimize risk.

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[86] Ackerman (2017).
[87] Lawson (2018).
[88] Pedestrian and Bicycle Information Center (2023).
[89] Yu (2021).
[90] Trommer et al. (2016).
[91] Dawn Project (2022).
[92] Eykholt et al. (2018).
[93] Sha (2020).
[94] Ibid.

### Air Quality and Other Public Health Benefits of AVs

The deployment of AVs may enhance public health in ways unrelated to motor vehicle accidents. First, as explored in Section V of this study, AVs could significantly reduce greenhouse gas and particulate emissions and so help prevent an estimated 7 million premature deaths per year from air pollution.[95] This contribution to public health will depend on the energy sources that generate the electric power. AV developers will also have to consider pollution from other sources in AVs, such as brake wear particles with high oxidative content and perhaps noise pollution from AVs that operate at higher speeds. [96]

Second, the widespread adoption of AVs may also promote public health by freeing up green spaces in urban and suburban areas and by encouraging more physical activity.

For example, AVs should reduce demand for urban parking spaces because AVs can park more efficiently and use less space.[97]

Some studies suggest that significant reductions in urban parking spaces could encourage the greater use of public transit, cycling, and pedestrian infrastructure[98] and that more green spaces can have positive effects on people's mental health and well-being.[99]

As a potential countervailing factor, some studies suggest that if the deployment of shared-ride AVs ends up producing greater urban and suburban sprawl, that could increase total VMT and discourage pedestrian and cycling activity.[100] Finally, widespread use of AVs could have other, indirect effects on people's health and well-being. For example, people riding in AVs can relax, thus reducing the stress that often accompanies driving, but some AV riders may choose to work while riding, which could expand their working hours and perhaps increase stress.[101]

The health and other related effects of AVs also will depend on public spending decisions, such as increases in public support for green spaces, safe walking areas, and the application of environmental regulations to AVs. The impact on different populations will also be affected by whether public planning and spending ensure access to AVs for people with impaired mobility. Incomes may also matter because people with the means to access AVs will receive most of the benefits from reduced accidents. More generally, a survey of the literature on these issues found that differences in the health effects from various scenarios for AV use depend significantly on people's incomes and access to alternative means of transport.[102]

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[95] World Health Organization (2022).

[96] Nadafianshahamabadi, Tayaraini, and Rowangould (2021). Some analysts also have also raised questions about whether electric-powered AVs might expose their passengers to harmful electromagnetic fields. However, numerous epidemiological studies have failed to establish links between exposure to nonionizing electromagnetic fields and cancer and other health risks. See Rojas-Rueda (2020)

[97] Harrison et al. (2022); Rojas-Rueda (2020).

[98] Ibid.

[99] Rojas-Rueda (2020).

[100] Harrrison et al. (2022).

[101] Almlöf et al. (2022).

[102] Ibid.

### Impact of AVs on the Insurance Sector

The principal health benefits of AVs from substantially reducing rates of motor vehicle accidents will also affect the health care and insurance industries. One analyst has estimated that the reduction in collisions arising from broad use of AVs would lower national health care costs by more than 16%,[103] and other studies similarly conclude that AVs could significantly reduce the size of the health care sector.[104]

In much the same way, the broad adoption of AVs could significantly affect the auto insurance and health insurance industries. Their initial adoption could increase insurance industry revenues if the cost of coverage for AVs is more expensive during the initial period of adoption and certification.[105] However, the expected reduction in accidents, especially serious collisions, should reduce premiums and lower industry revenues, a development that would be enhanced if AVs lead to fewer vehicles on the road.

## AVs’ Projected Effects on Public Health and Safety

We used our baseline model to evaluate the connections between AVs and public health. We applied the impact of transportation on public health and the impact of AVs on those transportation systems and then used those results and findings from other studies to estimate the likely impact of AV use on health and safety through traffic accidents.

Our model also draws from a 2020 study that analyzed 32 pathways through which AVs could affect public health, including negative and positive effects, adjusted for our baseline model’s assumptions.[106]

The positive effects include reductions in collisions and other improvements in traffic safety; enhanced access to jobs, healthy food, and health care for certain populations; reduced stress associated with driving; fewer transportation-related emissions; more efficient traffic flows; and potential savings in transportation infrastructure. Some adverse effects cited by existing research include possible increases in VMT and associated pollution; reduced physical activity due to changes in the cost, comfort, and time spent traveling in a vehicle; and safety risks arising from malfunctioning AV sensors and devices, cybersecurity issues, and AV responses to conditions that lead to unavoidable accidents.

Our simulation for these matters focuses on the major safety benefits of AVs, reductions in accidents and deaths, and the associated economic and taxpayer savings from those reductions. Given that various developers of AVs plan to adopt a range of features, we chose not to assume what AV capacities and features will be standard in the future.

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103. West (2016).
104. Alonso (202); Clements and Kockelman (2017).
105. Stanley, Grise, and Anderson (2020).
106. Sohrabi, Kreis, and Lord (2020).

Instead, we use three technological alternatives based on AVs' capacity to operate under a range of conditions, developed for the PTV Vissim traffic stimulator and the CoExist model for the European Union's AV project.[107] CoExist characterizes these alternatives as follows:

1. Basic: The AV observes traffic laws and always adopts safe behavior, including safe braking distances, safe behavior for lane changes and navigating intersections without signals, and speed limits. This alternative assumes large gaps between vehicles.

2. Standard: AVs operate like human drivers who obey traffic laws but also use sensors to accurately measure distances to other vehicles and objects and the speed of other vehicles.

3. Advanced: The AV's sensors and AI systems are aware of all surrounding features and can accurately predict the behavior of other vehicles and pedestrians. This alternative assumes small gaps between vehicles.

First, we simulated the impact on traffic accidents for each class of AV technology described previously under projected AV adoption rates. Using 2022 data as the baseline, we simulated the effects on accidents for each category of AV operating technology with AVs constituting 25%, 50%, 75%, or 100% of the U.S. motor vehicle fleet.

We also simulated those effects if AVs were connected through their capacity to communicate with each other—connected AVs or CAVs—and travel by "platooning" that reduces the distance between them. The results show significant reductions in accidents and deaths and significant economic and taxpayer savings (Table 2; Figure 1) The simulations show that the benefits increase with the degree of autonomous operations represented by the three categories of AV operating behavior, as expected. At 25% AV adoption, accidents decline by 11.1% with AV operations, 22.0% for Standard AVs, and 27.7% for Advanced AVs.

## Table 2. Change in U.S. Traffic Accidents Based on AVs' and CAVs' Adoption Rates, by AV and CAV Operating Features

| | | AV fleet penetration | | | |
|---|---|---|---|---|---|
| | | 25% | 50% | 75% | 100% |
| AVs | Basic | –11.1% | –3.9% | 0.6% | 0.6% |
| | Standard | –22.0% | –22.0% | –22.1% | –21.6% |
| | Advances | –27.7% | –25.6% | –26.3% | –30.7% |

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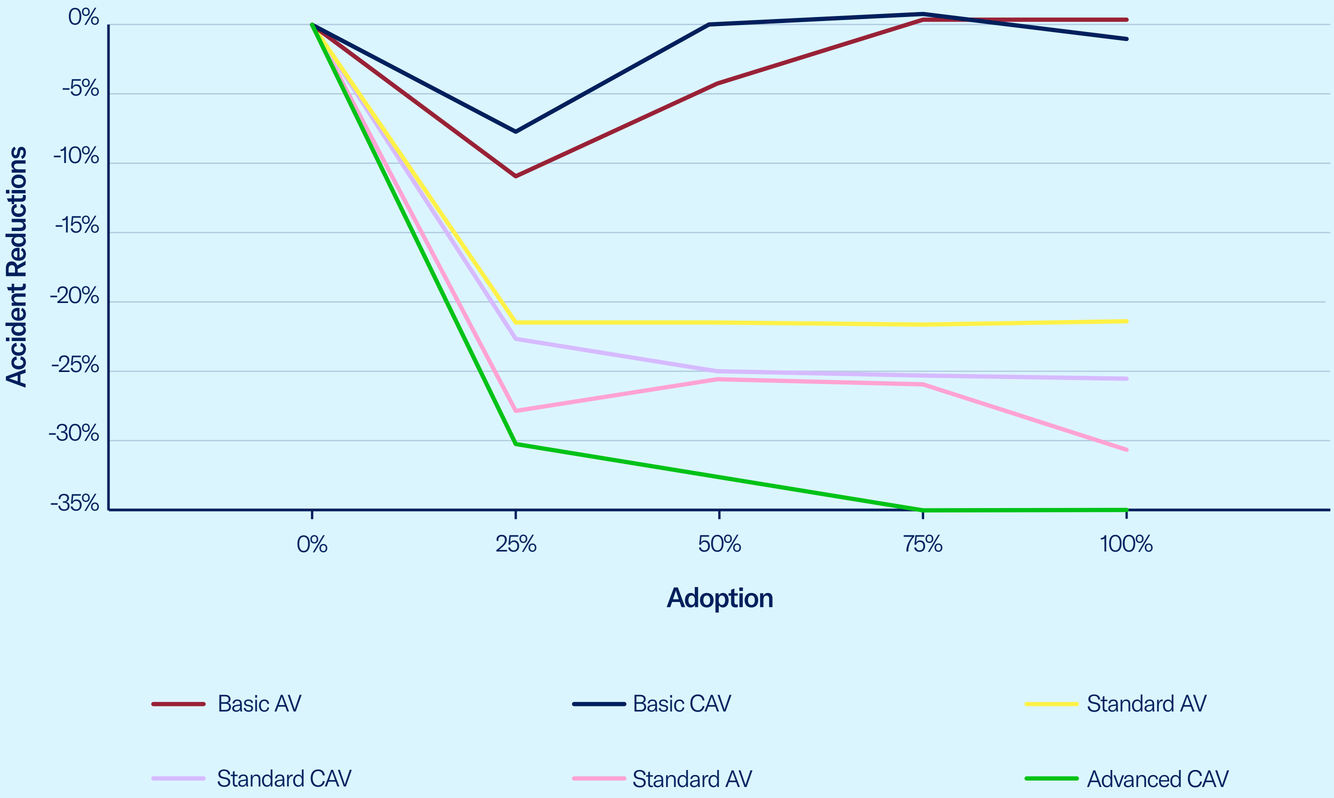
[107] Sukennik (2018).

| | | AV fleet penetration | | | |
|---|---|---|---|---|---|
| | | 25% | 50% | 75% | 100% |
| Connected AVs (CAVs) | Basic | –7.0% | 0.1% | 0.9% | –1.5% |
| | Standard | –23.3% | –24.6% | –25.3% | –25.6% |
| | Advanced | –30.2% | –32.3% | –34.9% | –35.0% |

Figure 1. Changes in U.S. Traffic Accidents Based on AV and CAV Adoption Rates



The simulations show that reduction in accidents for Standard and Advanced operating behavior depends on initial AV penetration, represented here by 25% adoption, and does not increase significantly with higher adoption rates.

Strikingly, Basic AV technology and operations not only produce the smallest decline in accidents but might also increase crashes at high rates of adoption. Other analysts have found similar results,[108] which appear to reflect secondary

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[108] Shunxi, Pang-Chieh, Xiao, and Chahine (2019).

effects when two vehicles operating under these cautious driving parameters interact. AVs that operate cautiously maintain large distances from other vehicles. In situations such as changing lanes, when the two basic AVs approach each other, their systems that enforce braking distances may cause the vehicles to stop, thus increasing the risk of rear-end accidents in the simulations.

Next, we use the results when AVs represent 25% of the U.S. fleet of motor vehicles to estimate the likely reductions in accidents and associated deaths and the economic and taxpayer savings arising from those reductions. The projected economic savings draw on the latest data from the NHTSA on the impact of crashes on medical costs, foregone productivity, legal and court costs, costs for emergency services and insurance administration, property damage, and congestion costs.[109] Moreover, because taxpayers bear about 9% of those costs, we can also estimate the associated taxpayer savings.

These simulations drew from 2022 data and analyzed these effects by category of AV operations. We also simulated those effects for CAVs with systems that communicate with each other, some of which are platooning.

This analysis confirms the widespread expectation that eliminating human driver failings, such as distracted or drunk driving, in 25% of vehicles has dramatic effects on accident rates and that those effects increase sharply as the AVs' operations become more comprehensive (Table 3). Based on their levels of technology, 25% AV penetration would reduce traffic accidents by 578,000 to 1,442,000 and would save the lives of 50,000 to 12,000 people. Moreover, those benefits from Advanced AVs increase significantly as their adoption rate rises. The analysis also indicates that the economic savings from these reductions in accidents range from $37.7 billion to $94.2 billion, and the associated taxpayer savings range from $3.3 billion to $8.3 billion.

## Table 3. Changes in U.S. Traffic Accidents and Deaths and Related Economic and Taxpayer Savings Based on 25% Adoption Rates for AVs and CAVs, by AV and CAV Operating Features

| | AV technology | Reductions in accidents | Reductions in deaths | Economic savings | Taxpayer savings |
|---|---|---|---|---|---|
| AVs | Basic | 578,000 | 5,000 | $37.7 billion | $3.3 billion |
| | Standard | 1,145,000 | 9,000 | $74.8 billion | $6.6 billion |
| | Advanced | 1,442,000 | 12,000 | $94.2 billion | $8.3 billion |
| Connected AVs (CAVs) | Basic | 364,000 | 3,000 | $23.8 billion | $2.1 billion |
| | Standard | 1,213,000 | 10,000 | $79.2 billion | $7.0 billion |
| | Advanced | 1,572,000 | 13,000 | $102.7 billion | $9.1 billion |

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[109] U.S. Department of Transportation (2023). These data cover police-reported crashes and estimates of unreported crashes.

# IV. AVs and Mobility: Impact on Access for People Who Are Travel Impaired

The successful adoption of autonomous vehicles could substantially expand the mobility of people who are travel impaired, including older people, people with disabilities, and nondrivers. As a result, broad AV use would significantly increase their access to jobs, public services, health care, and retail. Our analysis found that a 25% adoption rate for AVs would result in increases in the annual distance traveled of 4.6 billion miles by adults with disabilities, 4.9 billion miles by older people, and 2.4 billion miles by adult nondrivers.

### Accessibility to Low-Mobility Consumers and Regions

In 2018, 24.6 million Americans reported mobility-related disabilities that precluded their operating an automobile,[110] including 13.4 million adults of working age (18 to 64). Only 20% of those working-aged people (2.7 million) were employed. Notably, despite increases in remote work during the pandemic, access to transportation from home and the workplace remains a requirement for most jobs. In 2022, 72.5% of businesses reported that their employees rarely or never worked remotely, up from 60.1% in 2021 but nearly equal to the 76.7% before the pandemic.[111]

Public transit does not address the difficulties facing most people who have limited mobility. In most places, public transportation does not reach most residential and business areas—and low-income areas have disproportionately low shares of both public transit routes and job opportunities.[112] Even when public transit is available, one analysis found that people with personal cars can access six times as many jobs as those who depend on public transit.[113] These disparities help explain why more than 50% of adults with travel-related disabilities in 2021, numbering 6.9 million people, lived in households with incomes of less than $25,000.[114] AVs could reduce these barriers for many people unable to rely on traditional forms of transportation and could thus increase their ability to participate in the workforce.

Physical disabilities have large effects on people's mobility. The latest data (2017) show that working-age Americans (18 to 64) who are not disabled and travel impaired made an average of 3.6 vehicle trips per day compared with 2.6 trips per day for persons with disabilities.[115] Further, among employed people without disabilities, those trips averaged 12 miles compared with 9.4 miles for working disabled people. Among nonworking people, those trips for people who were not impaired averaged 9.5 miles compared with 7.5 miles for nonworking people with disabilities.[116]

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110. Brumbaugh (2018). In addition, 900,000 children have travel-related disabilities.
111. Goldberg (2023).
112. Ibid.
113. Ibid.
114. Ibid.
115. U.S. Department of Transportation (2022b).
116. Ibid.

As a result, employed people without disabilities traveled an average of 15,768 vehicle miles per year, 76% more than the average 8,921 VMT by workers with disabilities. Similarly, nonworking people without disabilities traveled an average of 12,483 vehicle miles per year, 75% more than the average 7,118 vehicle miles for nonworking people with disabilities.

AVs could also help millions of older Americans who have difficulties accessing transportation. More than 11.2 million Americans ages 65 and older had self-reported travel-related disabilities in 2021, representing 20% of the population ages 65 and older.[117] Some 22.8 million Americans are 75 years old or older, and the Census Bureau projects that the continuing aging of the large baby boom cohort will increase this older group to 34.5 million by 2030 and to 45.0 million by 2040.[118] According to the National Institute on Aging, factors impairing the ability of many older Americans to drive safely include difficulties seeing or hearing, the effects of arthritis and medications, and the fact that most people's reaction times and reflexes deteriorate with age.[119]

The impact of age on people's mobility is also large. The most recent data (2022) show that drivers ages 20 to 34 and ages 35 to 65 averaged, respectively, 15,098 and 15,291 VMT per year, nearly double the average 7,646 VMT by people ages 65 and over.[120]

Some of the difference reflects younger people who commute to work, whereas most older people are retired, and some of it reflects the challenges and burdens of driving for older people. Moreover, nearly 3 million Americans ages 65 and over currently cannot access public transportation services because of factors such as distance or wheelchair accessibility, issues that AVs could address through first-and last-mile mobility services. With coordination with transit agencies, AVs used for first- and last-mile transport could also help reduce the operating costs and could increase service quality for public transport systems.

Shared AVs could be a boon for the nearly 21 million Americans (7% of all adult Americans) who do not have driver's licenses[121] and the 14.5 million U.S. households (9.2% of all households) that have no access to automobiles.[122] Cost is a primary factor. In 2022, maintaining and operating a car costs an average of $10,728[123] or nearly three-quarters of the median income of the lowest-earning 20% of Americans. Shared-ride AVs are expected to be less expensive, with one analysis estimating that their use will cost a person 21 cents per mile compared with 59 cents per mile for privately owned automobiles.[124] Pilot programs provide further support for this argument indicating that shared AVs can reduce the financial barriers of older people and people with disabilities who are unable to rely on traditional forms of private or public transportation. In one case, a ride-hailing and sharing program serving Florida retirees reduced their transport costs by an average of 20%, and trials in Boston involving riders with disabilities who use ride-hailing vehicles similarly suggest that AVs can provide significant savings compared with standard taxi transport.

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[117] Census Bureau (2021).
[118] Census Bureau (2017).
[119] National Institute on Aging (2023).
[120] U.S. Department of Transportation (2022c).
[121] Statista (2022).
[122] Ezike et al. (2019a).
[123] Vandiver and Bradley (2022).
[124] Ezike et al. (2019b).

Our analysis found that of the 21.1 million adults who are nondrivers, 7.1 million are older and 5.3 million have disabilities.

Among younger adults without disabilities, 8.7 million cannot drive because they are not licensed. As expected, that status has significant effects on their mobility. Data from the Bureau of Transportation Statistics show that although drivers average 4.5 trips per day, nondrivers average only 2.6 trips daily.[125] This suggests that nondrivers travel by vehicle 57.8% as much as drivers do. Earlier, we found that adult drivers averaged 15,195 VMT per year, so the disparity in trips suggests that nondriving adults without disabilities averaged 8,783 VMT annually.

Networks of shared AVs with flexible routes will play a significant role in increasing mobility, but they cannot solve all mobility challenges. Networks of shared-ride AVs operating in areas not served by public transit could benefit millions of people who have limited mobility. The broader impact could be far reaching. Americans who are unable to work today because they cannot commute easily to jobs that do not offer remote work could become productive employees, and millions more whose job opportunities are limited to businesses along established public transit routes could find new opportunities and higher-paying jobs.

In addition, based on studies showing that access to rideshare services increased access to medical care for Medicaid patients, shared AVs also will increase access to medical care for millions of people with impaired mobility.[126]

Significant challenges will need to be addressed. Some people with disabilities and older people require assistance getting from their homes to vehicles and from the vehicles to their destinations. Maximizing the mobility benefits of AVs also will partially depend on public policies to offset some of the costs related to their initial adoption, including new software, hardware, and maintenance technologies,[127] and planning to ensure that AVs complement existing public mass transit systems.[128] Based on an examination of existing literature, if rollouts of AV services are not coordinated with the schedule and routings of an area's transit system, AVs could end up competing with existing buses and subways and could undermine the mobility benefits of public transit systems. With federal support, local governments may be able to reduce barriers to intermodal transport and to give AV companies incentives to offset the high costs of serving customers with low mobility and operating in low-density and low-income areas at night. Otherwise, AV services could end up serving mainly higher-income people without mobility issues. In addition, public outreach may be required to address any concerns about the safety and reliability of AV transport. Public education about AVs may be important for people with disabilities, as researchers have found that they adopt new technologies more slowly and less often than others.[129]

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[125] U.S. Department of Transportation (2005).
[126] Chaiyachati, Hubbard, Yeager, Mugo, Shea, Rosin, and Grande (2018).
[127] Littman (2022).
[128] Ibid.
[129] Perrin and Atske (2021).

# Selected Case Studies

Numerous communities have conducted pilot programs to explore how ride-hailing services or transportation network companies (TNC), including experimental AVs in some cases, could affect mobility, traffic management, and the need for incentives.

These case studies generally found that programs with subsidies can produce substantial benefits and, in some cases, savings over current operations.

In 2017, Innisfil, Ontario, contracted with Uber to subsidize rides to selected bus stops, train stations, and central city locations. Innisfil was one of the first cities to subsidize Uber rides in lieu of traditional bus transit. Riders paid a fee of $3 to $5 to travel to community hubs or received a $5 discount on fares to other destinations around the city. In the program's first year, it supported 8,000 trips per month at a cost of $150,000 compared with an $8 million cost to provide comparable bus services.[130] The results suggest that shared-ride services at subsidized rates can be less expensive and more equitable than comparable service using public buses.

Those findings were replicated in a one-year pilot program by the public bus system Wheels in Dublin, California, which provided subsidized Uber and Lyft rides in two neighborhoods in place of low-ridership bus routes. The subsidized rides cost $3 to $5 versus a $2 regular bus fare, and an average of 50 passengers per day used the subsidized rides, or roughly the ridership of the low-ridership bus routes. The program concluded that the system "may carry an equal or greater number of people than buses do at less cost to the public agency."[131] The program encountered pushback from drivers employed by the bus authority.

The Waymo company and the Valley Metro Board in Phoenix, Arizona, conducted a first- and last-mile pilot project in 2018.[132] The goal was to explore how AV technology could address the mobility challenges of ADA paratransit-certified people with disabilities and seniors ages 65 and older. This group currently has access to a subsidized door-to-door service that provides easier access to a larger network of rideshare providers. Participants thought that AVs could improve road safety and could help address mobility challenges, especially for people with special needs. Among participants in the pilot, only 29% strongly agreed that traditional RideChoice services were safe, whereas 70% strongly agreed that AVs were safe. AV rides were used considerably more than non–Waymo RideChoice options during the core months of the pilot.

The AV company Voyage conducted a trial program using AVs as public transit in the Villages retirement community in Florida. The Villages span 40 square miles with 750 miles of roads and 125,000 permanent residents, thus providing a slower and less high-traffic environment than most pilot programs. Early results suggest that AVs can provide improved transportation services for seniors in a slow-paced, enclosed environment.

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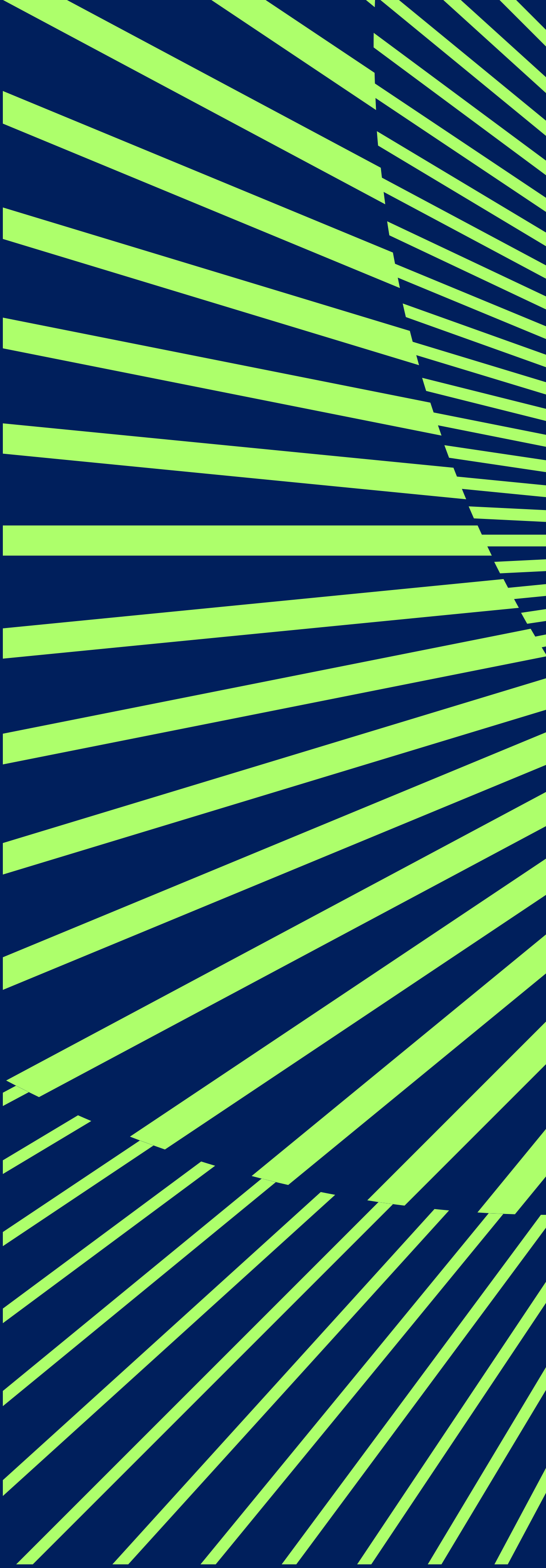
[130] The program costs increased to $640,000 in 2018 and to $900,000 for 2019.
[131] Cuff (2016).
[132] Randazzo (2018); Boehm (2018); Stern (2018); Schutsky (2018); and Templeton (2019).

An MBTA Boston Paratransit pilot program provided subsidies to customers of ride-hailing services for trips to MBTA facilities. Users who took Uber paid the first $1 and anything above $41, and those who used other services, such as Lyft and Curb, were responsible for the initial $2 plus anything above $42. In the first five months, the program provided 10,000 rides and increased transit use by customers of ride-hailing companies by 43% at an average cost of $9 per ride to MBTA. The program also registered high customer satisfaction.

In the Denver metropolitan area, the public shared mobility service Go Centennial contracted with Lyft and Via to provide fully subsidized rides to and from major transit hubs.

An independent audit found that the program increased ridership by 11.6% from January 2017 to May 2018, including a 5% increase in first- and last-mile riders,[133] and regional VMT fell by 2,925 miles over the six months. The subsidies averaged $4.70 per trip, and although an audit found that the benefit-to-cost ratio was low (from 0.50 to 0.37), the program produced significant cost savings over public transit last-mile services.



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[133] Centennial Innovation Team and Fehr & Peers (2017).

# AVs' Projected Effects on Access for People with Restricted Mobility

To estimate the impact of AVs on mobility by older people, persons with disabilities, and other nondrivers, we used a system dynamics model to simulate scenarios based on AV adoption rates (25%, 50%, and so on) and AV technology levels (Basic, Standard, and Advanced). The model examined how these factors affect the VMT, and we then converted the percentage of effects to miles per year. The results show, for example, that 25% and 50% adoption of Advanced AVs lead to increases in annual VMT, respectively, of 4.8% and 16.1% for older people, 3.1% and 8.0% for nondrivers, and 1.2% and 2.7% for people with disabilities. Those results translate into increases in the annual VMT by all older people of 2.5 billion miles and 4.9 billion miles, 2.4 billion miles and 6.1 billion miles for all nondrivers, and 4.6 billion miles and 10.4 billion miles for all people with disabilities.

The simulations found, as expected, that the capacity of AVs to increase mobility for people who are travel impaired increases as AV adoption increases and as AV technologies advance, from Basic to Standard to Advanced. As the results suggest, rising adoption rates lead to greater access to transportation, which in turn raises travel demand and VMT—and then leads to further adoption of AVs. We also assume that subsidies will be available for older people and people with disabilities for shared-ride services to bridge gaps in public transit, such as first-mile and last-mile service. The simulations found that such support increases demand, which again leads to greater adoption of AVs.

The results also suggest that AVs operating as cautious drivers (Basic) by always obeying speed limits and maintaining recommended distances between cars have unexpected effects. Such risk-averse operations increase congestion and thereby raise the cost of AVs, which in turn reduces the mobility benefits of AVs. Although we include the Basic category here, because many existing AVs currently used in pilot programs have this risk-averse driving technology, we expect that as AVs become widely available, they will use the Advanced or at least Standard technologies.[134]

### Results

The results suggest that AVs will have significant effects for the mobility of older people, nondrivers, and drivers with disabilities (Tables 4A, 4B, and 4C).

For example, at a 25% adoption rate, Advanced AVs would increase VMT by 4.8% for older drivers, 3.1% for nondrivers, and 1.2% for disabled drivers (Table 4A). The lower result for persons with disabilities may reflect the difficulties they can face when moving from their homes to the street or in places where AVs or public transit would be available. Setting aside Basic AVs, the model found that at adoption rates of 25% and 50%, AVs will significantly enhance the mobility of older people and nondrivers, and Advanced AV technology will also significantly increase the mobility of people with disabilities.

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[134] We also do not provide results for platooning CAVs because they would provide little if any additional utility for people with disabilities, older people, or nondrivers.

## Table 4A. Impact of AVs on Vehicle Miles Traveled by Drivers Who Are Travel Impaired and Nondrivers, by AV Technology and Fleet Penetration (percentage change)

| AV technology | Fleet penetration | | | |
|---|---|---|---|---|
| | 25% | 50% | 75% | 100% |
| **Drivers with disabilities** | | | | |
| Basic | –1.8% | –3.7% | –4.8% | –5.4% |
| Standard | –0.1% | –0.1% | 0.7% | 1.6% |
| Advanced | 1.2% | 2.7% | 3.8% | 4.6% |
| **Older drivers** | | | | |
| Basic | –8.7% | –18.2% | –26.5% | –32.8% |
| Standard | 2.4% | 5.2% | 3.9% | 9.6% |
| Advanced | 4.8% | 16.1% | 20.0% | 27.9% |
| **Nondrivers** | | | | |
| Basic | –3.9% | –7.1% | –12.9% | –17.3% |
| Standard | 1.7% | 1.4% | 4.0% | 4.7% |
| Advanced | 3.1% | 8.0% | 10.3% | 14.9% |

Applying the Department of Transportation estimates of VMT for each group in 2017 (the latest data available), this enhanced mobility from 25% adoption of Advanced AVs would increase annual VMT by 85 miles for an average person with disabilities, 367 miles for an older person, and 272 miles for a nondriver.[135]

With a 50% adoption rate, the mobility gains increase to 192 miles for a person with disabilities, 1,231 miles for an older person, and 703 miles for a nondriver (Table 4B).

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135. For people with disabilities, we use the miles traveled by nonworking (and younger) people with disabilities because 80% of working-age people with disabilities are not employed.

## Table 4B. Impact of AVs on Vehicle Miles Traveled by Drivers Who Are Travel Impaired and Nondrivers, by AV Technology and Fleet Penetration (miles per year)

| AV technology | Fleet penetration | | | |
|---|---|---|---|---|
| | 25% | 50% | 75% | 100% |
| | Drivers with disabilities | | | |
| Standard | – 7 | – 7 | +50 | +114 |
| Advanced | +85 | +192 | +271 | +327 |
| | Older drivers | | | |
| Standard | +184 | | | |
| Advanced | +367 | | | |
| | Nondrivers | | | |
| Standard | +149 | | | |
| Advanced | +272 | +703 | +905 | +1,309 |

Notably, the results for older people and people with disabilities understate the total impact because the available data require that the model focus on drivers in each category. In 2020, 47 million of 54.1 million older Americans had driver's licenses, and the remaining 13% did not. Similarly, of the 13.4 million working-age adults who have travel-impairing disabilities, 39.6% are not drivers. This suggests that the total impact could be up to 13% greater for older people and up to nearly 40% greater for people with disabilities.

Finally, we apply the average VMT for people in each of these travel-impaired groups to the number of people in each cohort to estimate the total increase in mobility for each group. Based on 2017 VMT data (the latest available) and a 25% adoption rate for AVs, access to Standard AVs by older people would increase their total annual VMT by nearly 2.5 billion miles, and access to Advanced AVs would increase their total mobility by more than 4.9 billion miles (Table 4C).

## Table 4C. Impact of AVs on Vehicle Miles Traveled by Drivers Who Are Travel-Impaired and Nondrivers, by AV Technology and Fleet Penetation (million miles per year)

| AV technology | Fleet penetration | | | |
|---|---|---|---|---|
| | 25% | 50% | 75% | 100% |
| Adults with disabilities | | | | |
| Standard | –388 | –388 | +2,705 | +6,167 |
| Advanced | 4,599 | 10,387 | +14,661 | +17,691 |
| Older people | | | | |

Similarly, at a 25% adoption rate, although access to Standard AV technology by disabled people could reduce their annual VMT by 388 million miles, access to Advanced AVs would increase their total annual mobility by nearly 4.6 billion miles. Finally, for the 8.7 million working-age Americans without disabilities who are nondrivers, at a 25% AV adoption rate, access to Standard AVs would increase their total annual mobility by nearly 1.3 billion miles, and access to Advanced AVs would increase their mobility by nearly 2.4 billion miles.

These results strongly suggest that AV service will provide significant mobility benefits for millions of Americans, including people with disabilities, older people, and nondrivers.

# V. AVs and the Environment: The Impact on Greenhouse Gas Emissions

The use of AVs could result in significant reductions in greenhouses gases and other pollutants. Federal regulations in place since 1975 have mandated reductions in motor vehicle pollution, and vehicle manufacturers have met those requirements mainly by applying a range of technological innovations, including variable valve timing, direct injection, new materials to reduce mass and weight, and the use of alternative fuels, especially electric batteries and fuel cells.[136] However, transportation continues to account for a substantial share for 38% of the country's CO2 emissions, 58% of which come from the use of personal vehicles.[137]

The extent of the environmental benefits from AV use will depend on several factors. Most importantly, will AVs be powered by electric powertrain systems and fuel cell technologies that produce zero or near-zero tailpipe emissions or by conventional fossil fuel engines?[138] Some analysts have reasoned that AVs will require electric or fuel cell powertrains because the safe operation of their sensor, communication, and AI technologies will depend on stable and reliable electric power.[139] AVs' impact on the environment will also depend on a range of other factors, including whether they are used for personal transportation or shared rides, the extent of their use, and whether their use reduces dependence on private combustion engine vehicles.

By providing on-demand transport services linked to public transit, AVs could generate environmental benefits by reducing personal car use and by increasing public transit ridership, thereby reducing total vehicle miles driven. AVs could also reduce emissions compared with personal vehicles because they will be programmed to operate more efficiently and avoid congestion. Finally, public acceptance of electric-powered AVs could accelerate the transition to electric vehicles (EVs).

Under certain conditions, the use of AVs could increase emissions. For example, total miles driven could well rise as AVs enhance mobility for people unable to use personal vehicles and enable people to relax or work in transit once freed of any responsibility for driving. AVs will also likely produce other contaminants such as brake dust, and fossil fuels to generate the electric power for AVs will offset some of the environmental benefits of EVs.[140] However, private and public investments to link AVs to public transit routes could mitigate some of these effects.

### AVs as EVs

There are compelling reasons why AVs are likely to be predominantly EVs. An AV's extensive computing hardware will require substantial electrical power that can be

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[136] National Academies of Sciences, Engineering, and Medicine (2021).

[137] Congressional Budget Office (2022).

[138] Ibid. Future possible technological improvements include variable valve life, variable compression ratio, cooled EGRvariable geometry turbine turbocharging, electric intake cam phasing, and increased fuel injection pressure.

[139] Nunno (2021).

[140] Nadafianshahamabadi, Tayarani, and Rowangould (2021); Sha (2020).

provided most efficiently and reliably by all-electric battery packs, whereas the electrical power produced by an internal combustion engine is less stable.[141] The safety of AVs will also depend on low latency—brief intervals between a program's decision regarding a maneuver and carrying it out—and electric propulsion systems have a lower latency and more consistent responses than internal combustion systems when accelerating.[142]

Electric fleets are easier to manage and require less maintenance than gasoline-powered fleets, so the introduction of electric-powered AVs could present an opportunity for companies and governments to undertake fleet-wide changes. And because the government already provides subsidies to accelerate the transition to EVs, those subsidies will extend to AVs when they move into production.

The climate benefits of fleets of electric-powered AVs supplanting the use of other vehicles should be substantial. Although producing the lithium-ion batteries for EVs creates significant CO2 emissions, operating EVs is more climate friendly than internal combustion engines. MIT researchers report that battery EVs emit an average of 200 grams of CO2 per mile, and hybrids and plug-in hybrids emit an average of 260 grams per mile, compared with more than 350 grams per mile by gasoline-powered automobiles.[143] Similarly, the Department of Energy reports that EVs create 3,932 pounds of CO2 equivalent per year, compared with 5,772 pounds for plug-in hybrids and 11,435 pounds for gasoline vehicles.[144]

### Vehicle Behaviors and Efficiency

Apart from AVs as EVs, much of the initial adoption of Advanced passenger AVs will be for shared use, and studies of pilot partnerships between ridesharing companies using the current generation of AVs and local governments in Arizona, California, Colorado, and Texas suggest that their use should significantly reduce CO2 and NOx emissions as well as congestion in other ways.[145] One study found that by reducing the number of vehicles in traffic, rideshare AVs reduced emissions by up to 15%,[146] and a survey of 429 studies concluded that in an environment dominated by passenger vehicles, the use of shared-ride AVs could result in an average 20% reduction in CO2 and PM2.5 emissions.[147] AVs can also be programmed to optimize their energy efficiency by optimizing the speed and routes they follow; accordingly, researchers have found that AVs lowered emissions by improving fuel efficiency and by encouraging the use of public transit. More advanced AVs will be able to communicate and coordinate with each other, and this capacity should enable them to decrease sudden braking and acceleration, improve traffic flow, and reduce congestion.

In addition, the National Renewable Energy Laboratory notes that AVs could reduce energy demand by rendering many current safety features unnecessary and could thereby substantially reduce the vehicles' weight.[148]

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[141] Lempert (2021).
[142] Ibid.
[143] Massachusetts Institute of Technology (2019).
[144] U.S. Department of Energy (2022).
[145] Lempert (2021).
[146] Ibid.
[147] Preston et al. (2020).
[148] Brown, Repac, and Gonder (2013). The weight of large batteries, however, could offset some of these benefits.

The judicious use of shared-ride AVs could lower emissions by enhancing efficiency and reducing congestion in other ways. An estimated 25% of traffic congestion is associated with accidents, and the majority of collisions involve human errors that AVs could avoid.[149] Another 30% of urban congestion is related to drivers who search for parking, but shared-ride AVs can discharge their riders without parking and can wait in uncongested areas for the next riders.[150] AVs' expected ability to communicate and coordinate with other AVs and parts of transportation infrastructure could produce smoother traffic flows that should also reduce emissions. However, these benefits could require significant financial investments in uniform road infrastructure that can communicate with the vehicles,[151] dedicated lanes for CAV platooning, and perhaps construction of AV loading and docking points.[152]

Careful planning also will be necessary to avoid secondary effects that could reduce the environmental benefits. After AV passengers disembark at their destinations or public transit spots, planners will have to figure out how to minimize travel by unoccupied AVs. To maximize emission reductions, AV travel will have to be broadly affordable, a consideration that their shared use should address. Some uncertainty exists about how the interactions of AVs and conventional vehicles will affect congestion.[153] Perhaps most importantly, AV routing may need to favor connections to current public transit networks.[154]

Other aspects of AV adoption could present environmental challenges. Widespread adoption could reduce the burdens of living farther from urban centers and could thereby contribute inadvertently to urban sprawl and development in rural areas that threaten deforestation and fragile habitats.[155] As noted earlier, AVs will require considerable energy drawn from the electric grid to power and operate their onboard systems. And as natural gas and other fossil fuels generate about 63% of U.S. electricity, transportation that includes electric-powered AVs could be a major source of greenhouse gas emissions for decades to come.[156]

AVs will play an important role in reducing emissions and urban congestion, given appropriate planning and management. Their net environmental benefits will depend on their fuel source, their rate of adoption, the public's acceptance of shared mobility, and how they interact with public transit and private vehicles.[157] Shared-ride AV networks will produce the largest environmental benefits, especially in dense urban areas with moderate public transit systems.[158]

In this regard, the Environmental and Energy Study Institute estimates that by 2050, shared-ride AVs used as public transit could reduce total VMT by 25% and could cut urban pollution by as much as 80%.[159]

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[149] Fagnant and Kockelman (2015).

[150] Shoup (2007).

[151] Lawson (2018).

[152] Marsden, Docherty, and Dowling (2020); Zhang and Wang (2020); Guhathakurta and Kumar (2019); Heaslip et al. (2020).

[153] Cumins, Sun, and Reynolds (2021).

[154] Littman (2022).

[155] Nogues, Gonzalez-Gonzalez, and Cordera (2020).

[156] Nunno (2021).

[157] Silva, Cordera, Gonzalez-Gonzalez, and Nogues (2022).

[158] Ibid.

[159] Nunno (2021).

## AVs’ Projected Effects on the Environment and Congestion

The use of internal combustion engines and the generation of their fuels are significant sources of CO2 emissions, the primary greenhouse gas contributing to climate warming, and NOx emissions, the gas that produces atmospheric ozone. To estimate the environmental impact of networks of AVs, we use a system dynamics model that incorporates insights from previous research and leverages the Environmental Protection Agency’s Motor Vehicle Emission Simulator (MOVES) to analyze CO2 equivalent emissions and NOx emissions from transportation sources.[160] The model’s emission estimates account for the age, energy consumption, cold start and operational emissions, vehicle occupancy rates, and acceleration and deceleration profiles of AVs and conventional vehicles, thus highlighting the traffic and consequent fuel efficiencies of AVs. We also adopt from the recent literature the assumptions about the weight of AVs, the electric grid’s CO2 intensity, and how cost affects travel choices.

Given AVs’ demand for stable, steady electric power to run their computer and sensor networks, we also assume that AVs will have electric powertrains rather than internal combustion engines. Electric-powered vehicles do not emit CO2 or NOx exhaust, but the electric power they use must be generated and distributed through the electric grid fueled by fossil fuels or other more sustainable sources of energy. The impact of electric-powered AVs on greenhouse gases, therefore, will depend on types of energy used to generate the electric power. Therefore, we posit three mixes of fuels for the grid: (1) Climate+: an increasing role for sustainable fuels and declining use of fossil fuels, thus lowering greenhouse gas emissions; (2) Climate Neutral: a continuing predominant role for fossil fuels with more modest use of sustainable fuels; and (3) Median: the median case between these two alternatives. The simulation examined the impact of electric Advanced AVs on motor vehicle emissions of CO2 and NOx based on the mix of fuels used to generate the grid’s power.

Because no one can say with any confidence precisely when the adoption of AVs will reach 25% or more, we measured the estimated reductions in CO2 and NOx emissions against their current emissions from the use of motor vehicles. Therefore, the question examined here is this: What would be the environmental benefits today if 25% of the U.S. motor vehicle fleet were Advanced AVs? Notably, the environmental benefits of Advanced AVs may be less than those from Standard or Basic AV operations because the technologies of Advanced AVs require more electrical power. The estimated emission reductions therefore should be considered the minimal benefits to be expected from the use of AVs.

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[160] Environmental Protection Agency (2022).

The results show that in all cases, the adoption of Advanced AVs would produce significant environmental benefits relative to the current CO2 and NOx emissions associated with the use of motor vehicles based on their greater efficiencies in traffic and their use of electric powertrains instead of internal combustion engines (Table 5). At a 25% adoption rate, the use of Advanced AVs would decrease current CO2 emissions related to motor vehicle use by 5.9% to 8.2%, with a median reduction of 7.1% (Table 5). Similarly, they would reduce the current NOx emissions related to motor vehicle use by 6.4% to 8.9%, with median reductions of 7.7%. At a 50% adoption rate, these AVs would reduce current CO2 emissions related to motor vehicle use by 15.7% to 22.0%, with a median reduction of 19.1%, and would reduce NOx emissions associated with motor vehicles by 17.1% to 23.8%, with a median reduction of 20.6%.

## Table 5. Change in Total Motor Vehicle CO2 and NOx Emissions with All Electric AVs, Based on the Mix of Fuels to Power the Electric Grid

| | Fleet penetration | | | |
|---|---|---|---|---|
| | 25% | 50% | 75% | 100% |
| *Grid mix: climate+ (enhanced reliance on sustainable fuels)* | | | | |
| **CO2** | –8.2% | –22.0% | –36.0% | –37.2% |
| **NOx** | –8.9% | –23.8% | –38.7% | –39.8% |
| *Grid mix: climate neutral (continuing reliance on fossil fuels)* | | | | |
| **CO2** | –5.9% | –15.7% | –25.7% | –26.6% |
| **NOx** | –6.4% | –17.1% | –27.8% | –28.6% |
| *Grid mix: median case* | | | | |
| **CO2** | –7.1% | –19.1% | –31.2% | –32.0% |
| **NOx** | –7.7% | –20.6% | –33.6% | –34.5% |

Overall, the adoption of AVs should produce significant environmental benefits. Although many challenges will have to be addressed, these potential benefits of AVs should indicate that policymakers, the business community, and environmental leaders need to collaborate to help realize those challenges.

# VI. Employment Implications of AVs

The adoption of AVs here and around the world could have significant effects on American jobs. AVs used as personal vehicles may displace demand for conventional vehicles with little aggregate effect on employment, but shared-ride AVs used to enhance mobility for people who are travel impaired may add to overall demand for motor vehicles and the jobs to produce them. The adoption of AVs will also affect the composition of the industry's employment, thus creating more jobs for technical and mechanical specialists for both AV manufacturers and the producers of their intermediate inputs, including increased jobs in electronics and computer manufacturing, telecommunication equipment and services, and infrastructure and construction. Jobs in manufacturing and assembling major components, such as vehicle bodies, chassis, drive trains, and interior features, may be affected, although increases may be offset by reductions in jobs that help manufacture and assemble conventional components that become unnecessary for AVs.

The aggregate employment effects from these dynamics are not completely known at this time, as AVs' technologies and components continue to evolve, and the pace of their adoption remains unknown. Nevertheless, AVs represent a significant new market, and the companies and countries that establish strong positions in that market will see significant job gains.

Apart from employment, the use of AVs could boost efficiency and productivity. Broad use of shared-ride AVs will lower people's travel costs and so enable them to travel farther, which in turn will both increase their access to jobs and expand talent pools for businesses.[161]

As noted earlier, the motor vehicle industry has been a major source of American employment, accounting for 2,922,000 jobs in 2021, or more than the total employment in real estate (2,125,000) and information services (2,650,000).[162] Motor vehicle and parts manufacturers (MVPMs) directly employed 957,000 Americans, and vehicle and parts dealers employed another 1,965,000 people.[163] The U.S. motor vehicle industry is also a major source of demand and jobs for the industries that supply their inputs.

We analyzed how these input purchases in 2021 affected employment in each of the industries producing them by applying the relationship between an industry's production and its employment, which economists measure by the number of jobs created for each $1 million in an industry's final demand.[164] We found that the input purchases by MVPMs in 2021 supported an additional 871,310 jobs in the industries that produced them.[165] MVPM input purchases were responsible for more than 100,000 jobs in three of those supplier industries: 181,305 jobs in the fabricated metal products industry, 142,715 jobs in computer and electronic

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[161] Mudge et al. (2018).

[162] Bureau of Economic Analysis (2022d). Information services include broadcasting and telecommunications, publishing, software, and data processing.

[163] Bureau of Economic Analysis (2022d).

[164] Bivens (2019). Appendix Table A2.

[165] Bureau of Economic Analysis (2022d).

products manufacturing, and 104,871 jobs in plastic and rubber product production.[166]

The inputs purchased by motor vehicle and parts dealers also supported jobs in many other industries. Our input–output analysis found that those dealers purchased $99.8 billion in inputs in 2021, including inputs of $1 billion or more from 23 other industries.[167] Our analysis further found that those input purchases directly supported another 398,542 jobs in the industries that produced them, including 112,000 jobs in professional, scientific, and technical services, and 71,000 jobs in warehousing and storage companies.[168]

All told, U.S. motor vehicle and parts manufacturers and dealers were responsible for 4,191,852 American jobs in 2021, directly employing 2,922,000 people and directly supporting the jobs of another 1,269,852 people through their purchases of inputs from other industries (Table 6). These motor vehicle industry and related jobs exceeded all direct employment in the education sector (3,457,000) and nearly equaled civilian and miliary employment by the federal government (4,304,000).

## Table 6. Direct Employment by Motor Vehicle and Parts Manufacturers and Dealers and Employment Directly Supported by their Purchases of Intermediate Inputs, 2021

| | Direct jobs | Input supplier jobs | Total |
|---|---|---|---|
| Motor vehicle and parts manufacturers | 957,000 | 871,310 | 1,828,310 |
| Motor vehicle and parts dealers | 1,965,000 | 398,542 | 2,363,542 |
| **Total** | **2,922,000** | **1,269,852** | **4,191,852** |

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[166] MVPM input purchases also supported 94,876 jobs in machinery manufacturing, 54,615 jobs in management services, and 52,095 jobs in primary metals production.

[167] We exclude intrasector inputs purchased by those dealers from MVPMs, totaling $7.6 billion in 2021, and focus on the $84.7 billion in purchases from those 23 other industries.

[168] Those purchases also supported 10,000 to 20,000 jobs in other transportation services, other retail services, food services and drinking places, plastic and rubber product manufacturing, insurance carriers, and wholesale trade services.

An important issue raised by the development of AVs is whether American motor vehicle companies and their suppliers will be more competitive or less competitive than they are today in the emerging U.S. and worldwide markets for AVs. As seen with other major innovations, the emergence of AVs could disrupt current motor vehicle market competition in significant ways. For example, China currently has certain advantages as by far the largest national market for motor vehicles and the largest producer for that market. However, China is much less competitive in the world's three other major markets—the United States, Europe, and Japan. However, China's greatest advantage in the coming competition for AV markets is political. Its government's stated policy is to generously support and promote R&D in AVs through its 14 state-owned motor vehicle companies and many of the 40 privately owned Chinese domestic vehicle producers. China's government also aggressively supports the state-owned and private Chinese enterprises that are developing computers, telecom equipment, and software for AVs, and is making the early investments in roadway infrastructure that advanced AVs will need.

The United States has important competitive advantages. American motor vehicle companies have established the most extensive global networks of suppliers, production facilities, and customers, thus creating efficiencies that Chinese producers can only try to offset through government subsidies. Moreover, American companies generally dominate most markets for the types of new technologies that AVs require. The United States is the world's preeminent developer of software, with 8 of the world's 10 largest software development companies,[169] and the preeminent producer of telecom equipment, with 5 of the world's top 10 producers.[170] In addition, 5 of the world's top 10 computer manufacturers are American.[171]

The United States, along with Europe and Japan, remains committed to promoting competition rather than simply providing government subsidies to serve the country's long-term economic interest. Given China's aggressive government support for its domestic private and state-owned producers and the substantial stakes at play in the coming global and U.S. markets for AVs, the American government can and should consider measures to promote continuing innovation and leadership in AVs.

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169. Bizvibe (2021a).
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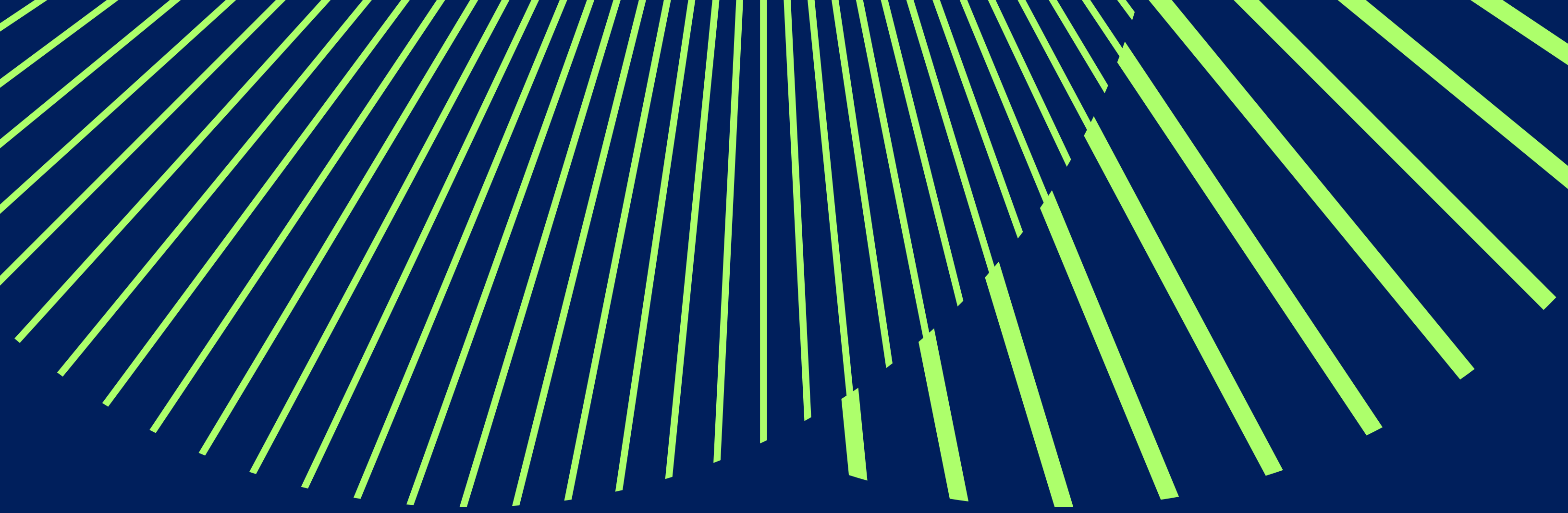


# VII. Conclusion

This study examined the potential social, economic, and environmental benefits from the large-scale adoption of AVs. We found that their widespread use—constituting 25% of motor vehicles—should lead to significant reductions in traffic accidents and associated deaths, injuries, and economic costs. We also found that large-scale use of AVs should substantially increase mobility and access for millions of people with disabilities who are travel impaired, older people, and nondrivers, with potentially substantial economic and social benefits. Finally, such broad adoption of electric-powered AVs should produce meaningful reductions in greenhouse gas emissions, even taking account of emissions produced to generate their electric power.

Given the size of the global and U.S. markets for motor vehicles, intense international competition over AV production and sales will accompany their widespread adoption. Today, many motor vehicle and technology companies around the world are invested in developing AVs, led by companies in the United States and China, the two leading countries for the production and sale of conventional motor vehicles. Looking ahead to this competition, Chinese companies have the advantage of aggressive subsidies and other government support for their efforts to develop commercially viable AVs. American companies have the advantage of global leadership in most areas critical to AV technology. Given the large economic stakes in this competition, U.S. policymakers should consider measures that would support the continuing innovation and technological leadership of American companies in this critical and emerging market.

# Appendix: The Models

We employed a multimethod approach to evaluate the safety, mobility, and environmental implications of AVs across various system variables, including the vehicle and user level, transport system level, and societal level. This methodology integrates the frameworks of conceptual modeling and existing transportation models. Given the general absence of empirical data on AVs, we use causal system dynamics models to investigate long-term processes and the influence of key variables on the societal effects of AVs. For this purpose, we used Vensim software for system dynamics modeling. We also draw on results from Motor Vehicle Emission Simulator (MOVES), Vissim, and EnViVer models that address current transportation concerns. These models, which have been used to analyze Transportation Network Companies (TNC), congestion, and greenhouse gas emissions, provide a more accurate foundation for simulating the effects of AVs.

Our scenarios represent a future in which technology and government support address U.S. mobility to benefit the American public. We assume that public investments, incentives, and regulations enable more people to share rides without cannibalizing public transit service and allow riders to transfer fluidly between modes of transit. These transportation policy assumptions were selected using six criteria: (1) transit ridership changes, (2) congestion levels, (3) financial impact on federal and municipal budgets, (4) equity in access to mobility, (5) political feasibility and public acceptance, and (6) technical feasibility and implementation ease.

Our underlying adoption rates are a modified version of scenarios and parameters presented by Litman (2022) and Stasinopoulos (2021), adjusted to reflect certain differences in assumptions such as the proportion of shared versus private fleets, public investment, and transportation management policies. We assume a broad use of rideshares and 100% adoption of electric vehicles. We also assume aggressive public investment in infrastructure and R&D to support the adoption of AVs, which we believe will be necessary to achieve their potential benefits. Further, we assume a federal AV TNC data-sharing policy to help maximize the benefits of AVs and to ensure their safe deployment.

These transportation and mobility policies would promote and support specific AV-enabled TNC routes and areas, for example, by subsidizing trips that fill gaps in public transit service, such as first- and last-mile connections and areas with limited access to public transit, as well as transit hubs.

We also assume the removal of barriers to intermodal transit through multimodal trip planning options. To limit congestion and prevent competition with public transit, we also assume limits on route authorization through geofencing. Finally, we assume three relatively optimistic projections of lower greenhouse gas intensity for the U.S. electric grid, as related to the environmental benefits of electric AVs.

# Data Sources

We drew on a wide range of data sources to develop the mobility model, including the U.S. Department of Transportation (USDOT) and NHTSA. The USDOT's Transportation National Household Travel Survey and the Federal Highway Administration's Highway Performance Monitoring System provided critical data on daily travel behavior and highway performance. To estimate the economic savings from reducing traffic accidents, fatalities, and injuries, we relied on the most recent NHTSA data on the impact of crashes on medical costs, foregone productivity, legal and court costs, emergency services, insurance administration, property damage, and congestion costs. We also used the National Transportation Atlas Database and Transportation Economic Trends data sources from the Bureau of Transportation Statistics to inform our analysis of the U.S. transportation system's geospatial data, transportation demand, capacity, and performance. Last, we incorporated data from the Statewide Transportation Improvement Program and Metropolitan Planning Organization transportation plans to inform our view of long-range transportation planning in specific states and metropolitan areas.

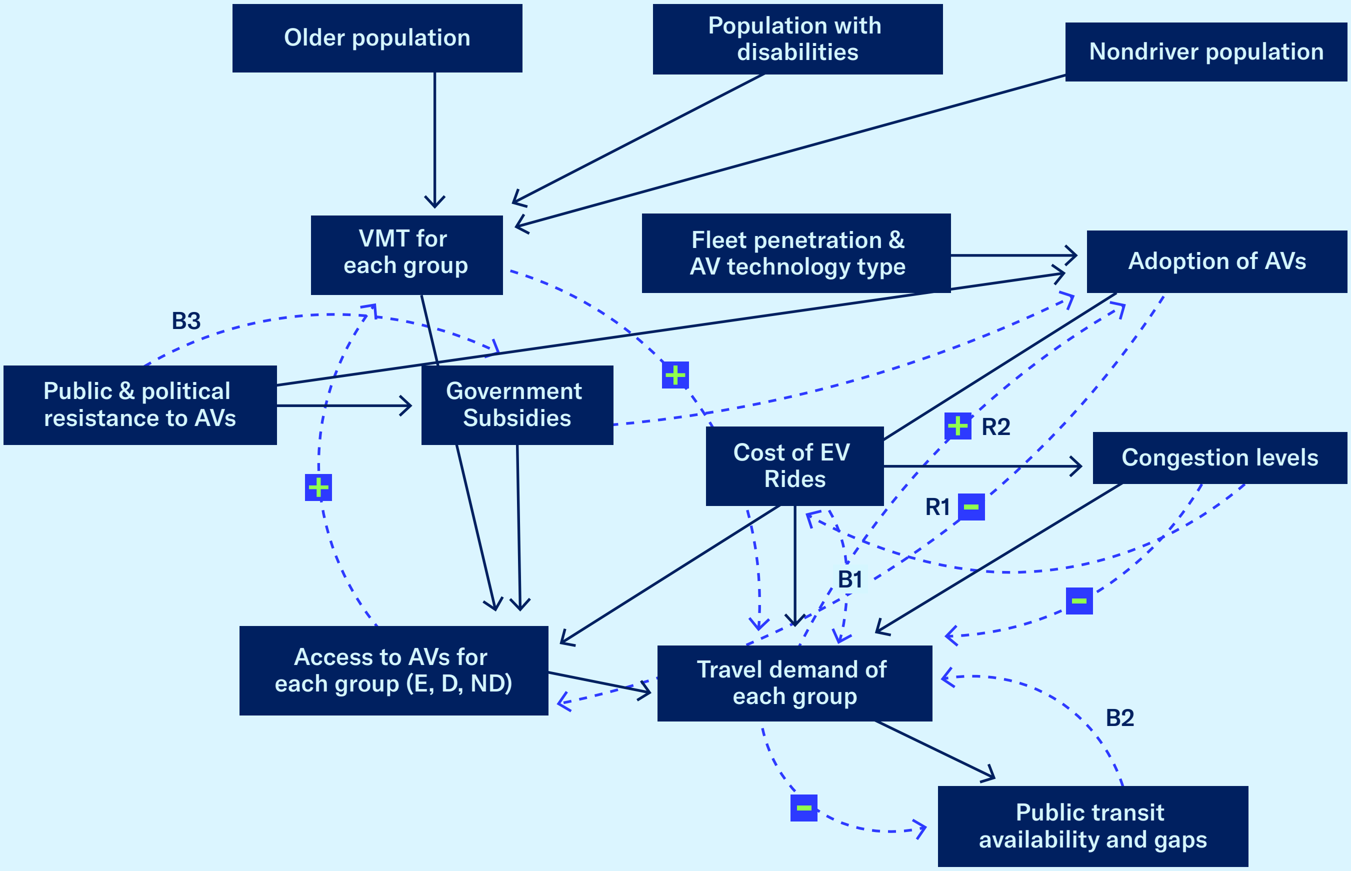
Demographic data were gathered from the U.S. Census Bureau, the Department of Health and Human Services, and USDOT. We relied on the Census Bureau's American Community Survey and Decennial Census for the demographic and housing characteristics at various geographic levels. The study also draws on USDOT estimates of vehicle miles traveled (VMT) for each mobility-restricted group in 2017.

For our greenhouse gas emissions submodel, we employed data from USDOT on daily travel behavior and occupancy rates gathered under the National Household Travel Survey, including information on trip purpose, mode choice, and travel time and distance. We also used the Federal Highway Administration's Highway Performance Monitoring System and the NHTSA's Vehicle Inventory and Use Survey for data on highway mileage, travel, and performance, including VMT by different vehicle types and on different road types. Data regarding vehicle age, energy consumption, and emissions came from the Environmental Protection Agency's (EPA) National Emissions Inventory and the MOVES model available from the EPA website. The Energy Information Administration provided our data on the electric grid's energy mix in its Annual Energy Outlook and the Electric Power Monthly, and the data on population and vehicle ownership are derived from the Census Bureau's American Community Survey and Vehicle Inventory and Use Survey.

# Mobility Submodel

To analyze the potential impact of AVs on the mobility of older people, people with disabilities, and nondrivers, we used a system dynamics model to simulate various scenarios based on different AV adoption rates (25%, 50%, 75%, and 100%), AV technology levels (Basic, Standard, and Advanced), and subsidies for shared-ride AV trips by those with disabilities and older people. Our model examined how these factors affect the VMT by each group to provide quantitative estimates of their increased mobility. The model generated estimates of the percentage change in VMT for each target group based on various combinations of AV adoption rates and technology levels. These percentage changes were converted to miles per year to calculate the overall impact on each group's total VMT. Figure A.1 is a visual representation of the organization of this model.

## Figure A.1. Simplified Causal Loop Diagram of Mobility Submodel



Our mobility analysis relies on the assumptions regarding AV adoption rates, technology levels, and government subsidies noted earlier, which may or may not capture future real-world conditions. First, we assume that AVs do not operate on routes currently served by public transit to avert direct competition between shared-ride AVs and public transit systems. We assume that subsidies are available for shared-ride AV trips that bridge gaps in public transit service, including subsidies for shared-ride AV trips that serve areas with limited access to public transit and first-mile and last-mile service. The model does not account for factors such as the spatial distribution of the target populations, variations in regional transportation infrastructure, or potential exogenous changes in public transit availability. Future research could explore these factors and their potential impact on AV use by people with restricted mobility.

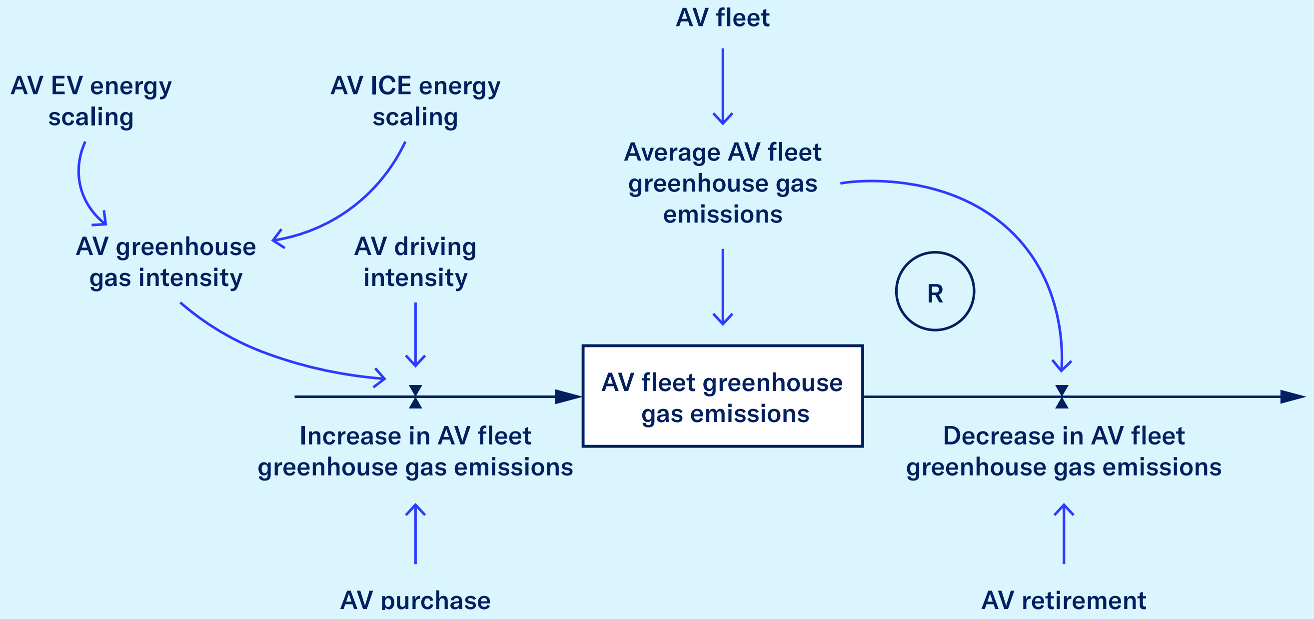
We identified several major causal loops in this analysis. The first such loop connects the adoption of AVs, access to AVs, VMT, and travel demand for each group. As the availability of AVs increases and adoption rates rise, access to transportation for these groups also increases, leading to higher travel demand and VMT, which in turn leads to further adoption of AVs, thus creating a reinforcing loop. Another reinforcing loop occurs among government subsidies for shared-ride AV trips, the adoption rates of AVs, and access to AVs for each group. As subsidies for shared-ride AV trips become available, more people in these groups will be able to afford and use AVs, which leads to increased adoption rates and further access to AVs that in turn reinforces the availability and use of the subsidies for these groups.

We also identified a balancing loop among the cost of AV rides, travel demand, congestion levels, and VMT for each group. As the cost of AV rides increases, travel demand decreases, which leads to reduced VMT and less congestion. This in turn leads to lower costs for AV rides, creating a balancing loop. We identified another balancing loop between public transit availability and gaps, travel demand, and VMT for each group. As public transit availability increases, travel demand decreases and leads to lower VMT and congestion levels. This in turn leads to less need for public transit and creates a balancing loop.

## Emissions Submodel

To evaluate the environmental effects of AVs and the implications for congestion, we used a system dynamics model to simulate scenarios for varying degrees of AV adoption. The model is based on previous research and uses the EPA's MOVES and results from EnViVer to estimate CO2 equivalent emissions and NOx emissions from transportation sources. The simulation accounts for factors such as vehicle age, energy consumption, cold start and operational emissions, vehicle occupancy rates, and acceleration and deceleration profiles. We calibrated the model to ensure its reliability by comparing its outputs with historical data. We ran simulations for the varying levels of AV fleet adoption and different grid energy mix scenarios (Climate +, Climate Neutral, Median).

Figure A.2. Simplified Causal Loop Diagram of Emissions Submodel



## Traffic Safety Submodel

We used a system dynamics approach that integrates many factors to simulate various scenarios for assessing the impact of AVs on transportation systems, traffic accidents, fatalities, injuries, property damage, and associated economic effects. We incorporated several considerations to evaluate the potential impacts of AVs in various driving environments. This approach required a meta-analysis based on microsimulation results derived from the use of VISSIM traffic modeling software, which has proven to be a valuable tool in traffic simulations and assessments. We further refined our model by considering conflicts arising from different time-to-collision thresholds such as 1.5, 1.25, 1.0, and 0.75 seconds. By accounting for these variations, we could capture a broad range of potential interactions between AVs and other road users. We also conducted simulations at multiple traffic speeds, and the final results represent a weighted average of those simulations. Our model further accounts for the diverse ways that AVs may affect public health and safety in both positive and negative ways. That analysis considers multiple pathways through which AVs can affect traffic based on 32 public health pathways drawn from the literature. We estimated the potential impact of AVs on health and safety through accidents by combining these pathways with the model's assumptions.

This model simulated the effects of AV adoption on traffic accidents based on different AV operating technologies, adoption rates, and platooning (connected AVs, or CAVs, that communicate with each other). We use the three alternatives for AV driving logic and behavior noted earlier based on parameters developed for the PTV Vissim traffic simulator to represent different levels of AV performance under varying conditions.

Our analysis revealed several causal loops related to the adoption and impact of AVs. The first is a positive feedback loop in which an increase in AV adoption leads to a reduction in accidents, which increases adoption rates and improves the effectiveness of AV technology. These dynamics can also lead to a negative feedback loop in which the increased accessibility and convenience of AVs cause increases in VMT, potentially leading to more accidents. Increases in AV adoption may lead to a reduction in physical activity because of increased reliance on the vehicles, potentially leading to negative public health outcomes. We also observed another positive feedback loop related to adoption of CAVs. As their use increases, their capacity to communicate and platoon improves, which leads to more efficient traffic flow and fewer accidents.

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# About the Authors

Robert J. Shapiro, PhD, is the chair of Sonecon, LLC, a firm in Washington, D.C., that provides economic analysis and advice to U.S. and foreign government officials, business executives, and leaders of nongovernmental organizations. He is also a fellow of the Georgetown University Center for Business and Public Policy, a board director of Overstock.com, and an advisory board member of Cote Capital and Civil Rights Defenders. Shapiro has advised Presidents Bill Clinton and Barack Obama, Vice President Albert Gore, Jr., British Prime Minister Tony Blair and Foreign Secretary David Miliband, Secretary of State Hillary Clinton, Treasury Secretaries Robert Rubin and Timothy Geithner, White House Chief of Staff Ron Klain, and other senior members of the Clinton, Obama, and Biden administrations and the U.S. Congress. Shapiro and Sonecon also have provided analysis and advice to companies, including AT&T, Exelon, ExxonMobil, Fujitsu, Gilead Sciences, Google, Nasdaq, and UPS, as well as nonprofit organizations, including the International Monetary Fund, the Brookings Institution, the Center for American Progress, and the U.S. Chamber of Commerce. Before founding Sonecon, Shapiro was the U.S. Under Secretary of Commerce for Economic Affairs. Before that, he was cofounder and vice president of the Progressive Policy Institute and the legislative director and economic counsel to Senator Daniel Patrick Moynihan. He also served as the principal economic advisor to Bill Clinton in his 1991–1992 presidential campaign, senior economic advisor to Hillary Clinton in her 2015–2016 campaign, and economic policy advisor to the campaigns of Joseph Biden, Barack Obama, John Kerry, and Albert Gore, Jr. He holds a PhD and MA from Harvard University, an MSc from the London School of Economics and Political Science, and an AB from the University of Chicago.

Isaac Yoder is a senior analyst at Sonecon, LLC, where he focuses on domestic public finance, economic development, and the creative economy. Before joining Sonecon, he was a teaching fellow at Harvard University's John F. Kennedy School of Government, served as a fellow in the Office of State Planning and Budgeting for the governor of Colorado, and was codirector of business development for Economic Security Planning. He has been a Harvard Dukakis fellow, a Bruner fellow, and a Cole scholar. Yoder holds an MPP in economic development from Harvard University and a BA from Oberlin College.

# About the U.S. Chamber

The Chamber of Commerce of the United States is the world's largest business organization. Our members range from the small businesses and chambers of commerce across the country that support their communities, to the leading industry associations and global corporations that innovate and solve for the world's challenges, to the emerging and fast-growing industries that are shaping the future. For all of the people across the businesses we represent, the U.S. Chamber of Commerce is a trusted advocate, partner, and network, helping them improve society and people's lives.

Since our founding, the U.S. Chamber has advocated for policies that help businesses create jobs and grow our economy. Building on a strong legacy of trust and track record of success, we help today's businesses start, grow, and thrive in a complex and constantly changing macro environment. We inform our members with timely policy analysis and legal advice, connect them with leaders in business and government through world-class events and intimate gatherings, and equip them with tools and resources to help them succeed. Above all, we serve as their ally and champion on Capitol Hill, in the courts, in the state houses, and in markets around the world. No matter who or where our members are, we are their seat at the table and voice in the debate.

We advocate, connect, inform, and fight for business growth and America's success.

While the country has changed since the U.S. Chamber of Commerce was established over a century ago, our foundational belief has not. We believe in the ability of American businesses to improve lives, solve problems, and strengthen society. And throughout the years, a clear pattern has emerged. When citizens, business leaders, and government officials work together, America works. There are greater opportunities for better jobs, new industries, and fairer laws. Communities thrive, the economy grows, and our nation's positive influence in the world increases. When that partnership breaks down, those opportunities and the country's optimism fade.

To us, the choice is simple. The future we want to build gives everyone the opportunity to build a better future for themselves. It's why our job today—and every day—is to build the strongest relationship possible among the American people, business leaders, and elected officials in Washington, state capitals, and countries around the globe. This empowers business to play a vital and needed role in a healthy democracy. It allows us to shape and deliver the bold policies that matter most to our members. And it enables millions of businesses to create the jobs and economy that offer every American the chance to pursue their goals.