Preparing GREATER PHILADELPHIA for HIGHLY AUTOMATED VEHICLE DEPLOYMENT

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What's Already Happening in Greater Philadelphia

SCENARIOS INSIDE

Delayed Expectations: Automated vehicle development stalls due to stagnant economy.

People Power: Federal government advancing truck platooning, connected vehicles, and automated shuttles.

Tech in the Driver's Seat: Automated vehicles are here. Are we ready?

Inclusive Tech: Open source principles and federal regulations shape automated vehicles.

DECEMBER 2020

GREATER PHILADELPHIA FUTURES GROUP
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The Delaware Valley Regional Planning Commission (DVRPC) is the federally designated Metropolitan Planning Organization for a diverse nine-county region in two states: Bucks, Chester, Delaware, Montgomery, and Philadelphia inPennsylvania; and Burlington, Camden, Gloucester,and Mercer in New Jersey.

DVRPC's vision for the Greater Philadelphia region is a prosperous, innovative, equitable, resilient, and sustainable region that increases mobility choices by investing in a safe and modern transportation system; that protects and preserves our natural resources while creating healthy communities; and that fosters greater opportunities for all.

DVRPC's mission is to achieve this vision by convening the widest array of partners to inform and facilitate data-driven decision making. We are engaged across the region and strive to be leaders and innovators, exploring new ideas and creating best practices.

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Tables and Figures

Executive Summary

An automated vehicle (AV) has one or more automated components ranging from lane-keeping to adaptive cruise control to traffic jam assistance to self-driving capability. The Society of Automotive Engineers (SAE) has designated six levels of vehicle automation where human drivers are the primary drivers without assistance at Level 0 with increasing help from advanced-driver assistance systems (ADAS) in Levels 1 and 2. In Levels 3 and 4, automated driving systems (ADSs) can drive the vehicle in specific areas and under specific conditions—known as an operational design domain (ODD). At Level 5, the highest automation level, the vehicle can operate on any road under all conditions. As a result of the software's ability to operate a vehicle, Level 3 and higher vehicles are called highly automated vehicles (HAVs). Many of the vehicles on the road today have Level 2 automated capabilities. Waymo vehicles in Phoenix, AZ and the Silicon Valley in California, Uber vehicles in Pittsburgh, PA, and various low-speed automated shuttles operating around the world are considered Level 2.5 because they go beyond commercially available technologies, but have not yet achieved HAV capabilities. Waymo launched the first Level 4 HAV operation in Chandler, AZ, without a backup safety driver in the vehicle, in the summer of 2020.

Preparing Greater Philadelphia for Automated Vehicle Deployment involved considerable background research on AVs, and information gathered during a joint Futures Group and Regional Safety Task Force meeting, called *Merge Ahead: How Will Automated Vehicles Affect Vision Zero*, held on June 14, 2019. The goal of this effort is to better understand where HAVs are in development, how they could be deployed, and consider how to best shape their use to benefit the public. The research and dialogue identified five key takeaways:

1. The public sector should better understand the uncertainty in how HAVs will be developed, rolled out, and the outcomes that could result from their deployment in order to identify the challenges, opportunities, benefits, and risks that these vehicles will bring.
2. While the timing for HAV deployment remains difficult to pin down, Level 4 HAVs could be operating on the region's roads within a year and are very likely to be within the next five to 10 years, while Level 5 HAVs are likely much further away (potentially even decades)—but many of the benefits we associate with HAVs won't be realized until the vast majority of the fleet is almost entirely comprised of Level 4 and 5 HAVs.
    a) The strongest Level 4 HAV business cases appear to be: middle-mile freight movement, personal delivery devices, and automated shuttles.
3. Once deployed, HAVs are likely to:
    a) Continue to expand the role of the private market in transportation services, which started with transportation network companies (TNCs), and potentially infrastructure development.
    b) Further erode the viability of the gas tax, especially if they are powered by electric drivetrains, while increasing demand for infrastructure investment.
4. The region needs to:
    a) Articulate a clear vision for how it would like HAVs to be deployed, which should then guide the strategies and policies that are developed to prepare for them; and
    b) Develop new ways for transportation agencies, the private market, and other organizations to coordinate and collaborate in ways that go well beyond business as usual by creating a regional partnership to prepare for technology deployment.

5. Even in lieu of a defined vision, there are many low- or no-regret strategies that the region can begin implementing now in order to prepare for HAV deployment.

1. HAV Uncertainty

The public sector, in particular, needs to better understand the considerable uncertainty in how HAVs will be developed and deployed. Uncertainties surrounding development and deployment include safety of HAVs compared to conventional driving, the role of Artificial Intelligence (AI) technologies and reliance on technology for HAV development, creating profitable business models, infrastructure investment needs, cybersecurity risks, regulations for HAVs, and impacts from current events such as COVID-19 and the Black Lives Matter protests (see Table ES-1). Once HAVs are deployed, further uncertainty results from the potential impacts to the economy and jobs; mobility and congestion; energy use and greenhouse gas (GHG) emissions, urban vitality and preservation of open space, equitable transportation access; need and opportunity to redesign the transportation network; and data collection (see Table ES-2). Appendix C documents In-depth research on each of these HAV uncertainties. Understanding these uncertainties is the first step in identifying the challenges, opportunities, benefits, and risks that will come with the arrival of HAVs.

Table ES-1. Summary of First-Degree Uncertainties for HAV Development and Deployment

Could Slow Down Deployment	Uncertainty	Could Speed Up Deployment
Hacking; complex human-machine interactions; sensor failures; software bugs; riskier behavior	**Safety**	Machine precision and vigilance, less impaired driving, compliance with laws
Machine learning and AI limitations slow down HAV development; humans remain in the loop; need to program human morality into technology; increased risk of cascading system failures	**Artificial Intelligence & Reliance on Technology**	Artificial General Intelligence enables rapid development of Level 5 HAVs; algorithms better make moral & other decisions
Slow HAV rollout and/or Level 2 to 4 costs > benefits, which limits commercial interest; failure to overcome public skepticism	**Profitable Business Models**	'Moonshot' approach quickly delivers Level 5 HAVs; middle-mile trucking and/or personal delivery devices prove feasible; more federal government support
Need to simultaneously: accommodate many new technologies and vehicle types, connected vehicle technologies, curb management, and improve state-of-repair	**Infrastructure Investment Needs**	HAVs able to operate along existing infrastructure; AI and 3D printing redevelop infrastructure; less need for signs and traffic signals and other infrastructure
Passive hacking; lack of computing power; complex systems; external connections; lag time between emerging threats and vehicle production response to them	**Cybersecurity Risks**	HAVs designed with cybersecurity best practices; over-the-air software updates; more collaboration between key vehicle cybersecurity developers
Regulations push for safety & equity before deployment; roadway testing proves unsafe; contradictory federal and state laws	**HAV Regulations**	Limited to expand competition & speed up deployment; lobbyists write the rules; federal government sets uniform HAV standards
On-road testing delayed, auto industry strained by recession; HAVs must show they don't place an undue burden on historically marginalized and disenfranchised communities	**COVID-19 & BLM Protest Impacts to Deployment**	New demand and urgency for last-mile robotic delivery services and middle-mile goods movement; more demand for individual, non-shared operations; algorithms prove to make fairer decisions

Source: DVRPC, 2020.

Table ES-2. Second-Degree Uncertainties for HAV Deployment Outcomes

Could Worsen Outcomes:	Uncertainty	Could Improve Outcomes:
Artificial General Intelligence displaces human workers; rise of monopolistic services; HAVs strengthen 'surveillance capitalism'	**Economy & Jobs**	Technology creates more high-skill jobs than the lower-skill ones it disrupts; more productivity; reduced transportation costs
Some combination of less dense development, rebound effect, zero-occupant trips, lower vehicle operating costs, expanded mobility for non-drivers, and mode shift away from transit, bike, ped trips increase travel and gridlock; less road capacity due to following all road rules and/or defensive driving	**Mobility & Congestion**	Vehicle sharing, mobility-as-a-service (MaaS), and denser development support space efficient multimodal transportation; reduced headways, smoother traffic flow, shorter signal lag times, fewer crashes, right-sized vehicles, and more efficient routing; the young, the elderly, and persons with disabilities have more travel options
Rebound effect; HAVs continue to use internal combustion engines; resource shortages limit electric vehicle, solar, and wind energy development	**Energy Use & GHG Emissions**	HAVs facilitate move to EVs; more efficient routing; eco-driving
Increased willingness to travel; AVs enable more spread out development patterns	**Urban Vitality / Open Space Preservation**	Network effects (where regions become stronger and more efficient as population and density increase); MaaS; less parking
Payment for priority; AI fails to detect darker skin tones; use of age, gender, race in algorithms; technologies aren't designed for or otherwise limit access for persons with disabilities	**Transportation Equity**	Algorithms remove human biases; costs are lowered for everyone; a portion of transportation cost savings are used to subsidize low-income individuals
More auto dependence if HAVs disrupt walking, biking, and transit; need to accommodate many new technologies, vehicle types, and travel speeds proves challenging; increased system complexity	**Redesigned Transportation Network**	HAVs operate in existing infrastructure; AI and 3D printing improve infrastructure; less need for signs and traffic signals; Vision Zero safety engineering; connected vehicle technologies; curb management; MaaS; private-market infrastructure development
5G networks capture overwhelming amounts of data; data is kept proprietary and/or commercialized for 'surveillance capitalism'; 'bad' data limits its usefulness	**Data Collection**	Privacy protections limit data collection; data is made open and shared with appropriate safeguards

Source: DVRPC, 2020.

The degree of uncertainty surrounding HAVs makes scenario planning a critical tool for analyzing and preparing for a range of potential impacts and outcomes. This report is a companion to DVRPC's *Dispatches from Alternate Futures: Exploratory Scenarios for Greater Philadelphia* (*'Dispatches,'* DVRPC Publication #20012), developed with the Futures Working Group (FWG). The FWG comprised approximately 100 subject matter experts and the general public, which undertook an exploratory scenario planning process that: brainstormed driving forces of change; voted to identify the highest impact and most uncertain forces; created axes of uncertainty for the high impact and high uncertainty forces; used the axes of uncertainty to develop a matrix of scenarios; and then analyzed the implications of each scenario. See the *Dispatches* report for more information about scenario planning and how these scenarios were developed. For this report, DVRPC staff expanded the *Dispatches* scenarios to identify a wide range of potential deployment futures for self-driving vehicles in Greater Philadelphia.

The following section outlines the definition, transportation vision, HAV deployment, and outcomes for each scenario:

- **Delayed Expectations** – climate change, sharp political swings, ongoing civil discord, and a slowdown in innovation lead to a lack of direction and economic stagnation.
  - Transportation Vision: No compelling vision for the future emerges, and the system muddles along without significant changes even as infrastructure conditions deteriorate.
  - HAV Deployment: The costs and difficulty of developing HAV technologies becomes overwhelming, causing most firms to pull the plug on research and development following a long-term economic downturn that started during the COVID-19 pandemic, and worsening effects from climate change.
  - Deployment Outcomes: While ADAS technologies become ubiquitous in the vehicle fleet, crashes and fatalities remain stubbornly high as warnings get tuned out.
- **People Power** – Grassroots democracy gives citizens more input into the development of their communities and the economy, while readily available technologies are deployed to fight climate change.
  - Transportation Vision: Focus on expanding bike, pedestrian, and transit systems.
  - HAV Deployment: As HAV development costs and difficulties overwhelm the private sector, the Federal government steps in with a focus on truck platooning, automated middle-mile goods movement, connected vehicles, and automated shuttles to advance the technology.
  - Deployment Outcomes: The slow roll out of HAVs allows for more trial and error, time to undertake the difficult work of building public acceptance, development of public-private partnerships, and lets the industry address early safety concerns in order to create a better final product. Slow-moving automated shuttles create a well mapped urban environment for when commercial Level 4 HAVs are eventually commercially deployed.
- **Technology in the Driver's Seat** – Markets drive economic growth through Big Data, algorithms, and innovation.
  - Transportation Vision: A private-market administered, HAV-based mobility-as-a-service (MaaS) network emerges.
  - HAV Deployment: Level 4 HAVs roll out on the region's roads well before most communities are prepared, with an operational design domain (ODD) focused on limited-access facilities and suburban arterials.
  - Deployment Outcomes: While ODDs expand over time, Level 5 capabilities are not achieved by 2050. As gridlock worsens, HAVs begin to be disrupted by aerial passenger drones.
- **Inclusive Tech** – A collaborative, networked, open source economy of abundance emerges from societal efforts to make technological advances more sustainable and equitable.
  - Transportation Vision: Create a nonprofit, integrated, multimodal MaaS network.
  - HAV Deployment: Level 5 HAV capabilities are achieved thanks to open source principles, and federal investments in key technologies such as quantum computing and Artificial General Intelligence (AGI). Thanks to federal innovation policy geared to increasing the sustainability, equity, and safety of new technology, a wide variety of automated vehicles, which bear little resemblance to conventional human-driven cars, are hitting the road.
  - Deployment Outcomes: These different modes are incorporated into a public and non-profit managed, open source shared mobility framework. Thanks to a focus on Vision Zero, safety culture has taken root across society, spreading well beyond the transportation sector.

HAV deployment will create major challenges and generate considerable debate over their merit and fairness.[1] While these challenges are vast, there are pathways forward where HAVs offer the potential opportunity to greatly improve transportation, quality of life, equitable access to transportation and the opportunity that mobility brings, and environmental sustainability. However, it is unlikely that HAVs will yield these benefits on their own. Achieving these goals will require governments to look out for the public good.

2. Level 4 Versus Level 5 HAVs

Level 4 HAVs will likely be operating either through private ownership or as part of shared mobility services in the region within the next decade, but Level 5 HAV deployment is probably still several decades away. Many of the benefits we associate with HAVs don't really kick-in until the vast majority of the fleet is largely made up of Level 4 and 5 HAVs, and the point where this happens is further away than Level 5 deployment. Until then, it should not be assumed that HAVs will substantially alleviate congestion, greatly improve safety, significantly reduce GHG emissions, or achieve many of their other widely predicted benefits.

Level 4 HAVs can drive themselves only within a specific ODD and may still require a safety driver, ready to take over at a moments' notice, in some—or all—instances, or remote assistance at a minimum. This could greatly limit their appeal for personal HAV ownership; and reduce it only to a lesser extent for shared mobility and freight applications since specific vehicles can be set up and programmed to operate on a fixed route or within a designated area. This may provide an opportunity to advance MaaS, and allow people to move away from having to own a vehicle to participate in much of the economy (outside of Center City, Philadelphia).

3a. Expanded Role for the Private Market

The need to drive outside an ODD could still limit the appeal of Level 4 HAVs for personal ownership. This creates an opportunity to develop and expand MaaS networks, as the best business cases for Level 4 HAVs include shared mobility services—think Uber or Lyft without a driver—within an ODD. Certain freight and automated shuttle applications may also be viable, since specific vehicles can be set up and programmed to operate on a fixed route or within a designated area. In fact, there are examples of all of these services already operating around the country. In addition, at least one company is testing out an AV tunnel system in both Las Vegas and Los Angeles. This suggests there is potential for expanded private market transportation infrastructure provision, it remains more experimental and it's not clear there is a business case for it. Equally important, for HAV technology and the transportation network to positively impact social equity and be inclusive, they must be managed as a public good.

[1] Todd Litman, *Autonomous Vehicle Implementation Predictions* (Victoria, CA: Victoria Transportation Planning Institute, April 24, 2018) www.vtpi.org/avip.

3b. Reduced Revenues, Increased Demand for Transportation Infrastructure Investment

Assuming that HAVs shift vehicle powertrains to battery-electric power, the gas tax will be fully rendered obsolete if another funding source isn't identified. At the same time, HAVs will increase demand for smoother pavement to operate on, better maintained lane markings, connected vehicle technologies, standardized signs, more transportation systems management and operations, real-time work zone data, 5G, and other digital infrastructure investments.

4a. Crafting a Vision for HAV Deployment

Successfully preparing Greater Philadelphia for HAVs will require setting a vision and goals for their deployment and use, and then make policy and investment decisions that support the vision—which should be consistent with the region's long-range plan and based on continuous and ongoing dialogue with a diverse group of regional citizens and stakeholders. At a minimum, the vision for HAVs should consider safety, equity, climate and environment, jobs and the economy, and community walkability and bikeability. *Preparing Greater Philadelphia for Automated Vehicle Deployment* suggests some key themes to choose from for developing a vision around whether mobility should be more motorized or multimodal, and whether it should respond to individual level needs or aim for efficiencies through shared mobility services, see Figure ES-1. In addition, Appendix D contains an initial vision for HAV deployment in Greater Philadelphia consistent with the *Connections 2045* Long-Range Plan.

4b. Create a Greater Philadelphia 'Advanced Mobility Partnership'

Developing a vision and strategies highlights the need for transportation agencies to coordinate and collaborate in ways that go well beyond business as usual, and calls for the creation of new partnerships focused on technology deployment. Creating an 'Advanced Mobility Partnership' for Greater Philadelphia is recommended to enable regional transportation agencies work more closely together on preparing for HAV deployment and other new technologies—depending on how broad its mandate is. This effort can pool public resources and build off the work already being done by various transportation agencies around the region, particularly PennDOT. Greater Denver's *Advanced Mobility Partnership* can serve as a potential model. This new partnership should initially be tasked with working with the public to develop the vision and critical long-term universal and adaptive strategies to guide HAV deployment. It can create a platform for ensuring interoperability across jurisdictions, coordinating on pilot projects and programs as well as reporting on their results, and identifying further needs and opportunities to deploy new technologies.

Figure ES-1. Alternative Visions for the Future of Transportation

Individual Mobility

Motorized Mobility

Multimodal Mobility

Privately-Owned HAVs – A continuation of the existing private vehicle ownership model.

Pros
- Ease of mobility.
- Continued individual expression through ownership.

Cons
- No reduction in parking demand.
- Limited reduction in transportation costs.
- Limited active mobility.
- Continuation of auto-oriented development patterns.

Multimodal Shared Mobility Network – A MaaS model where travel is purchased through subscriptions or by trip and uses an app to determine the best available mode.

Pros
- Reduced parking demand.
- Potential for lower transportation costs.
- Support of multimodal development patterns.
- More active transportation and safety for all road users.

Cons
- Lower travel speeds.
- Longer travel times.

Shared Motorized Mobility – A MaaS model where vehicle trips are purchased through subscriptions or by trip instead of vehicle ownership.

Pros
- Reduced parking demand.
- Potential for lower transportation costs.

Cons
- Less active transportation.
- Continuation of auto-oriented development patterns.

Active Mobility – Prioritizes walking, biking, and conventional and automated transit; HAVs fill hard to make trip gaps and supplement peak period demand.

Pros
- Reduced parking demand.
- Lower transportation costs.
- More walkable communities.
- More active transportation and safety for all road users.
- Reduced greenhouse gas emissions and energy use.
- Less reliance on complex technologies.

Cons
- Lower travel speeds.
- Longer travel times.

Shared Mobility

Source: DVRPC, 2020.

5. Short-Term Low- Or No-Regrets Strategies

The *Dispatches* scenarios and research were used to identify potential universal and adaptive strategies to help the region prepare for HAV deployment. Universal strategies are beneficial across a range of plausible AV futures. Adaptive strategies are based on responding to specific futures that may be unhelpful, or even harmful, in others. Adaptive actions could be considered for implementation if signposts, identified in Section II of this report, indicate that elements of a particular future are coming to fruition. Universal strategies can be broken up into short-term, low- or no-regret strategies that are unlikely to have any significant risk associated with them and won't set the region on any negative path dependence or technological lock-in directions. Medium, and long-term universal strategies are generally a heavier lift, with more associated risk.

The region can pursue short-term, no- or low-regret universal actions now even before defining a vision to begin preparing for HAV deployment. Many of them will provide benefits even if HAVs don't appear on the region's roads by 2050.

- ☐ Learn from technology deployment **best practices** from around the world.
- ☐ Conduct extensive public **engagement and education** on HAVs, with extra focus on reaching historically marginalized and disenfranchised communities.
- ☐ Work with state departments of transportation (DOTs) on **plans for safe HAV testing and deployment**.
- ☐ **Prioritize roadway state-of-good repair** and maintenance needs, particularly for lane markings, standardizing road signs, updating roadway geometry standards, transportation system management and operations, connected vehicle technologies, and work zone locations updated in real time.
- ☐ **Reduce speed limits** and pursue other Vision Zero strategies.
- ☐ Use governmental **procurement to advance vehicle technologies**.
- ☐ Expand and **integrate shared mobility options with transit** through mobility hubs, dedicated pick-up / drop-off curb space, reduced parking minimums, and an open source, real-time trip information, booking, routing, and payment platform.
- ☐ Pursue **transit-first strategies**: transit signal priority, off-board fare payment, and dedicated bus lanes.
- ☐ **License private shared mobility services** to operate only if they commit to: serving everyone, sharing data, integrating with transit and other transportation providers, following curb regulations, and meeting safety standards. Renew licenses if requirements are met.
- ☐ **Equitably distribute infrastructure improvements** across the region.
- ☐ Work with state and local governments to determine **data** needs, create open data standards for shared mobility providers, and build local government data management and processing capacity.

See the recommendations in Section IV for more detail on these low- or no-regret short-term strategies. Future additional medium- and long-term universal and adaptive recommendations should be determined by a future 'Greater Philadelphia Advanced Mobility Partnership' or another more in-depth visioning and strategy identification planning process. Appendix D has a set of initial medium- and long-term universal and adaptive strategies that were developed for the initial vision in this effort. An Advanced Mobility Partnership is critical to guiding HAV deployment since no report can capture all the complexity and uncertainty of these new technologies. This further highlights the need for ongoing dialogue to build shared knowledge and understanding.

I. Introduction

Automated vehicles (AVs) and highly automated vehicles (HAVs) have been the subject of considerable media hype over the past decade. While their promise and potential have been well documented, many questions remain. There is a lack of understanding about the capabilities of various automation levels, uncertainty about the timing at which they may be available for use by the traveling public, and how they will be deployed. *Preparing Greater Philadelphia for Highly Automated Vehicle Deployment* is a companion report to the Delaware Valley Regional Planning Commission's (DVRPC) *Dispatches from Alternate Futures: Exploratory Scenarios for Greater Philadelphia* (*Dispatches*, DVRPC Publication #20012). It extends the *Dispatches* exploratory scenarios to further inform different ways in which HAVs may, or may not, be deployed and operated in the region. This report aims to better understand the future of transportation, through the lens of vehicular automation; the types of uncertainty that could arise with the deployment of HAVs; consider what the vision should be for their deployment and how they can improve transportation in Greater Philadelphia, and identify strategy options for achieving the vision.

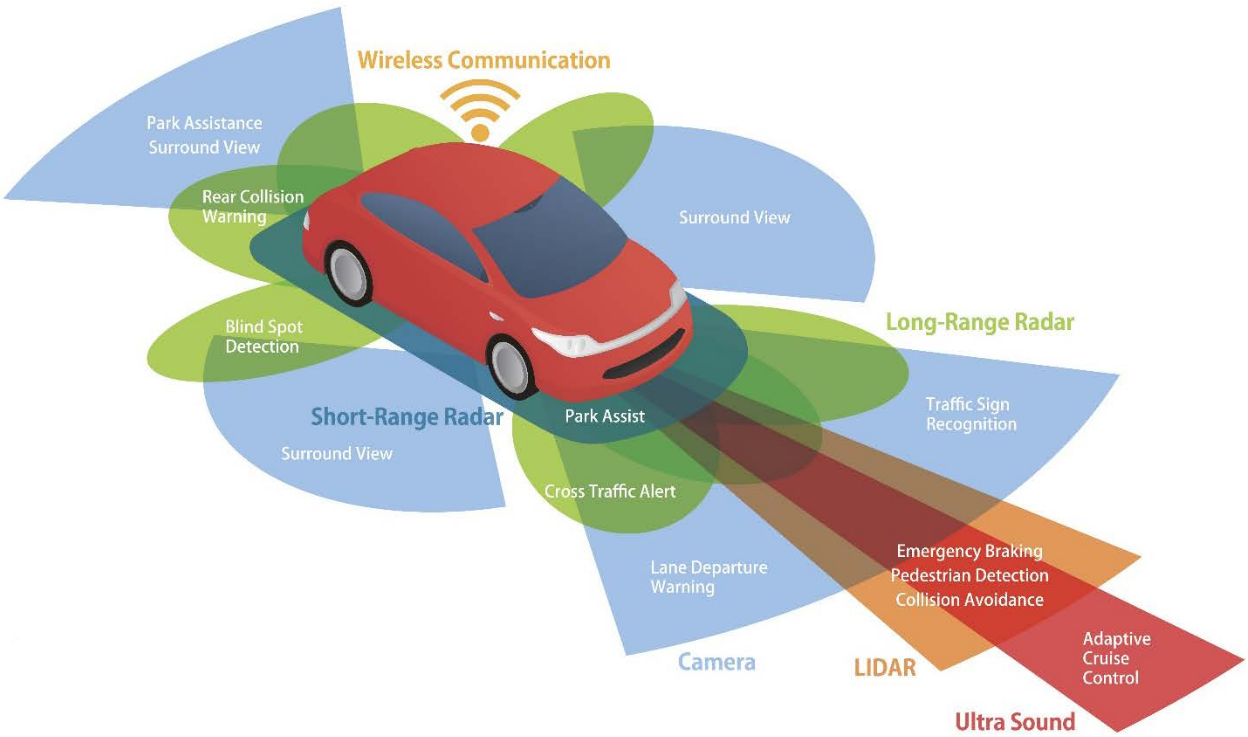
The remainder of this introduction section contains a short synopsis of what AVs are and explores where they presently are in their development. Section II considers the future of HAV development, including seven key development and deployment uncertainties and seven additional outcome uncertainties—both sets determined from considerable background research and dialogue with DVRPCs Futures Group and Regional Safety Task Force during a joint meeting held on June 14, 2019, called *Merge Ahead: How Will Automated Vehicles Affect Vision Zero*. The four *Dispatches* scenarios consider how these uncertainties could play out differently in the future. Section III identifies the need to develop a vision for HAV deployment and considers competing visions for the future. Section IV provides recommendations for crafting the vision and developing strategies to achieve it; and identifies a series of short-term universal strategies that are applicable to a broad range of different plausible AV futures. These strategies can be implemented even in advance of the vision as they provide benefits beyond HAV deployment and are unlikely to set technological lock-in or path dependence that would cause future regret. Section V is the conclusion, which highlights key takeaways from the report. In addition, there are five appendices:

A. Glossary of key terms.
B. Describes the related technologies—connected vehicles (CVs), electric vehicles (EVs), shared mobility, and real-time data--that are also seen as keys to the future of transportation.
C. Summarizes the research around the uncertainties.
D. Presents a draft vision and set of strategies for HAV deployment based on the *Connections 2045* Plan as a model for what this effort should consider.
E. Acknowledges and thanks the report's reviewers.

What is an Automated Vehicle?

An AV has one or more automated components ranging from lane-keeping to adaptive cruise control to traffic jam assistance to self-driving capability. Hardware and software, both remote and on-board, perform the functions needed to drive a vehicle. The key hardware components include an on-board computer that makes decisions, along with servers and power supplies, a global positioning system (GPS) signal system; an inertial measurement unit for when the GPS is out of signal; radar sensors that detect nearby vehicles; ultrasonic sensors that detect other vehicles and objects alongside the AV; light detection and ranging (LiDAR) that identifies lane markings; and video cameras that read traffic signals and road signs, and watch for pedestrians and obstructions.

Figure 1. Automated Vehicle Sensor System



The software is either an advanced driver assistance system (ADAS) or an automated driving system (ADS). An ADAS can support human steering, braking, and acceleration for a period of time. An ADS is capable of operating without driver control for a duration under specific conditions. The ADS is programmed to work in a specific context, known as the operational design domain (ODD), these include geographic location, weather, time of day, traffic volumes, and road conditions. ADSs scan and react to the environment through a four-step operations process that is repeated many times each second:[2]

1. Determine precise position using sensors to locate the vehicle within a detailed high-definition (HD) map contained on an on-board computer. This HD map has all roadways within the vehicle's ODD. The map is developed for ADS operations and includes road profiles, curbs and sidewalks, lane markings, crosswalks, traffic signals, speed limits, signage, fixed objects, and other features.
2. Scan the roadway and surrounding areas using sensors with a range of hundreds of yards to identify vehicles, bicyclists, pedestrians, animals, potholes, signage, and other objects.
3. Predict the path of every movable object based on current location, previous movements, and speed; while accounting for how roadway conditions and features may affect other objects' pathways.

[2] James Hedlund, PhD, *Preparing for Automated Vehicles: Traffic Safety Issues for States* (Washington, DC: Governors Highway Safety Association, August 2018).

4. Act on speed, trajectory, and steering adjustments as needed.

Automated controls for steering, brakes, and signals are a combination of hardware and software. AVs may also access short- and long-range wireless networks.[3] Short-range systems are used for vehicle-to-vehicle communications, while long-range systems are needed to access maps, perform over-the-air (OTA) software updates, and obtain road reports.[4] They will also necessitate navigation systems, such as GPS, and highly detailed maps, as well as critical component testing and maintenance.[5]

Automated Vehicle Levels

The Society of Automotive Engineers (SAE) has created a chart showing how AV technologies could progress in steps over time, and is intended to simplify this process in order to communicate it to the public and to standardize definitions (see Figure 2). It doesn't account for how automation relates to other technologies, such as CVs, EVs, and shared mobility. Level 0 has no automated features, but may offer warnings and momentary assistance. Level 1 uses ADAS to automate some driving tasks through one of the following:[6]

- Adaptive cruise control, lane-keeping assistance, or dynamic driving assistance.
- Collision alerts such as forward collision warning, lane departure warning, blind spot warning, rear cross traffic warning, parking obstruction warning, and pedestrian detection.
- Collision mitigation features such as forward automatic emergency braking, reverse automatic emergency braking, and automatic emergency steering.
- Parking assistance features such as semi- or fully-automated parking assistance, remote parking, trailer assistance, and surround view cameras.
- Other driving aids such as automatic high beams, night vision, and driver monitoring.

Level 2 automation expands Level 1 through a combination of ADAS capabilities such as adaptive cruise control and lane-keeping assistance.[7] The driver remains responsible for the driving task in both Level 1 and Level 2. Many vehicles sold today are Level 2. This level accounts for a wide range of self-driving capabilities including AVs being tested on roads in Pittsburgh, Phoenix, the Silicon Valley, and elsewhere. The latter vehicles are sometimes referred to as Level 2.5 as a result.

Level 3 is the first to enable automated systems, but only in specific conditions such as stop and go traffic on a highway.[8] BMW has filed a voluntary safety self-assessment with the National Highway Traffic Safety Administration (NHTSA) to launch the first Level 3 HAV incorporated within the iNext EV. The Level 3 ADS may be available as soon as 2021 and can only be used on limited access highways in warm weather with environmental conditions that don't impair its sensors.[9] A takeover

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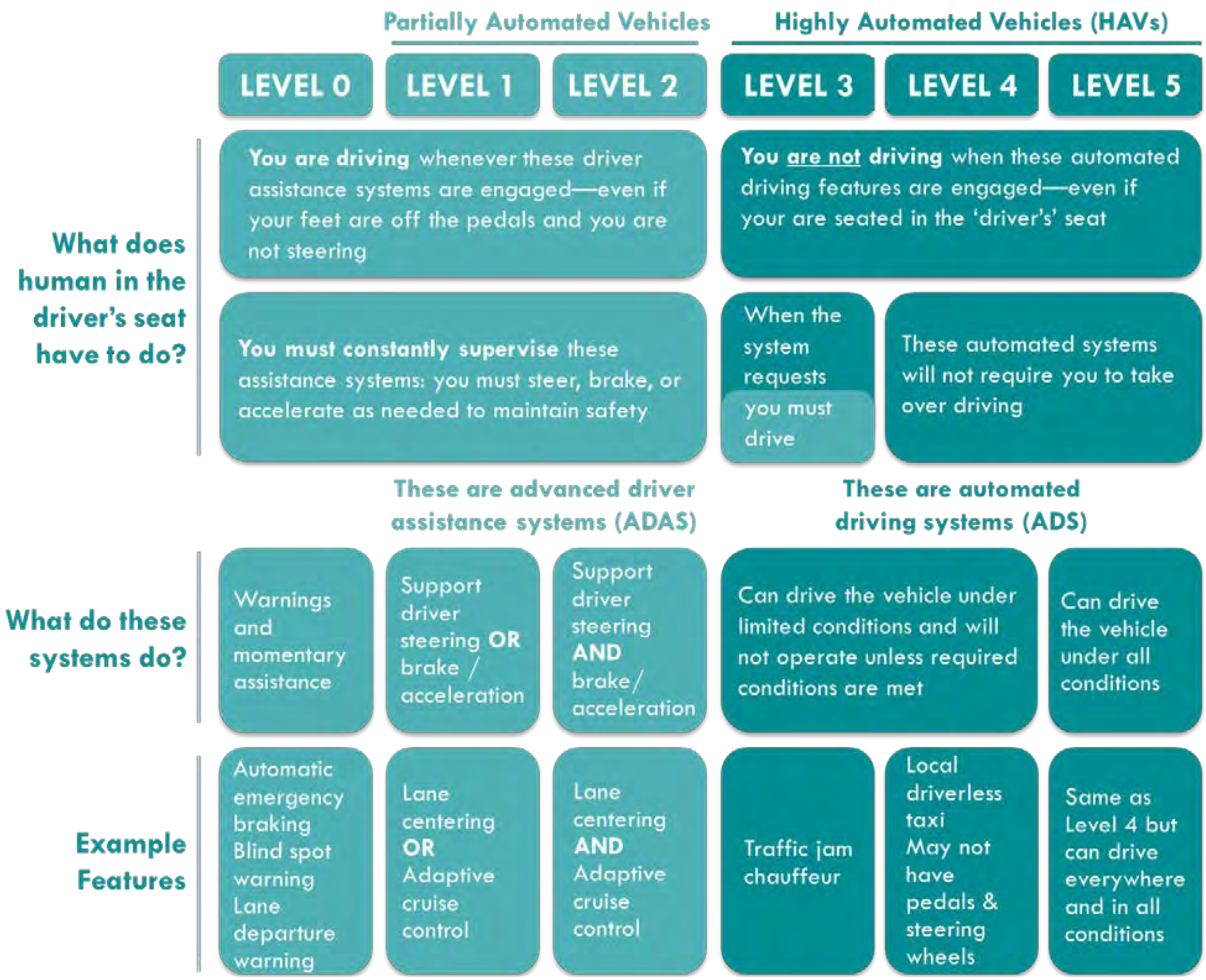
[3] Todd Litman, *Autonomous Vehicle Implementation Predictions* (Victoria, CA: Victoria Transportation Planning Institute, April 24, 2018) www.vtpi.org/avip.
[4] Litman, *Autonomous Vehicle Implementation Predictions*.
[5] Litman, *Autonomous Vehicle Implementation Predictions*.
[6] *Advanced Driver Assistance Technology Names: AAA's Recommendation for Common Naming of Advanced Safety Systems* (Washington, DC: AAA, January 2019) www.aaa.com/AAA/common/AAR/files/ADAS-Technology-Names-Research-Report.pdf.
[7] Steven Schladover, "The Truth About Self-Driving Cars," *Scientific American*, June 2016, www.scientificamerican.com/article/the-truth-about-ldquo-self-driving-rdquo-cars/ (accessed August 26, 2019).
[8] Schladover, "The Truth About Self-Driving Cars."
[9] Murray Slovick, "BMW Takes Self-Driving to Level 3 Automation," *Electronic Design,* July 10, 2020, www.electronicdesign.com/markets/automotive/article/21136427/bmw-takes-selfdriving-to-level-3-automation (accessed July 24, 2020).

request will be issued with enough time to ensure the driver can take control back before the ADS reaches its performance limit.[10] Drivers must be awake, buckled in, and ready for a takeover request.[11] The vehicle will come to a complete stop as safely as possible if the driver doesn't take control back when requested.[12] A camera will watch the driver to ensure that he or she is awake.[13] Lights in the steering wheel, audio alerts, and seat vibrations all warn the driver to take back control.[14] A steering-torque sensor, pedal-position sensor, and a hands-on steering wheel detection sensor will all let the ADS know when the driver has retaken control of the vehicle.[15]

Figure 2. Society of Automotive Engineers Vehicle Automation Levels



Source: adapted from Society of Automotive Engineers.

[10] Slovick, "BMW Takes Self-Driving to Level 3 Automation."
[11] Slovick, "BMW Takes Self-Driving to Level 3 Automation."
[12] Slovick, "BMW Takes Self-Driving to Level 3 Automation."
[13] Slovick, "BMW Takes Self-Driving to Level 3 Automation."
[14] Slovick, "BMW Takes Self-Driving to Level 3 Automation."
[15] Slovick, "BMW Takes Self-Driving to Level 3 Automation."

Level 4 HAVs will handle all driving tasks within specific conditions, such as enclosed parking garages or dedicated freeway lanes.[16] These parking garages may need to be suitably equipped—sensors to communicate where empty spaces are—and exclude both pedestrians and non-automated vehicles.[17] An ODD represents the operating conditions—geographic location, weather, time of day, traffic volumes, and road conditions—that a Level 3 or 4 system is capable of operating in.[18] Each model of HAV may have a unique ODD. Level 4 vehicles are already operating without safety drivers in a few applications. For instance, Waymo has just launched a passenger-carrying service in Chandler, AZ. Shared mobility, transit applications, parcel delivery, and, to a degree, trucking can all be confined to specific routes or roadways where an ODD around the specific use case can enable Level 4 operations without a safety driver who is ready to take over at any moment if the ADS encounters a situation it can't handle. While the industry aims to develop vehicles that can operate without a safety driver, the ability to do so will depend on regulatory approval, the cost and effectiveness of safety drivers, the effectiveness of alternatives to safety drivers, and the size of the ODD the ADS can operate in. At a minimum, Level 4 HAVs will need a remote operator, which increases the importance of connectivity and safe places to stop alongside the road—mainly shoulders. Areas with significant numbers of vulnerable bicyclists and pedestrians may want to limit Level 4 applications to speeds of 20 miles per hour or slower for safety reasons.

Level 5 HAVs, which can go from any point to any other point in any condition without requiring a safety driver, are likely decades away from becoming commercially available.[19] Some experts doubt we will ever get true Level 5 capabilities.[20] However, most of the benefits we imagine from HAVs won't be achieved until Levels 4 and 5 HAVs make up all or a vast majority of vehicles on the road. There are two main ways in which Level 5 expands use cases. First, consumer vehicles will become more appealing to purchase since owners will be able to use them anywhere and everywhere. Second, since Level 4 is restricted to specific ODD and locations where a high-definition map is available, there may be equity and accessibility issues—which means government should play a proactive role to address those gaps before services start operating.

The fifth generation cellular wireless network, 5G, promises to increase connection speeds by utilizing more high-band, short-range airwaves to increase the number of available channels.[21] This will give cellular networks lower latency (the time between making a request and having the network execute it) and the capacity to connect with more devices, including CVs and AVs.[22] 5G may be a necessary component to HAV deployment, but could take a generation to build out.[23] It will mostly be developed by the private market, but portions of it may need public support.[24]

The software found under the hood of an AV uses data collected from the surrounding environment and algorithms to guide decision making. ADS developers test this software starting during basic development, followed by extensive simulation, on closed test tracks, and finally trials on public

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[16] Schladover, "The Truth About Self-Driving Cars."
[17] Schladover, "The Truth About Self-Driving Cars."
[18] Kyle Hyatt, "Roadshow Explains the SAE's New Self-Driving Testing Guidelines," *Roadshow by CNET*, October 6, 2019, www.cnet.com/roadshow/news/roadshow-explains-sae-self-driving-car-road-testing-guidelines/ (accessed October 10, 2019).
[19] Schladover, "The Truth About Self-Driving Cars."
[20] Justin T. Westbrook, "2018 Was a Hard Reality Check for Autonomous Cars," *Jalopnik*, December 19, 2018, www.jalopnik.com/2018-was-a-hard-reality-check-for-autonomous-cars-1831182272 (accessed December 31, 2018).
[21] Sascha Segan, "What is 5G?" *PC Mag*, January 2, 2020, www.pcmag.com/article/345387/what-is-5g (accessed January 10, 2020).
[22] Segan, "What is 5G?"
[23] Anthony Townsend, "Fables of the Driverless Revolution," *TD Future Cities Speaker Series*, May 21, 2019, www.facebook.com/EvergreenCanada/videos/327925417872999/ (accessed May 25, 2019).
[24] Townsend, "Fables of the Driverless Revolution."

roads with a safety driver ready to take control of the vehicle if needed.[25] The ADS is like a human driver, which may be tested similar to driver's license testing for minimal skill sets and safe driving judgements in an artificial setting. While no ADS can guarantee it will always perform safely in every situation, artificial intelligence (AI) can enable AVs to learn collectively and quickly from their experiences. Due to the rapid pace of technological advancements and their proprietary nature, there is little publicly available information about how auto manufacturers and software developers are creating the algorithms that guide AV behavior.[26] Appendix C provides further details about the role of AI in developing HAVs.

Notes on Terminology

Throughout this report, HAVs and ADSs will refer specifically to SAE Levels 3, 4, or 5. AVs will refer to the full range from Levels 1 to 5. ADAS will refer to Levels 1 and 2.

Autonomous and automated vehicle terms are generally used interchangeably although there is a difference in their meanings. Autonomous suggests independent operations, meaning that decisions are made without input from outside the vehicle. Instead of being connected, they rely solely on their internal sensors, cameras, and LiDAR to read and react to their operating environment. It seems unlikely that vehicles will operate autonomously, though Level 5 HAVs may do so, as this may pose greater risks from sensor failure and would not benefit from the safety benefits from communicating with other vehicles and infrastructure. Autonomous vehicles may be less susceptible to hacking if they are not connected to 5G networks. A separate, but related technology, for connected vehicles (CVs) would also use 5G cellular vehicle-to-everything (C-V2X) and possibly dedicated short-range communications (DSRC), to enhance communications from vehicle-to-vehicles (V-2-V) and vehicle to infrastructure (V-2-I), to enhance safety and provide information and warnings to drivers.[27]

The term urban area is used in this report in a generic sense to refer to a range of communities, from major cities to small towns and older streetcar suburbs, to new, low density exurbs.

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[25] Hedlund, PhD, *Preparing for Automated Vehicles: Traffic Safety Issues for States*.
[26] Laura Sandt, PhD, and Justin M. Owens, *Discussion Guide for Connected and Automated Vehicles, Pedestrians, and Bicyclists* (Chapel Hill, NC: Pedestrian and Bicycle Information Center, August 2017) www.pedbikeinfo.org/pdf/PBIC_AV.pdf.
[27] The Federal Communications Commission voted in November 2020 to repartition a portion of the 5.9 GHz bandwidth that had been preserved solely for connected vehicle communications, despite staunch opposition by all 50 state DOTs. The repartition allows the lower 45 MHz of this bandwidth to be used by wireless applications, and reserves the upper 30 MHz for C-2VX. This decision essentially renders a second more proven connected vehicle technology, dedicated short-range communications (DSRC), obsolete. See the 'Maintaining the 5.9 GHz Band' section of Appendix C for more info.

II. The Future of Vehicle Automation

In the early 2020s, vehicle automation is in a seemingly contradictory place. On the one hand, Waymo, GM, and Lyft have lobbied NHTSA regulators to allow AV manufacturers to remove driver controls, such as brake pedals and steering wheels in their vehicles.[28] Waymo is offering Level 4 robo-taxi passenger service in Chandler, AZ, without a safety driver, but with remote supervision.[29] This service may expand to Los Angeles and Florida next.[30] Chinese electric vehicle (EV) manufacturer NIO has partnered with Mobileye to test a Level 4 HAV in Israel in the summer of 2020.[31] BMW has announced plans to launch a Level 3 HAV, the highest level made commercially available thus far, as early as 2021.[32]

On the other hand, passengers using these existing services have complained about being dropped off at wrong locations, being taken on indirect routes, and encountering harrowing roadway experiences.[33] Some AV developer executives—including Ford's Jim Hackett, Chris Urmson formerly with Alphabet/Waymo, Gill Pratt from Toyota Research Institute, Huei Pen from the Michigan Transportation Center, and Raqual Urtasun from Uber's self-driving lab—are now publicly saying that the timeline for HAVs will be much longer than they previously anticipated, particularly in light of forecasts that they would be widely available and in use by 2019.[34] Waymo's John Krafcik has doubted that HAVs will ever be able to handle every road condition.[35]

In addition to AVs, there are a series of a related, but separate, technologies that are emerging alongside automation. These include connectivity between vehicles and infrastructure through 5G cellular networks or DSRC if it remains viable; electric powertrains; shared mobility services; and real-time information. These technologies are further explored in Appendix B. Combined with vehicle automation, they are all seen as jointly influencing the future of transportation.

More immediately, COVID-19 has walloped the United States. It was first detected in the U.S. in Seattle in late January 2020, then surged in the New York City metro area, then to much of the South and West by the summer of 2020, with even worse outbreaks in nearly every state by the fall of 2020. A third wave of the virus had arrived by December 2020, though it appears a vaccine will begin to be distributed early in 2021. Amidst the horrific human toll, the pandemic could speed up the deployment of certain types of vehicles, greatly alter business models, and may influence their development. Even if COVID-19 is defeated in 2021, the risk of future viruses remains.

The automated future aims to use advanced technologies to create a safer, and more efficient and sustainable transportation network. However, HAVs still have many technological, legal, administrative, and societal acceptance hurdles to overcome before being deployed. The SAE AV levels suggest a linear, straight line process, though this is largely to simplify the progression for

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[28] Michael Wayland, "GM, Lyft, Waymo Want to be Allowed to Remove Driver Controls on Autonomous Cars," *CNBC News*, August 30, 2019, www.cnbc.com/2019/08/30/gm-lyft-urge-regulators-to-remove-driver-controls-on-autonomous-cars.html (accessed September 3, 2019).
[29] Jeff Link, "Waymo Knows You're Scared of Driverless Cars. That's Why it's Pouring Money into UX," Built In, Updated October 14, 2020, www.builtin.com/design-ux/driverless-car-trust-design (accessed October 15, 2020).
[30] Hawkins, "Waymo's Robot Taxi Service is Improving, but Riders Still Have Complaints."
[31] Dubi Ben-Gedalyahu, "China's Nio, Mobileye Launch Level 4 Trials in Israel," *Globes*, June 2, 2020, en.globes.co.il/en/article-Chinas-NIO-Mobileye-launch-level-4-trials-in-Israel-1001331025 (accessed August 29, 2020).
[32] Slovick, "BMW Takes Self-Driving to Level 3 Automation."
[33] Hawkins, "Waymo's Robot Taxi Service is Improving, but Riders Still Have Complaints."
[34] "Driverless Cars are Stuck in a Jam," *The Economist*, October 10, 2019, www.economist.com/leaders/2019/10/10/driverless-cars-are-stuck-in-a-jam (accessed October 15, 2019).
[35] Westbrook, "2018 Was a Hard Reality Check for Autonomous Cars."

communicating with the public. In reality, this is just one of many potential pathways for AV deployment. It also obscures the vast degrees of uncertainty fraught with each of these levels. There will likely be a long transition period between the current Level 2 deployment and achieving Level 5, fully autonomous vehicles that can drive everywhere. A better understanding of this transition period is needed.

- Will Level 2 vehicles be connected and cooperative with each other, road infrastructure, and other things, or will they operate independently (autonomously) using only their on-board sensors and operating systems? If they are connected, how big of a role will this technology play?
- Will there be obstacles to Level 3 due to human-machine transition issues, or will this level be skipped over altogether as a result? It also remains to be seen whether people will pay for HAVs that they may have to take over driving in a moment's notice.
- When Level 4 arrives, what areas will be within the ODD where the vehicle can drive itself. Will the ODD be just along highways? In rural areas? In suburban areas? In urban areas? The supporting technology may be more readily available in urban areas, but the complexity found in these places may be too great for HAVs to safely operate. Will state and local governments have any say in a vehicle’s ODD?
- What will it really take to get to Level 5 HAVs that can take a person from anywhere to anywhere else, regardless of weather and other road conditions? Can this even be done? Will the current approaches of machine learning and deep learning get us there? Or will it take artificial general intelligence (AGI)? Are current levels of computing power enough for AGI? If not, is quantum computing needed as well?[36]

While there are no HAVs available on the road today, Levels 3 and 4 could plausibly arrive within a year and be able to operate in specific areas under certain conditions. They are quite likely to appear within the next decade at the latest. Level 5 HAVs that can drive themselves everywhere in all conditions, though, could be decades away. Much discussion about HAVs jumps straight to a world with fully automated vehicles that can drive anywhere, and skips over what will likely be a long transition period from today’s vehicles. While there is a possibility that Level 5 HAVs could arrive sooner, there are many reasons why they are likely far away due to limitations with AI and sensor technologies, lack of computing power, and the difficulty of dealing with complex and unpredictable road environments and human behaviors. Most of the benefits that are typically associated with HAVs only kick-in once the vehicle fleet is entirely Levels 4 and 5. But even when Level 5 HAVs arrive, there will still be a long transition period where human-driven and ADS vehicles share the road. Achieving the full projected benefits of automation may require HAVs to operate on their own facilities. This won’t happen anytime soon, unless human driving is banned or separate HAV-only facilities are designated within existing infrastructure or built new.

Although automated technologies can currently sense people, other vehicles, animals, and objects in and alongside the road; predicting what each will do next is much more challenging.[37] AVs struggle with responding to construction zones and railroad crossings;[38] going through

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[36] Quantum computers use combinable qubits, which can be any combination of value of 0s and 1s, and may be able to enable computational speed and possibilities far beyond classical computing capabilities, which are based non-combinable bits that can be either 0 or 1.

[37] Neal E. Boudette, "Despite High Hopes, Self-Driving Cars Are 'Way in the Future,” *The New York Times*, July 17, 2019, www.nytimes.com/2019/07/17/business/self-driving-autonomous-cars.html (accessed August 28, 2019).

[38] Lance Eliot, “Why Railroad Crossings are a Grave Danger for Self-Driving Cars,” *Forbes*, September 19, 2019, www.forbes.com/sites/lanceeliot/2019/09/19/why-railroad-crossings-are-a-grave-danger-for-self-driving-cars/ (accessed October 1, 2019).

roundabouts; turning left across traffic; driving in snow or ice, or along changing road surfaces, bike lanes, and passing police vehicles, pedestrians, crossing guards, and emergency vehicles.[39] Each of these challenges is different in different contexts, such as urban and rural areas.[40] Five unnamed Waymo engineers were recently reported as saying the company's AVs still struggle with basic infrastructure comprehension and driving tasks, such as making unprotected left turns and stopping at signals on highway on- and off-ramps.[41] Weather conditions need to be sunny and clear for AVs to operate. A former Uber AV operations manager has been warning about the dangers of on-road testing.[42] Other unexpected human factors provide serious additional concerns: AVs have had a hard time detecting pedestrians with darker skin tones;[43] their machine-like driving is causing many passengers to have motion sickness;[44] and people are protesting AVs by throwing rocks at them, running them off the road, and doing other malicious things to them.[45] At least two crashes have been caused by people yelling at AVs in fits of rage.[46]

While there has been some progress on these automation challenges—for instance Waymo's AVs can read construction zones—much of what is currently deemed automated driving is really just an advanced form of cruise control with lane centering.[47] These capabilities only enable travel on highways at the same speed and direction as other vehicles on the road and do not have to make quick turns or account for pedestrians.[48] The reality is that "easy parts have yet to be proven safe, and difficult aspects have yet to be proven even possible."[49] It is expected that these challenges will be resolved before HAVs are made commercially available, though this will likely slow their deployment. This divergence reflects that while Level 4 HAVs may soon be commercially available, the technical challenges that remain for Level 5 HAVs suggest they may be much further off. However, even this can't be said with any certainty, since technological development often occurs in unexpected and non-linear ways. Therefore, the arrival of Level 5 HAVs could still happen much faster than currently anticipated. Likewise, there is no guarantee that Level 4 HAVs won't run into some unforeseen challenges that slow their arrival.

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[39] Greg Driskell, "AV Video," *YouTube*, April 16, 2018, www.youtube.com/watch?v=io4H0kcRjRU&feature=youtu.be (accessed August 20, 2018); Schladover, "The Truth About Self-Driving Cars."; and U.S. Department of Transportation, *Preparing for the Future of Transportation: Automated Vehicles 3.0* (Washington, DC: U.S. Department of Transportation, 2018).
[40] U.S. Department of Transportation, *Preparing for the Future of Transportation: Automated Vehicles 3.0*.
[41] Westbrook, "2018 Was a Hard Reality Check for Autonomous Cars."
[42] Aaron Short, "BRAKE TIME: Autonomous Vehicle Testing Endangers Pedestrians," *Streetsblog USA*, August 21, 2019, www.usa.streetsblog.org/2019/08/21/brake-time-automatic-vehicle-testing-endangers-pedestrians/ (accessed September 4, 2019).
[43] Chris Teale, "Study: AVs May Struggle to Detect Pedestrians with Dark Skin," *Smart Cities Dive*, March 6, 2019, www.smartcitiesdive.com/news/autonomous-vehicles-detection-pedestrians-dark-skin/549860/ (accessed March 6, 2019).
[44] David McCourt, "The Biggest Problem with Autonomous Driving has Nothing to do with AI," *Androidpit*, November 26, 2018, www.androidpit.com/autonomous-driving-motion-sickness (accessed December 2, 2019).
[45] Simon Romero, "Wielding Rocks and Knives, Arizonans Attack Self-Driving Cars," *New York Times*, December 31, 2018, www.nytimes.com/2018/12/31/us/waymo-self-driving-cars-arizona-attacks.html (accessed January 8, 2019); and Tristan Greene, "Anti-Robot Vigilantes in Arizona try to Scare off Waymo's Self-Driving Cars," *The Next Web*, undated, www.thenextweb.com/artificial-intelligence/2018/12/12/anti-robot-vigilantes-in-arizona-try-to-scare-off-waymos-self-driving-cars/ (accessed December 20, 2018).
[46] Greene, "Anti-Robot Vigilantes in Arizona try to Scare off Waymo's Self-Driving Cars."
[47] Mark Wilson, "The Fate of Self-Driving Cars Hangs on a $7 Trillion Design Problem," *Fast Company*, December 5, 2018, www.fastcompany.com/90275407/the-fate-of-self-driving-cars-hangs-on-a-7-trillion-design-problem (accessed December 6, 2018).
[48] Lee Gomes, "Silicon Valley Driven Hype for Self-Driving Cars," *New York Times*, July 9, 2016, www.nytimes.com/2016/07/10/opinion/sunday/silicon-valley-driven-hype-for-self-driving-cars.html (accessed July 14, 2016).
[49] Gomes, "Silicon Valley Driven Hype for Self-Driving Cars."

HAV Uncertainties

Major paradigm shifts can increase uncertainty in all kinds of ways. For one, there is uncertainty with the technology itself. Will the hardware work with the software? Will operating systems be compatible across vehicle types and manufacturers? When will different levels of HAVs be commercially viable, where are they on the cost curve, and what will be their rate of uptake once they are on the market? It is impossible to predict how consumer behavior may change with access to this technology. Public acceptance will ultimately be a critical factor in HAV deployment. While much focus will be on the benefits of taking people out of the driver's seat, how uncertainties around HAV deployment play out largely depends on decisions made by humans, for example:

- HAV use will be shaped by the business models that people develop to deploy them, particularly if they are shared or keep the current personal ownership model. Finding a profitable business model may prove to be a major hurdle to deployment, which could slow their arrival.
- Consumer willingness to pay for automated technologies, especially systems that require continuous supervision.
- The rules that regulators set around HAV deployment and operations; and not regulating them is still a decision about regulation.
- The user fees and taxes collected to pay for the infrastructure HAVs need, which can go a long way in shaping behavior.
- Governments will have to determine how much priority they will give to HAVs and state departments of transportation (DOTs) will choose how much supporting infrastructure they will build for self-driving cars, trucks, and other types of vehicles.
- The ways in which cities change zoning and building codes to facilitate HAV operations.
- Even the types of trips that people decide to take in HAVs.

Complex adaptive systems (CAS) is a term we give to situations where random events and individual actions shape outcomes. CASs are made up of a set of parts or things that work together as a unified whole or interconnected network. This system responds to changes in its operating environment, and it can also cause changes to the environment itself. As a result of this two-way adaptation it is hard to predict outcomes. Predictability is even more difficult when humans—and human behaviors—are added to the loop.

CASs can be seen in organizations, the economy, organisms, urban areas, ecosystems, the Internet, or the transportation network. They are self-organizing and can retain their integrity and coherence over long periods of time, even when individual parts change or cease to exist.[50] Urban areas all over the U.S. removed streetcar transit routes starting in the 1950s and 60s and now have started removing highways over the last decade. We widen roads, give them road diets, realign them, ask them to carry new modes and different vehicle types, and yet the system continues to function—though perhaps better in some ways and worse in others. CASs are also highly counterintuitive.[51] As a result, when we intervene in them we often worsen the problems we are trying to solve. For example, we keep trying to widen roads to solve congestion when we have more than 70 years of evidence that this worsens congestion by increasing reliance on vehicle travel.

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[50] Robert Goodspeed, *Shaping Places with Scenarios: A New Approach to Urban and Regional Planning* (Ann Arbor, MI: Lincoln Institute of Land Policy, Draft 2018).

[51] Donella H. Meadows, *Leverage Points: Places to Intervene in a System* (Hartland, VT: The Sustainability Institute, 1999) www.donellameadows.org/archives/leverage-points-places-to-intervene-in-a-system/.

When outcomes depend on individual decisions and behaviors, it is highly challenging to obtain the best results for society. But we can control our destiny if we act collectively. Successfully navigating HAV deployment will also require transportation network designers and decision makers to better understand how individual facility-level interventions affect system-level outcomes. A good place to start is by better understanding the uncertainties associated with HAV development and deployment and then the possible second-degree outcomes from HAV deployment.

First-Degree HAV Development and Deployment Uncertainties

The following uncertainties on the deployment and use of HAVs were identified through information gathered during the *Merge Ahead* event along with considerable background research. The first-degree uncertainties highlight where the ultimate HAV development and the timing for their deployment outcomes are currently unclear. Things that may speed up their deployment won't necessarily bring about wide societal benefits, such as if lobbyists write the rules for HAVs or regulations are otherwise limited to speed up their deployment.

1. **HAV safety** – Greater safety through machine precision and vigilance is seen as the top benefit of vehicle automation. But, HAVs will need to demonstrate they are safer than conventional vehicles to a skeptical public. Once this has been demonstrated, HAVs offer an opportunity to advance Vision Zero and safety culture within the region. However, there are risks from new types of crashes, and potentially increased exposure from more travel and shifting away from safer modes.
2. **Artificial Intelligence (AI) and reliance on technology** – AI programs are being embedded into HAV architecture. Current machine learning approaches have yielded considerable advances in ADSs, but may not be capable of delivering Level 5 autonomy. It could be decades before the advances in AI and quantum computing are ready to bring about the fully driverless capabilities that most people think of when they think about HAVs. Computers increasingly carry out more and more of our decision making, including moral choices. As a result, mistakes can be compounded when something goes wrong because human skills atrophy; and we risk being less able to make our own decisions in the future.
3. **Developing profitable business models** – With Level 5 autonomy seemingly out of reach, Level 3 HAVs still require back-up drivers, and Level 4 may require backup drivers or on-demand remote assistance and may operate only in specific areas. This would limit their appeal to goods movement and transportation networking companies. While some drivers will pay for Level 2 technologies it's not clear there are enough consumers out there to make these systems profitable. Business models will also help to determine whether HAVs are shared or individually owned.
4. **Additional infrastructure investment needs** – AV developers intend for the technology to operate within existing infrastructure, but fast paced innovation could require more frequent redesign and upgrades to existing facilities. At a minimum, good pavement conditions, roadway lane markings, traffic signals, and consistent signage are likely to be critical for safe and efficient operations—but these roadway infrastructures are all too often in poor condition. In addition, there is a need to expand integrated corridor management, which serves as an entree into automation, and CVs. CV technologies, including 5G networks, may also be critical to HAV operations—or not used at all. There is not enough funding to address both maintaining existing infrastructure and upgrading with additional digital technologies needed for HAV operations.
5. **Cybersecurity and other technical challenges** – Safety critical systems on CVs and HAVs may be vulnerable to remote cyberattacks because their operating systems are closely connected to and rely on external connections. Other technical challenges include limitations with sensors, reliance on complex electrical systems, the need for more powerful computers that use less

energy than are available on the market today, and all CAV systems must be able to function in a wide-range of extreme environmental conditions.

6. **Regulating AVs** – The regulatory process can be used to promote safer and more equitable innovation. However, setting standards so high that only the best can attain them could reduce competition and increase the economy-of-scale advantages that lead to monopoly services. At a minimum, regulations and codes will need to be updated for insurance liability, driver licenses, roadway testing, and when it is acceptable for HAVs to break the law (such as going around a double yellow strip to avoid a double-parked vehicle). Regulations may also help determine whether HAVs are individually owned or shared.
7. **COVID-19 and Black Lives Matter protests effects on AV development** – How long the pandemic will last and how bad its economic fallout will be are currently unknown. Fear of the virus, or a new pandemic, could cause people to avoid shared mobility over the long-term. COVID-19 may accelerate some forms of automation, such as personal delivery devices, middle-mile delivery vans and trucks, and personal vehicles, while slowing the development of others, such as automated shuttles and other small, shared vehicles. Black Lives Matter Protests indicate that transportation needs reconciliation and dialogue before undertaking major policy changes. HAVs must prove that they don't place undue burden on people of color and low-income individuals.

Table 1. Summary of First-Degree Uncertainties for HAV Development and Deployment

Could Slow Down Deployment	Uncertainty	Could Speed Up Deployment
Hacking; complex human-machine interactions; sensor failures; software bugs; riskier behavior	**Safety**	Machine precision and vigilance, less impaired driving, compliance with laws
Machine learning and AI limitations slow down HAV development; humans remain in the loop; need to program human morality into technology; increased risk of cascading system failures	**Artificial Intelligence & Reliance on Technology**	Artificial General Intelligence enables rapid development of Level 5 HAVs; algorithms better make moral & other decisions
Slow HAV rollout and/or Level 2 to 4 costs > benefits, which limits commercial interest; failure to overcome public skepticism	**Profitable Business Models**	'Moonshot' approach quickly delivers Level 5 HAVs; middle-mile trucking and/or personal delivery devices prove feasible; more federal government support
Need to simultaneously: accommodate many new technologies and vehicle types, connected vehicle technologies, curb management, and improve state-of-repair	**Infrastructure Investment Needs**	HAVs able to operate along existing infrastructure; AI and 3D printing redevelop infrastructure; less need for signs and traffic signals and other infrastructure
Passive hacking; lack of computing power; complex systems; external connections; lag time between emerging threats and vehicle production response to them	**Cybersecurity Risks**	HAVs designed with cybersecurity best practices; over-the-air software updates; more collaboration between key vehicle cybersecurity developers
Regulations push for safety & equity before deployment; roadway testing proves unsafe; contradictory federal and state laws	**HAV Regulations**	Limited to expand competition & speed up deployment; lobbyists write the rules; federal government sets uniform HAV standards
On-road testing delayed, auto industry strained by recession; HAVs must show they don't place an undue burden on historically marginalized and disenfranchised communities	**COVID-19 & BLM Protest Impacts to Deployment**	New demand and urgency for last-mile robotic delivery services and middle-mile goods movement; more demand for individual, non-shared operations; algorithms prove to make fairer decisions

Source: DVRPC, 2020.

Second-Degree HAV Deployment Outcome Uncertainties

Once deployed, there are wide-ranging potential HAV implications for vehicle ownership, vehicle miles traveled (VMT), road capacity, crashes, pavement distress, and jobs. Shared mobility services and potentially high purchase costs could reduce vehicle ownership. However, if HAVs allow for new types of smaller, lighter weight vehicles, costs could go down, which could strengthen the current ownership-based model. While automated vehicles promise many potential benefits, there is no guarantee that these will be achieved. The following second-degree uncertainties will emerge once HAVs are deployed.

1. **Impacts to jobs and the economy** – HAVs could provide a range of economic benefits through increased productivity, energy efficiency, reduced congestion, lower transportation costs and more valuable use of time. However, there are major concerns about job displacement, as digital technologies have generally displaced lower-skill jobs while creating more higher-skill ones. While this is likely to continue, there is uncertainty whether the high-skill jobs of the future will pay as well as those of today. Wages could decline as a result of monopolies that digital networks tend to form, and substituting labor with capital and technology could decrease the demand for workers.
2. **Mobility and congestion** – Improved mobility and reduced congestion may be possible through a variety of shared transportation modes, combined with increased road capacity thanks to closer vehicle spacing and smaller vehicles. HAVs could speed up traffic through reduced spacing distances between vehicles (due to quicker machine reaction times), smoother traffic flow, shorter signal lag times, fewer crashes, and more efficient routing. Increased traffic speeds or volumes could reduce the appeal of walking and biking, though greater safety could increase the allure of active transportation. If HAVs increase road capacity and lower costs, the rebound effect suggests they would equally increase VMT. If the rebound effect increases system use over its ability to handle it, raises questions about the ability to bring about both of these benefits. Zero-occupant vehicles may clog the road, and raise the need for road pricing. Travel speeds may go down if HAVs are programmed to be overly cautious and follow all rules of the road. These slower speeds could limit HAV attractiveness compared to human driving.
3. **Energy use and greenhouse gas emissions** – A move to electric powertrains, programmed eco-driving techniques, smaller vehicles, and more mobility options could decrease GHG emissions, however, the rebound effect has shown that more efficient use of a resource generally increases its total consumption.
4. **Maintaining urban vitality and open space** – HAVs could strengthen the market force for sprawl if they increase willingness to travel and the safety and convenience of doing so, while lowering transportation costs. Alternatively, if HAV technology is incorporated into transit and shared vehicles, then vehicle ownership could decline in favor of transit and MaaS, and could result in growth focused in existing urban areas. Less need for parking could enable denser development in urban and suburban locations.
5. **Achieving equitable access** – While HAVs could help to level the playing field through access to safe and low-cost transportation, those most in need may have less access to them absent government intervention as early adopters tend to be technologically savvy and wealthier. Low-income households could be made worse off and the technology may harm those who do not use HAVs through degraded walking and bicycling conditions, reduced investments in transit, and/or restrictions on human-operated vehicles.[52]
6. **Redesigning the transportation network** – HAVs present an opportunity to redesign the transportation network driven to operate as a shared, integrated multimodal network through

[52] Litman, *Autonomous Vehicle Implementation Predictions*.

MaaS. One where shared HAVs fill gaps in a transportation hierarchy that puts biking and walking at the top, followed by transit, then motorized mobility. However, HAVs risk making the region even more auto dependent, especially if they displace walking, biking, and transit trips.

7. **Data and privacy** – Data generated by CVs and HAVs can be used to improve decision making, enhance traffic control, public utilities monitoring, road safety, and to guide transit enhancements and identify infrastructure needs. Privacy concerns abound, however, as most consumers aren't even aware, nor have they given consent, to all the data being collected.

In many ways, each of these uncertainties will add new layers of complexity to the transportation network, and will create many challenges that will need to be overcome in order to successfully deploy HAVs. Appendix C further details each of these uncertainties.

Table 2. Second-Degree Uncertainties for HAV Deployment Outcomes

Could Worsen Outcomes:	Uncertainty	Could Improve Outcomes:
Artificial General Intelligence displaces human workers; rise of monopolistic services; HAVs strengthen 'surveillance capitalism'	**Economy & Jobs**	Technology creates more high-skill jobs than the lower-skill ones it disrupts; more productivity; reduced transportation costs
Some combination of less dense development, rebound effect, zero-occupant trips, lower vehicle operating costs, expanded mobility for non-drivers, and mode shift away from transit, bike, ped trips increase travel and gridlock; less road capacity due to following all road rules and/or defensive driving	**Mobility & Congestion**	Vehicle sharing, MaaS, and denser development support space efficient multimodal transportation; reduced headways, smoother traffic flow, shorter signal lag times, fewer crashes, right-sized vehicles, and more efficient routing; the young, the elderly, and persons with disabilities have more travel options
Rebound effect; HAVs continue to use internal combustion engines; resource shortages limit electric vehicle, solar, and wind energy development	**Energy Use & GHG Emissions**	HAVs facilitate move to EVs; more efficient routing; eco-driving
Increased willingness to travel; AVs enable more spread out development patterns	**Urban Vitality / Open Space Preservation**	Network effects (where regions become stronger and more efficient as population and density increase); MaaS; less parking
Payment for priority; AI fails to detect darker skin tones; use of age, gender, race in algorithms; technologies aren't designed for or otherwise limit access for persons with disabilities	**Transportation Equity**	Algorithms remove human biases; costs are lowered for everyone; a portion of transportation cost savings are used to subsidize low-income individuals
More auto dependence if HAVs disrupt walking, biking, and transit; need to accommodate many new technologies, vehicle types, and travel speeds proves challenging; increased system complexity	**Redesigned Transportation Network**	HAVs operate in existing infrastructure; AI and 3D printing improve infrastructure; less need for signs and traffic signals; Vision Zero safety engineering; connected vehicle technologies; curb management; MaaS; private-market infrastructure development
5G networks capture overwhelming amounts of data; data is kept proprietary and/or commercialized for 'surveillance capitalism'; 'bad' data limits its usefulness	**Data Collection**	Privacy protections limit data collection; data is made open and shared with appropriate safeguards

Source: DVRPC, 2020.

HAV Deployment Scenarios

Scenario planning is a tool for dealing with uncertainty and preparing for a range of plausible futures. DVRPC recently conducted an exploratory scenario planning exercise with the Futures Working Group (FWG)—comprised of a transdisciplinary group of approximately 100 subject matter experts, stakeholders, and the general public. Many AV projections consider the technology in isolation. The four *Dispatches* scenarios are used in this analysis to set AVs and HAVs within a broader socioeconomic context (see Figure 3) and to further inform different ways in which HAVs could be deployed in Greater Philadelphia over the next several decades.

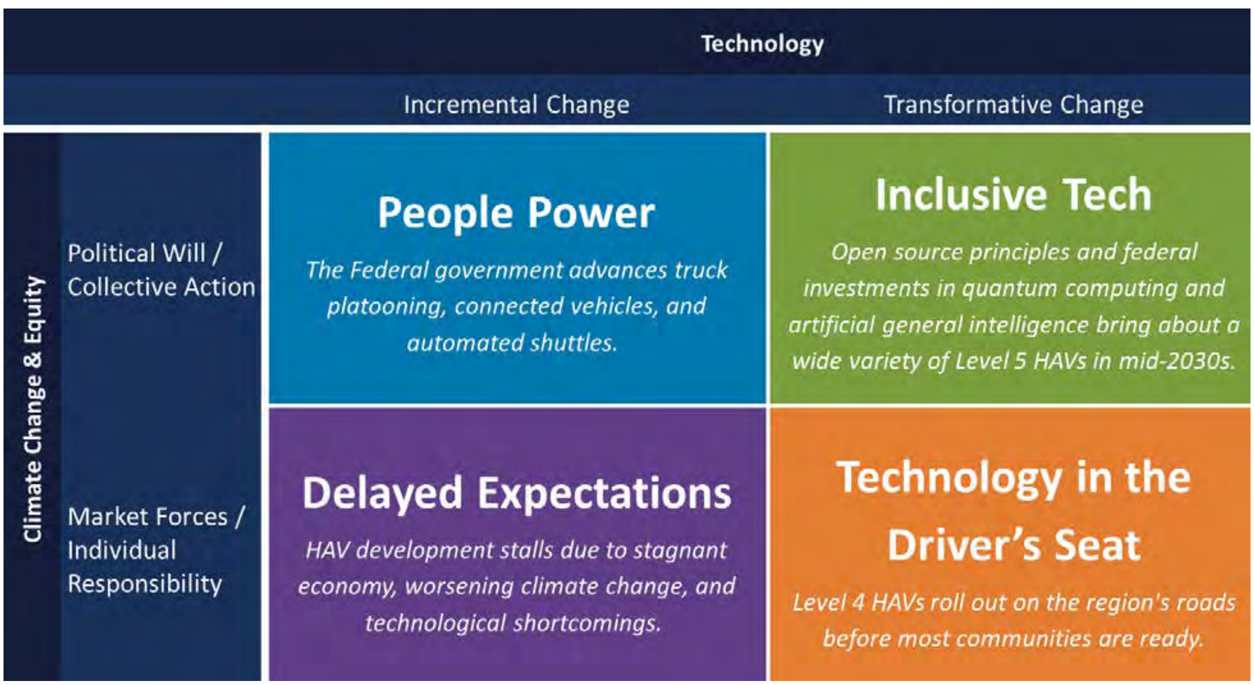
Figure 3. *Dispatches from Alternate Futures* Scenarios

Source: DVRPC, 2019.

The FWG brainstormed driving forces of change, voted to identify the highest impact and most uncertain forces, created axes of uncertainty for the high impact and high uncertainty forces, used the axes of uncertainty to develop a two-by-two matrix of scenarios, and then analyzed the implications of each scenario. The axes of uncertainty consider (1) whether or not future collective actions will be taken to reduce inequality and climate risks, and (2) if technologies from the Digital Revolution will advance at an incremental rate or be transformative and disruptive between now and 2050. *Dispatches from Alternate Futures* has more information about scenario planning and how these scenarios were developed.

In addition to an automated future, there is a second, either competing or complementary, vision for the future of transportation based on creating more walkable, bikeable, and transit-oriented communities. This alternative vision would use urban design to give people more non-motorized and transit options to get around. The desire for this alternative future can be seen through rapidly increasing housing prices in walkable, transit accessible neighborhoods—as a result of growing interest and limited supply. The downside of this vision is that walkable places are becoming the new luxury item, leading to gentrification and equity concerns.[53] These approaches aren't necessarily mutually exclusive, and the most successful future locales may find ways to equitably blend both technology and design. Figure 4 identifies the key AV deployment expectations in each of the *Dispatches* scenarios.

Figure 4. Highly Automated Vehicle *Dispatches* Scenarios



Source: DVRPC, 2020.

In Delayed Expectations, automated vehicle development stalls due to stagnant economy. In People Power, the federal government advances truck platoons, connected vehicles, and automated shuttles. In Technology in the Driver's Seat, Level 4 HAVs are deployed before communities are

[53] "Autonomous Vehicles: Separating the Hype from Reality," *Strong Towns Podcast*, June 28, 2018, www.strongtowns.org/journal/2018/6/28/autonomous-vehicles-separating-the-hype-from-reality (accessed July 3, 2018).

ready. And in Inclusive Tech, open source principles and federal regulations shape HAVs. Table 3 summarizes each scenario's assumptions for vehicle automation levels, different degrees of CV and EV technology deployment, and development of shared mobility services. Table 4 summarizes how different HAV development and deployment uncertainties play out differently in each future, and Table 5 summarizes how deployment outcomes vary in each scenario. Ultimately, these scenarios are used to analyze extreme, but plausible HAV deployment pathways with regard to the identified first- and second-degree HAV uncertainties. They can help to better understand the potential pitfalls and opportunities, to inform a vision for incorporating HAVs into the region's transportation network, and then link policy recommendations to clear and measurable goals.

Table 3. Automated, Connected, Electric, and Shared Mobility Development by Scenario

Technology	Delayed Expectations	People Power	Technology in the Driver's Seat	Inclusive Tech
HAV Availability (Level 4 & Level 5)	No Level 4 or Level 5 HAVs by 2050	Level 4 HAVs by Late 2030s, No Level 5 HAVs by 2050	Level 4 HAVs in early 2020s; No Level 5 HAVs by 2050, Passenger drones deployed in 2040s	Level 4 HAVs by mid-2020s; Level 5 HAVs in early 2040s
Connected Vehicles	CV technologies are not widely deployed	CV technology deployed even in advance of HAVs	Private market deploys CV technologies unevenly, lack of standards means not all vehicles can communicate with each other and some HAVs are autonomous	CV and HAVs are jointly developed and deployed, CV technology is critical to unlocking Level 5 HAV capabilities
Shared Mobility	Existing vehicle-ownership model remains in place	Major transit expansion and growth in micromobility, worker protections harm TNCs	Mix of personal ownership and MaaS models, but MaaS companies operated as 'walled gardens'	Integrated, multimodal mobility-as-a-service (MaaS) network emerges
Electric Vehicles	Limited EV deployment	Expansive EV deployment	Considerable EV deployment, but not all HAVs are EVs	Expansive EV deployment-

Source: DVRPC, 2020.

DVRPC modeled the *Dispatches* scenarios with two programs. The first, Impacts 2060, is an open source, sociodemographic system dynamics model that develops future-year population and employment, based on changes to birth rates, death rates, migration rates, and economic conditions; and projects resulting shifts in travel demand and land use. The second modeling program, UrbanSim, simulates regional real estate developer and household locational choices and how these are influenced by government policies and investments. These models were used to further understand and illustrate how the differing future assumptions could shape the region's demographics, travel demand, and land use. This is illustrated in Table 6, which shows the percent change in each indicator between a 2015 base year and 2050 horizon year across the scenarios. Each scenario's socioeconomic overview section adds more details to its modeling results.

Table 4. HAV Development and Deployment Summary by Scenario

Uncertainty	Delayed Expectations	People Power	Technology in the Driver's Seat	Inclusive Tech
Safety	Limited deployment of CV technology, ADAS gains limited by warning fatigue	More safe transit, walking, and biking options; and deployment of CV technology	While HAVs increase safety, critics contend safety comes second to profits	A new safety culture changes how risk is viewed and prioritized in societal decision making and investments
AI & Reliance on Technology	AI investment falters	AI helps to deliver Level 4 HAVs	AI helps to deliver Level 4 HAVs	AGI achieved in 2030s, helping deliver Level 5 HAVs
Profitable Business Models	Development of a MaaS app fails to get drivers out of their vehicles; most firms go bankrupt or stop R&D as HAV capabilities stall	Federal government funds automated technologies to develop business cases, micromobility grows, TNCs harmed by more worker protections	Private Market Shared Mobility operates as 'Walled Gardens'	Nonprofit(s) and/or public sector build open source framework for multimodal MaaS network
Infrastructure Investment Needs	MBUF doesn't raise enough revenue to improve poor infrastructure conditions	Federal investment in transit, walking, and facilities, and improved road conditions	Private market leads or dictates needs, equity is too often an afterthought	Mobility hubs, AGI signal systems, programmable roads
Cybersecurity Risks	Vehicles don't undergo security redesign from chassis up; Internet loses reliability	Level 4 HAVs redesigned in 2040s with cybersecurity best practices	Level 4 HAVs redesigned in 2020s with cybersecurity best practices	AGI and quantum computers used to increase cybersecurity protections
HAV Regulations	Lack of federal HAV regulations increases deployment uncertainty	Federal investments focus on making transportation more sustainable and equitable	Limited federal regulations	Strong federal regulations guide HAV development to be more sustainable, equitable, and innovative
COVID-19 & BLM Protest Impacts to Deployment	Shovel ready stimulus fails to modernize transportation; no lessons learned from COVID or BLM	COVID slows HAV development, HAVs fit into federal investments to make transportation more equitable	Increased delivery demand during pandemic speeds up HAV deployment	The pandemic accelerates decentralized production and increases working from home

Source: DVRPC, 2020.

Table 5. HAV Deployment Outcomes Summary by Scenario

Uncertainty	Delayed Expectations	People Power	Technology in the Driver's Seat	Inclusive Tech
Economy & Jobs	Economic growth is stagnant in the face of changing climate, jobs look similar but use more technology with more independent contracting	Jobs look similar to today, but continued displacement of low-skill positions with high-skill ones	Global corporations dominate the economy, limiting opportunity and displacing high paying jobs with low paying ones; UBI substitutes for hard to come by work	Economic decentralization means more people work on their own; as automation displaces work, a community jobs act provides work for anyone who needs it
Mobility & Congestion	VMT and congestion decline	Transit, walking, biking increase mobility while reducing congestion	VMT increases, leading to endless gridlock—despite congestion pricing	Travel increases on all modes; space efficient vehicles limit congestion
Energy Use & GHG Emissions	Limited deployment of EVs	Greenhouse gas emissions reduced substantially using readily available technologies	Emissions continue to rise, despite new efficiencies	New innovations substantially decrease greenhouse gas emissions
Urban Vitality / Open Space Preservation	Digital Revolution continues to promote recentralization, but climate change is pushing for development on higher grounds	Increased land preservation, combined with investments in walkable communities across the region	Population growth centralizes in high-tech hubs and large regions, but suburban sprawl is on the rise in Greater Philadelphia where Level 4 ODDs are located	Areas with access to open space and natural amenities are desirable; nature and natural functions incorporated into urban areas as never before
Transportation Equity	Lack of improvements to transportation limits access to opportunity	Federal focus on transportation equity helps to increase access to opportunity	Private market shared mobility is undercutting transit, raising questions about long-term viability and how to serve everyone	Small shared HAVs lower transportation costs and increase access to opportunity, but some challenges remain
Redesigned Transportation Network	Lack of a compelling vision to move away from vehicle-ownership status quo	Transit, walking, and biking serve as backbone to shared mobility network, HAVs play niche role	Congestion pricing used to expand roads, private market develops new tolled facilities	Shared, on-demand MaaS network emerges, blending together wide range of vehicle types
Data Collection	Increasing quantities of data collected, but is often of poor quality	Privacy protections limit data collection	Massive data collection empowers big companies, who resell it through proprietary services	Data Bill of Rights builds in privacy protections, allows for data collection and open sharing

Source: DVRPC, 2020.

Table 6. Percentage Change in Key Regional Indicators by Scenario, 2015-2050

Factor	Delayed Expectations	People Power	Technology in the Driver's Seat	Inclusive Tech
Population	-1%	+10%	+15%	+8%
Population <16	-18%	-9%	-15%	-19%
Population >65	+44%	+53%	+68%	+70%
White, Non-Hispanic Population	-11%	-14%	+1%	-10%
Minority (Non-White) Population	+17%	+50%	+48%	+37%
Employment	+3%	+11%	+16%	+5%
Households	+1%	+16%	+26%	+21%
Single-Person Households	+3%	+31%	+51%	+47%
Persons per Household	-1%	-6%	-10%	-11%
Low-Income Households	+5%	+5%	+30%	+14%
Medium-Income Households	-1%	+31%	+16%	+34%
High-Income Households	-11%	+8%	+34%	+11%
Vehicles	+5%	+17%	+5%	+13%
Vehicle Miles Traveled (VMT)	-4%	-5%	+53%	+21%
Vehicle Trips	-4%	0%	+31%	+34%
Transit Trips	-1%	+20%	+9%	+31%
Walking/Biking Trips	+13%	+29%	-4%	+17%

Source: DVRPC, 2020.

The following sections give an overview of each scenario, along with HAV deployment, and deployment outcomes. HAV deployment reflects different first-degree uncertainties: safety, AI, developing profitable business models, additional infrastructure investment needs, cybersecurity, regulations, and COVID-19 implications. Deployment outcomes reflect second-degree uncertainties, including impacts to jobs and the economy, changes to mobility and congestion, energy use and GHG emissions, maintaining urban vitality, achieving equitable use and access, redesigning the transportation network, and data and privacy. None of these descriptions are seen as optimal or preferred futures for Greater Philadelphia. Rather, they show the opportunities and challenges in how key driving forces may shape the region over the next several decades, and how the decisions we make and our reactions to these forces may shift their implications.

Delayed Expectations

In the **Delayed Expectations** scenario, climate change, sharp political swings, ongoing civil discord, and a slowdown in innovation lead to a lack of direction and economic stagnation. Without a compelling vision for transportation, the system muddles along even as infrastructure conditions continue to deteriorate. Figure 5 highlights some of the key developing news stories for AVs and transportation in Delayed Expectations.

Figure 5. Delayed Expectations Developing News Stories

Year	How it Started	Year	How it's Going
2028	Congress Narrowly Passes Transportation Legislation, Shifts Funding Mechanism to VMT Fees	2044	With Transportation Funding Stalled, What to Do with Closed Section of I-95 in South Philly?
2029	Following Fatal Passive Hacking Crash, Autodrive is the Latest Self-Driving Car Company to Shut Down Operations	2043	Who Killed the Automated Vehicle?
2032	New MaaS-Philly App Brings Together Service Providers, Wayfinding, and Fare Payment	2036	No MaaS—How Lack of Supportive Policies Doomed MaaS-Philly

Source: DVRPC, 2020.

Delayed Expectations Socioeconomic Overview

The region's total population remains stagnant, and aging fast. Political polarization slows immigration, while climate change is a major drag on the economy—employment levels and income are largely flat or declining. The number of jobs increases by just three percent between 2015 and 2050, while the region's population has declined by one percent over this period. Lack of affordable housing restricts new household formation—and causes more families to live in multigenerational households. Even single people are increasingly living with roommates. Worsening transportation system conditions increases the cost of transportation and dampens demand for roads—VMT is down by 4 percent between 2015 and 2050. Transit ridership is surprisingly down by just one percent, despite declining system reliability due to aging vehicles and infrastructure.

Delayed Expectations AV Deployment

The COVID-19 pandemic subsides in 2021. Stimulus bailouts to recover from the aftermath of the pandemic focus on shovel-ready projects that reinforce the status quo and are not designed in a way to reduce pre-existing shortcomings in equity, safety, and sustainability with the transportation system. This is a major missed opportunity to promote much needed change and innovation in the sector.[54] No real lessons are learned from the pandemic and it doesn't lead to any fundamental changes so that the mid-2020s look much like 2019. When further pandemics crop up over time, the nation remains poorly prepared to respond. Inability to deal with systemic racism hinders all kinds of opportunities for societal progress, from responding to climate change to deploying HAVs.

Technology suffers a massive loss of trust due to surveillance fatigue; increasing cyberterrorism; lack of reliability of the internet; and concerns about 5G deployment, ranging from national security to conspiracy theories to community design—as it requires erecting new wires, poles, and digital equipment. The Internet routinely goes down as cyberattackers expose underlying vulnerabilities

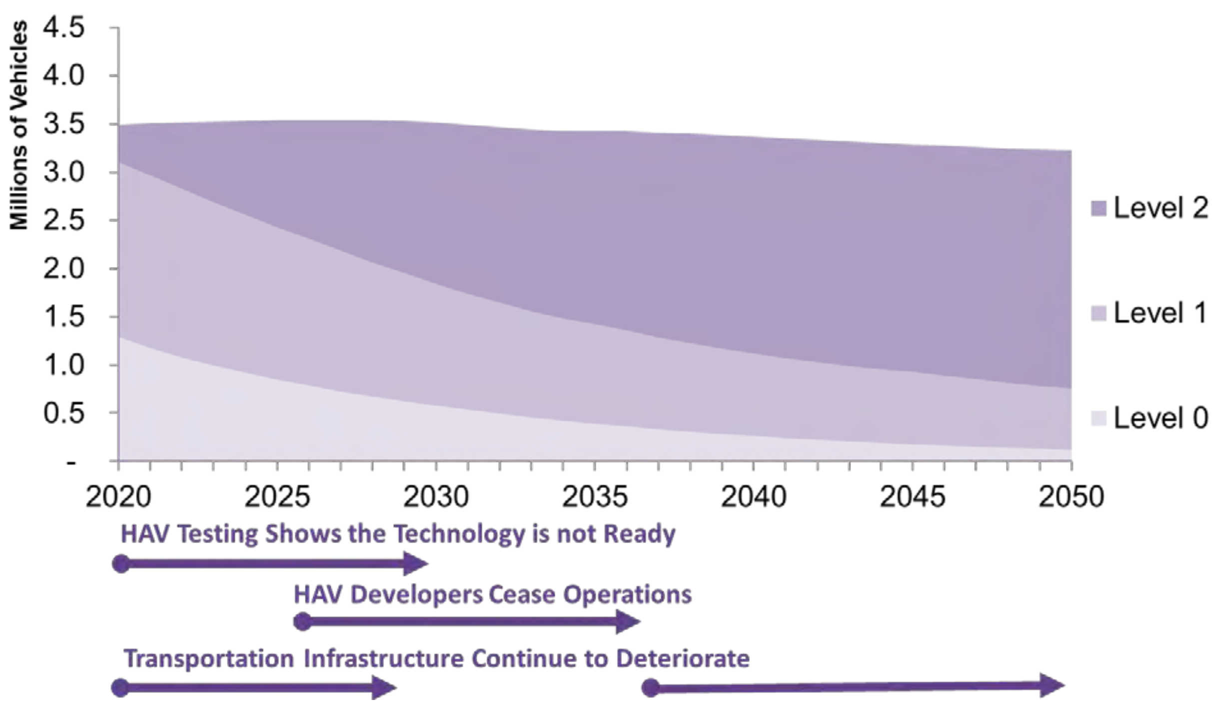
[54] COVID-19 AVs & Shared Mobility Implications," *Transportation Research Board (webinar)*, May 13, 2020.

and storm surges combined with rising sea levels take out key network infrastructure.[55] The growing tech backlash serves as the first sign of trouble for the AV industry.

HAVs struggle with poor infrastructure conditions that disrupt the sensors they need to operate. Slow moving vehicles during pilot projects generate considerable frustration from human drivers, even causing some malicious road rage incidents. A series of high-profile crashes and developers' unwillingness to share road testing performance data increases public skepticism. Machine learning runs up against limitations in responding to new situations, interpolating what different objects on and alongside the roadway are, and predicting what other road users and objects will do next. This brings about a new AI winter where research and development slow down considerably.

As the costs and challenges of developing HAV technologies becomes overwhelming, calls for more support from the public sector go unheeded by governments struggling to respond to fast moving climate change and economic stagnation. Most firms eventually pull the plug on their HAV projects and many smaller companies go bankrupt. The failure to develop a comprehensive regulatory system for AVs at the federal, state, or local levels may have, ironically, contributed to the demise of the industry by adding uncertainty to HAV development and deployment. Figure 6 shows the progression of the region's vehicle fleet by SAE automation levels over time in Delayed Expectations along with key events shaping AV deployment.

Figure 6. Delayed Expectations AV Pathway



Source: DVRPC, 2020.

The Funding an Equitable, Accessible, and Sustainable Transportation Infrastructure Act (FEASTIA) of 2028, a six-year, $480 billion bill includes sweeping changes to financing the nation's roads, bridges, and transit systems. The legislation eliminates the federal gas tax (18.4 cents per gallon

[55] Greta Jochem, "Rising Seas Could Cause Your Next Internet Outage," *Wired*, July 18, 2018, www.wired.com/story/rising-seas-could-cause-your-next-internet-outage/ (accessed July 18, 2018).

for regular and 24.4 cents for diesel) and replaces it with a mileage-based user fee (MBUF) of 2.0 cents per mile traveled for light-duty cars and trucks, and 2.5 cents per mile for medium- and heavy-duty trucks. Despite this legislation, there is little progress in improving infrastructure conditions, roadway safety, or access to opportunity. Over time, VMT decreases due to a stagnant economy and individual concerns about climate change—this wasn't expected with the move to the MBUF and leads to flat longer-term funding levels. Climate-driven, severe weather hastens the decline in transportation infrastructure, further stretching limited transportation funds.

Public and private regional transportation service providers band together to build a single wayfinding and fare payment MaaS app. While this app increases convenience for those who use it, it largely does not convince many transportation system users to give up their cars or significantly change travel behavior as it lacks key supportive policies around parking fees, transit service frequency, and bike and pedestrian infrastructure.[56] As a result, interest in MaaS wanes over time.

While CV technologies are not widely deployed in transportation infrastructure, conventional vehicle safety improves through the implementation of ADAS technologies. However, some of these gains are negated over time by warning fatigue and overly trusting the technology. As people become comfortable with the abilities of lane centering and adaptive cruise control, they are less vigilant in watching the road. Increased speeds, thanks to declining traffic and congestion, cause a rise in fatal crashes starting in the mid-2030s. This highlights the danger of transportation infrastructure that is over-engineered for speed. While only a minor consolation, less new technology deployment reduces the risk from unintended consequences.

Delayed Expectations AV Deployment Outcomes

The economic slowdown in the wake of the COVID-19 outbreak reduces new vehicle sales and delays the transition to EVs. As hotter weather strains the region's aging electrical grids brownouts are becoming more common, further inhibiting the deployment of EVs and even harming transit service reliability. Legacy automakers, transportation network companies (TNCs), and micromobility operators benefit the most from non-deployment of EVs and HAVs. Shared mobility grows slowly in lieu of HAV deployment. Vehicles haven't undergone a redesign from the chassis up for cybersecurity purposes. This was expected to happen with HAV development. As a result, vehicles continue to have components vulnerable to hacking.

The inability to develop HAVs feels like a missed chance to better link people and opportunity. Despite the backlash against it, technology and algorithmic decision making continue to advance, albeit slowly. There still have not been needed societal conversations about or protections for individual privacy, and ensuring biases have removed from algorithmic decision-making systems.

The slow continuation of the Digital Revolution creates a pull factor toward higher density agglomeration economies. Though, this is tempered to a degree in Greater Philadelphia when Hurricane Therese lands a direct hit on the region in the early 2030s, leaving considerable damage in her wake as she travels up the Delaware River. Memories of evacuating the region convinces many to hold onto their personal vehicles. Development patterns begin to shift to higher grounds, even as they seek dense centers. Declining government revenues reduce many of the subsidies granted to lower density areas, creating a push factor away from these communities. Former

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[56] David Zipper, "There's No App for Getting People Out of Their Cars," *Bloomberg CityLab*, November 13, 2019, www.bloomberg.com/news/articles/2019-11-13/going-car-free-will-take-more-than-mobility-apps (accessed November 3, 2020).

suburban McMansions are subdivided into multigenerational housing.[57] Even as the region recentralizes, there is little rethinking about the role of cars in cities.

In the 2040s, jobs still look much like they did two decades earlier, though they use more technology. Individuals are even more likely to be freelancers or work in the gig economy. As traditional full-time employment decreases, there are fewer nine-to-five work schedules. This reduces peak hour travel demand, congestion, and transit ridership.[58] And while demand for goods movement has only grown slowly, there is a severe shortage of truck drivers.

Crumbling transportation infrastructure is struggling to meet demand, while conspiracy theories rage about government cabals secretly blocking HAV development, even though the technology itself failed to perform. The solution to all kinds of transportation challenges is always to create another app. While apps can reroute traffic around a closed bridge, crash, or endless gridlock, it eventually runs out of options for doing so. Lack of investment in roads, walking, biking, and transit infrastructure is why most people have only limited options available for getting around. And while there's a lot of data being collected, it's not always accurate and reliable and using it to drive change remains challenging.

People Power

In **People Power**, grassroots democracy gives citizens more input into the development of their communities and the economy, while readily available technologies are deployed to fight climate change. Transportation investments prioritize bicycle, pedestrian, and transit movements. Figure 7 highlights some of the key developing news stories for AVs and transportation in People Power.

Figure 7. People Power Developing News Stories

Year	How it Started	Year	How it's Going
2024	Automated Vehicle Developers Say Fair New Deal's Data Privacy Protections Will Slow Innovation	2028	With Private Market Bowing Out, Federal Government to Invest in Platooning, and Automated Freight and Passenger Shuttles
2029	Federal Officials Investigate Truck Platoon-Related Crash on PA Turnpike	2030	New Campaign Aims to Show Drivers How to Safely Operate Around Truck Platoons
2031	SEPTA to Launch New Automated Shuttle Route in Center City	2035	Chestnut Street Busway and Pedestrian Zone Reopens

Source: DVRPC, 2020.

People Power Socioeconomic Overview

The Fair New Deal (FND) is a series of federal bills that strengthen the social safety net, antitrust measures, and personal privacy; and uses existing technologies to reduce GHG emissions, while shifting many independent contractors back onto company payrolls—thereby weakening the gig economy. It results in greater educational attainment and slows the decline in birthrates. The FND focuses on reducing energy use and GHG emissions using readily available technologies such as:

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[57] David Levinson, "What Happened to Traffic?" *Transportationist*, November 11, 2013, www.transportationist.org/2013/11/07/what-happened-to-traffic/ (accessed August 10, 2015).
[58] Nicole DuPuis, Cooper Martin, and Brooks Rainwater, *City of the Future: Technology and Mobility* (Washington, DC: National League of Cities, 2015) www.nlc.org/Documents/Find%20City%20Solutions/Research%20Innovation/City%20of%20the%20Future/City%20of%20the%20Future%20FINAL%20WEB.pdf.

- Net zero energy building standards and land preservation.
- Building energy efficiency and electric vehicle tax credits.
- Conservation tillage.
- A doubling of vehicle fuel efficiency requirements for ICEs, pushes more car buyers toward EVs.
- Carbon capture and storage.
- Solar and wind microgrids.
- Reduced vehicle miles traveled and shift to alternative modes by expanding transit networks and walking and biking facilities.

The FND's expanded worker protections help to broadly expand the middle class as the number of households making between $40,000 and $100,000 (in 2010 $s) increased by 31 percent from 2015 to 2050. The nation's borders are increasingly open to immigrants, helping grow the region's population. Growth and development are spread evenly around the region and reduces the economies-of-scale that have benefitted some regions over others in the Digital Revolution. Communities and neighborhoods—urban, suburban, and rural—are made more walkable, bikeable, and transit oriented thanks to FND investments. This helps to reduce VMT by five percent, while increasing transit ridership by 20 percent and biking and walking trips by 29 percent between 2015 and 2050.

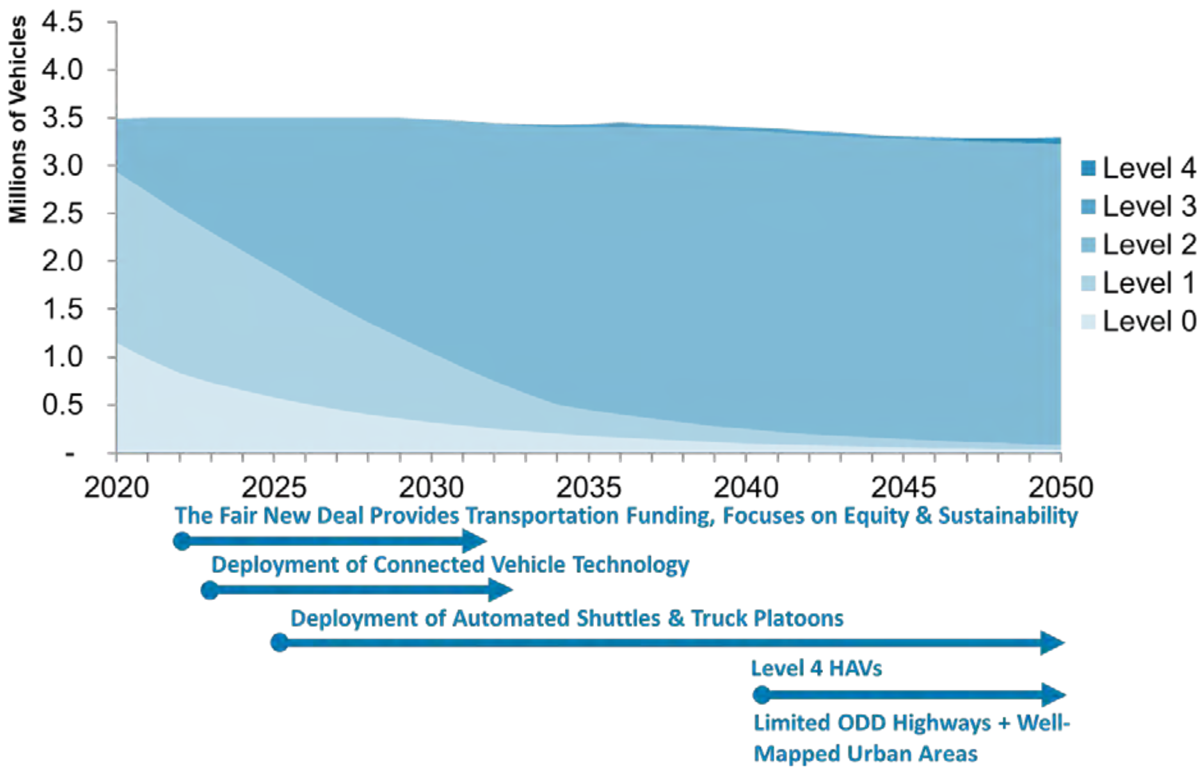
People Power HAV Deployment

The COVID-19 crisis lasts for years, as a vaccine is slow to be developed and distributed. This severely slows HAV development, on-road testing, and the resulting economic downturn stresses many companies developing the technology. Privately developed HAVs also falter in the face of public and safety concerns, and technological shortcomings. Automakers focus on rolling out EVs in response to regulatory demands in the FND. As a result, the federal government takes the lead in advancing truck platooning and CVs, and with transit agencies to experiment with automated shuttles. Figure 8 shows the progression of the region's vehicle fleet by SAE automation levels over time in People Power along with key events shaping HAV deployment in this scenario.

The Safe Connected and Automated Trucks and Vehicles (SCATV) Act, a part of the FND, made a strategic decision to focus on freight automation before approving the technology's use for personal vehicles due to public safety concerns. A major driver behind the SCATV Act was the exponential rise of e-commerce, resulting in ever-increasing demand for truck delivery that continues to strain the nation's roadways. The SCATV Act sets tough standards for HAV safety and performance, which must be satisfied before granting any commercial licensing. Some HAV developers blame regulations for being overly burdensome and slowing rollout, even though technological challenges are the true cause of the delay.

Truck platooning is initially deployed in midwestern and western states with low traffic, straight, wide, and flat roads. These locations have less complexity; and can generate useful data before implementing in more challenging locations, such as the Pennsylvania Turnpike. Public education campaigns aim to help human drivers to identify and recognize truck platoons, and to inform the driving public on safe interactions with platoons. There are still frustrations, such as how longer platoons create obstacles for passing and accessing exit ramps, which occasionally leads to aggressive human driving around them. Truck platoons do not initially lead to a significant reduction in truck crashes and fatalities, decreasing trust in the technology.

Figure 8. People Power AV Pathways



Source: DVRPC, 2020.

Federal investments in CV technologies vastly enhance safety by detecting and audibly and/or visibly warning other vehicles of potential crash risks, thereby reducing human error. CVs transmit precise and in-depth real-time location, speed, and other data to traffic management systems that DOTs use to assess traffic conditions and identify data-driven opportunities to improve safety. This enables a focus on maximizing the safety and value of existing technologies.

Investments in freight applications and advances are slow to translate into personal travel innovations. While hype around HAVs tamps down considerably, there is still concern that the technology isn't really ready even as it is being deployed on the nation's roads. However, this slow roll out allows for more trial and error, more time to undertake the difficult work of building public acceptance and to develop public-private partnerships, and lets the industry address early safety concerns in order to create a better final product. In the meantime, transit undergoes a renaissance, thanks primarily to increased funding. Additional expenditure helps pay for new transit routes in major metro regions across the country. Slow-moving automated shuttles are employed along fixed guideway routes, limiting how much HD mapping and programming is required for their deployment. These shuttles begin operating in urban cores in the late 2020s, creating a well mapped urban environment for when commercial Level 4 HAVs are deployed. Transit drivers move into a concierge role, assisting and guiding passengers, but are also on hand to take back control of the vehicle whenever an ADS encounters a situation it can't handle. Overall, transit operating costs increase, which are affordable thanks to increased federal transportation investment.

Major cybersecurity advances occur when Level 4 HAVs begin to be deployed in the early 2040s. A well-developed MaaS network is in place by the time Level 4 HAVs become commercially available.

Despite having ODDs in dense urban and suburban centers and neighborhoods, Level 4 HAVs play a niche role in expanding transportation options and service coverage areas.

People Power HAV Deployment Outcomes

The FND generates additional transportation funding through a fee based on how much VMT each real estate property generates combined with a tradable driving credits system. This system gives each person an annual allotment of VMT. This benefits those who drive less, as they can sell their unused miles through an exchange. Regulations that limit independent contracting serve as the death knell for TNCs. However, micromobility—through shared e-scooters, e-bikes, and bikes—grows significantly thanks to more walkable communities. It fills gaps in the transit network that open up in the wake of TNC declines. Despite cross-cutting purposes, governments continue to subsidize existing low-density development to increase the supply of affordable housing.

Public scrutiny over the collection and use of personal data leads to new protections as part of the FND. This severely limits private companies' ability to collect personal information, and leads to accusations of purposefully slowing down innovation. Thanks to consumer demand for worker rights, cooperatives and benefit corporations become the principal business structures. Jobs look similar to today but technology continues to displace low-skill positions with high-skill ones.

Incorporating the infrastructure to support platoons and automated shuttles often requires truck only lanes, roadside truck parking areas with local driver access points, communications technology to enable trucks and cars to talk with each other at high speeds, and dedicated shuttle only facilities. Truck platoons can move goods more efficiently with positive impacts on the economy and air quality, and reduced GHG emissions; and help address the shortage of truck drivers. Critics contend that platoons decrease labor costs and increase truck travel.

An emphasis on achieving the Vision Zero goal of no transportation fatalities or serious injuries by 2050 has led to a promotion of safety culture throughout society—in all kinds of fields well beyond the realm of transportation—extending the view that human deaths and injuries are preventable and unacceptable. Specific transportation safety projects have included slowing down vehicle speeds and widely applying CV technology along highways and major roadway facilities in advance of HAV deployment. This allows AVs to develop in a more cooperative environment.

Technology in the Driver's Seat

In **Technology in the Driver's Seat**, markets drive economic growth through Big Data, algorithms, and innovation. The private market brings about a HAV-oriented transportation network. Figure 9 details some key developing transportation and AV news stories in Technology in the Driver's Seat.

Figure 9. Technology in the Driver's Seat Developing News Stories

Year	How it Started	Year	How it's Going
2023	Ready or Not, the Automated Vehicle Race Arrives in Philly Area	2043	Highly Automated Vehicles Make Up Half the Fleet, Why Aren't Road Fatalities Down More?
2026	Transportation Network Companies Finally Profitable Thanks to Driverless Vehicles	2032	Fast Growing TNCs Are Building Walled Gardens as they Battle for Road Supremacy
2041	It's a Bird, It's a Plane, It's a … Flying Taxi?	2048	eVTOL Services Take Off, Help Those Who Can Afford them to Bypass Road Congestion

Source: DVRPC, 2020.

Technology in the Driver's Seat Socioeconomic Overview

The economies-of-scale created by the Digital Revolution strengthen. As a result, the nation's growth and development increasingly centralizes in a handful of innovation hubs and the most populous regions. The region grows more than forecasted—by 15 percent for population and 16 percent for jobs between 2015 and 2050—but it still declines to just the 12th largest region in 2050 after being the seventh largest in 2015—as several other regions grow at a much faster pace. Technology is helping people live longer than ever, at least for those who can afford it. People and jobs are highly mobile, leading to a lot more people moving in and out of the region. Increasing divorce rates mean more single-person households, which grow by more than 50 percent between 2015 and 2050. Incomes remain highly unequal. The region and nation have become even more auto-oriented. Even though transit ridership grows by a slight nine percent between 2015 and 2050, private-market services increasingly cut into use of the public system. This harms transit's ability to serve everyone, especially those who have limited transportation options or financial resources.

Technology in the Driver's Seat HAV Deployment

The increased demand for delivery during the COVID-19 pandemic further accelerates HAV technology development and deployment, while reducing regulatory limitations. As a result, the 2022 Rolling Out Bot Operated Transportation In Creating Driverless Roadway Infrastructure and Vehicle Innovation for New Growth (ROBOTIC DRIVING) Act had four major components aimed at speeding up HAV deployment:

- Removal of nearly all existing vehicle safety regulations for HAVs, giving NHTSA one-year to create a new regulatory structure for them.[59]
- Limits the ability of state and local governments to restrict the use of HAVs on their roadways or the deployment of infrastructure related to the rollout of HAVs, including 5G.
- Grants states the right to apply congestion pricing on interstates and other highways.
- Requires manufacturers to develop plans for collecting data and ensuring privacy, and communicating this to consumers.

These federal policies don't always align with state and local policies, and key agencies aren't set up to coordinate. Limited involvement of regulatory parties through a hands-off approach, and under-resourced local governments have a hard time managing HAVs. Soon after the ROBOTIC DRIVING Act's passage, Level 4 HAVs drop onto the region's streets with little public input or government readiness. These HAVs can initially operate along highways, and some suburban and rural arterials with relatively simple operating environments, during good weather and traffic conditions. Each HAV developer is in fierce competition to have the largest ODD, and the range of conditions where and when they can operate expands over time. Figure 10 shows the progression of the region's vehicle fleet by SAE automation levels in Technology in the Driver's Seat along with key events shaping HAV deployment through 2050.

Rapid deployment does reduce road fatalities, though less than had been widely hoped for. Driver trust is often greater than performance reality, and some people find ways to operate HAVs outside their ODD. Mixed human and ADS driving proves challenging, and it's become clear that substantially improving safety and reducing congestion may only be possible if HAVs are operating in their own right-of-way. The private market deploys CV technologies, without a federal mandate,

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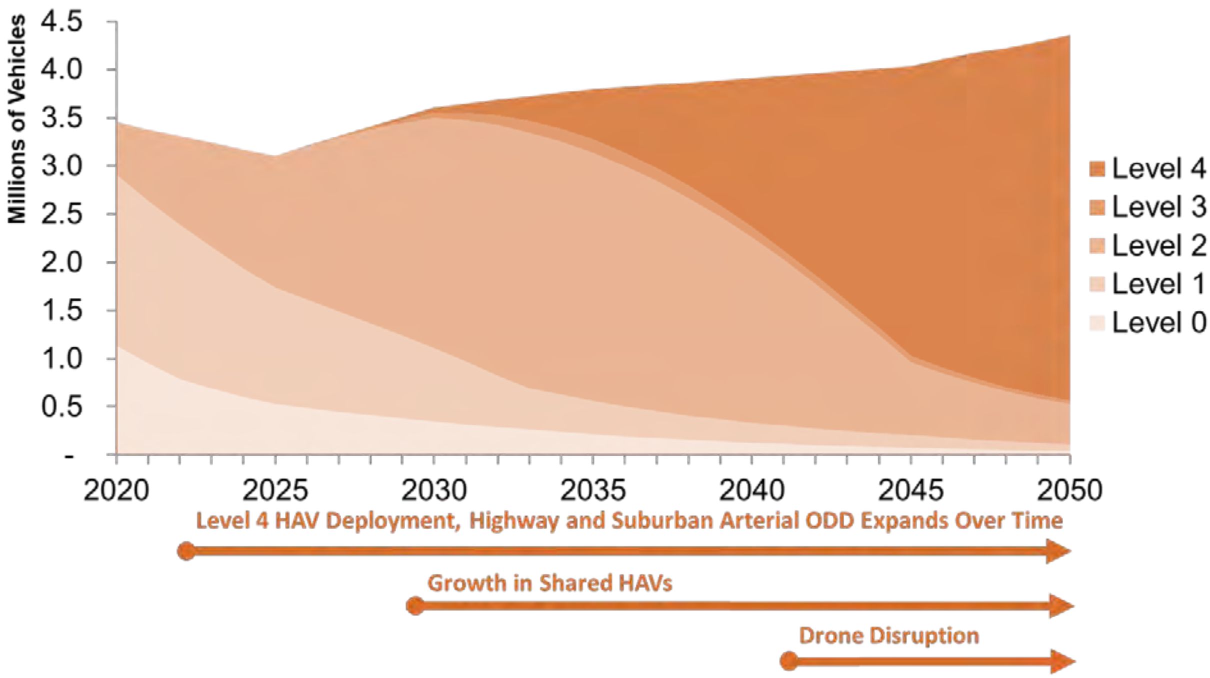
[59] "COVID-19 AVs & Shared Mobility Implications."

but lack of standardization means that not all systems can communicate with each other and many vehicles are not connected. Safety and security concerns affect travel behavior for specific groups, such as women avoiding nighttime trips or reduced willingness to use shared mobility because it is seen as less safe. Critics contend that safety comes second to private-market profits.

Figure 10. Technology in the Driver's Seat AV Pathways



Source: DVRPC, 2020.

Gridlock grows with VMT increases, particularly in suburban locations where Level 4 ODDs cover the most area. Transportation revenues move to congestion pricing in hopes of curtailing congestion and emissions, while generating badly needed funding for infrastructure. Congestion pricing is initially successful in reducing congestion and gains increased public support. However, VMT starts to increase as EVs and HAVs bring down the cost of transportation, and inflation reduces the fiscal impact of the highest allowable per-mile charges. As a result, congestion pricing becomes less effective in managing roadway demand over time, as politicians are unable to come to agreement on raising the maximum rates. This situation is worsened as revenues are used to significantly expand roads and maintain higher-order facilities that pay for themselves; while leaving many collector and local facilities in poor condition—particularly in low-income areas. These poor conditions create new first-mile and last-mile challenges, especially for deliveries. There are growing calls to privatize the most potentially profitable roads, in order to better address maintenance and keep technologies up to date. This raises concern about public policies and planning practices, which are already seen as favoring HAVs over other road users.[60] As the use of public transit and other alternative modes decreases, they come to be seen as less necessary and pressure grows to divert funding from them to roadways.

[60] Litman, *Autonomous Vehicle Implementation Predictions*.

Advances in deep learning, and related techniques, helped to bring about Level 4 self-driving vehicles, but are unable to deliver Level 5 capabilities. The technology stalls as the market consolidates in a handful of large companies. By the 2040s, passenger electric vertical take-off and landing (eVTOL) services are undergoing trials so the Federal Aviation Administration can test regulations, policy, procedure, guidance, and training programs to support their operations. Never-the-less, the pace of regulation is largely seen as falling behind technological innovation.

Technology in the Driver's Seat HAV Deployment Outcomes

Increased investment in roads results in positive economic spillovers and network efficiency gains, such as lower costs for goods movement. New types of jobs emerge around the maintenance of HAVs and supporting technologies. Central to this economic expansion was the buildout of the Internet of Things (IoT)—including installation of public wi-fi networks, cameras, sensors, 5G networks, CV technology, and plug-in energy infrastructure along the nation's roads and parking lots—largely funded by the federal government. Investments in the IoT hope to overcome the long-term tradeoff between resilience and efficiency, and achieve them both at the same time.

Development patterns continue to recentralize until Level 4 HAVs start to become commonplace in the early 2030s, and lead to a shift to more decentralized land uses. The built environment is increasingly reshaped to accommodate HAV needs, to the detriment of other modes. As the population spreads out to areas where ODDs are most widely available, health and well-being suffer from decreased physical activity and people feel more isolated—despite increased mobility.[61]

Large e-commerce platforms become dominant across production, sales, and consumption.[62] These global corporations use data to dominate the economy, and automation to displace some jobs. They increasingly act as rentiers by extracting value out of other market participants, and work to choke off threats from new innovation. Increased use of technology in the economy requires more workforce skills. Workers increasingly telecommute and share office space. There are fewer nine-to-five schedules—reducing peak-hour demand on the transportation network.[63]

While the early phases of AV development had a myriad of different players, industry consolidation began as soon as vehicles started to be deployed at scale on the nation's roads and highways. By the 2030s, a few large, monopolistic companies dominate the industry. Increasingly, a single company offers a variety of different shared mobility options in exchange for a monthly subscription. These services operate as walled gardens, where a monthly payment pays for a fixed amount of travel on a variety of modes, including forms of transit-like shared mobility. They don't integrate with services offered by other companies, effectively limiting the options that consumers have in getting around. Mega MaaS providers import the Internet business model, bombarding riders with ads and collecting every possible bit of personal data.[64] They also offer some free rides in exchange for watching advertising or ordering something from either a physical or virtual merchant, and frequently undertake deceptive, shady, and underhanded practices.[65]

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[61] Townsend, "Fables of the Driverless Revolution."

[62] National Academies of Sciences, Engineering, and Medicine, *Socioeconomic Impacts of Automated and Connected Vehicles* (Washington, DC: National Academies Press, 2018) www.nap.edu/25359.

[63] DuPuis et al., *City of the Future: Technology and Mobility*.

[64] Anthony Townsend, "Ghost Road: Beyond the Driverless Car," *C-SPAN2 BookTV* (webinar), May 31, 2020, www.c-span.org/video/?472840-1/ghost-road (accessed August 13, 2020).

[65] David Roberts, "Here's the Real Nightmare Scenario for Self-Driving Cars," *Vox*, March 27, 2018, www.vox.com/energy-and-environment/2018/3/27/17163264/autonomous-car-self-driving-advertising-business (accessed April 16, 2018); and Rohit Chopra and Sam Gill, "Techlash/Tech Policy: A Look at What's Next," *Gallup and Knight Foundation* (webinar), June 9, 2020.

Drivers prove unwilling to pay for significant costs for HAVs that they still have to drive in many instances and continuously monitor in others. HAVs grow more as shared-ride services than through personal ownership as a result. Transit and shared mobility begin to blur together as the private market offers more and more transit-like services. Private-market MaaS providers dictate terms for integrating with transit. Critics contend this is intended to siphon away transit users. While overall transit ridership is up, the private market is crowding out public transit services, despite higher prices. With ridership on public transit down, its long-term viability is threatened. This raises major questions about transportation equity if and when services are cut. Pedestrians and cyclists have been banned from some facilities to reduce conflict with HAVs.

Package delivery has become so inexpensive that retailers send packages to households that they didn't order—a retail form of spam—and if it isn't wanted they simply send it back.[66] More e-commerce adds convenience; but increases noise and air pollution, and off-peak delivery vehicles all negatively impacting quality-of-life in urban areas.[67] Residential areas under-equipped for automated delivery are becoming delivery deserts, worsening the effects of long-standing lack of access to retail and fresh, healthy food.[68] In the winner-take-all digital economy, smaller shared mobility and freight logistics firms with less access to data, have a harder time attracting riders and participating within the supply chain.[69]

HAVs increase mobility—and traffic volumes—for those living in rural and suburban areas within their ODDs, and decrease energy consumption and air pollution through EV drivetrains. Use of congestion pricing, AI, and other technologies help to better regulate and control traffic flow and increase road capacity. New and widened roads start appearing throughout the region, thanks to additional transportation demand from HAVs and revenue generated by congestion pricing. West Philadelphia's High-Line is repurposed as an HAV-highway by day, while still getting use by freight trains during the night. This is critical to supporting the massive new Schuylkill Yards development near 30th Street Station in Philadelphia. The private market also tries its hand in developing new underground HAV tunnels, but the high tolls needed to support their development and operation combined with the need for higher level automation to use them limits their market. These facilities struggle to generate enough use, and often require public bailouts. In some instances, they are handed over to the public sector for management.

By the 2040s, Universal Basic Incomes (UBIs) are substituting for hard to come by well-paid work. The UBI meets basic life needs, but critics contend they are largely intended to prop up corporate profits and help sustain the existing economic order. There is a sharper contrast between *haves* and *have nots* than ever before—based on who controls the algorithms and data that largely define daily life. HAV technology is expensive and not designed to be equitable. Higher-income households are more likely to own a HAV, which are marketed as luxury goods. The technology goes where there is money and demand, not necessarily places with the greatest needs—such as rural or low-income areas. Wealthier residents spread out from Center City intensifying gentrification in other areas of the region. This pushes low-income individuals further behind. Less well-off individuals already have the least access to opportunity and employment, and are likely to

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[66] "Life After Lockdown: Learning from Asia's All-Delivery Future," *CoMotion Live* (webinar), June 10, 2020, www.us02web.zoom.us/rec/play/7pckdu6t-D43S9HAuASDC6N5W460K_isgCkW-vEKmUrmWnkFOgbyZLNDYLbTmsx8VyRdg8kR31W7iXQF (accessed June 20, 2020).
[67] "Life After Lockdown: Learning from Asia's All-Delivery Future."
[68] "Life After Lockdown: Learning from Asia's All-Delivery Future."
[69] "Life After Lockdown: Learning from Asia's All-Delivery Future."

be highly impacted by climate change, and are also technology poor. Low-income areas and less technologically-savvy groups and individuals are less receptive to HAVs. HAV crash rate declines are greater in middle to upper class socioeconomic communities based on who has access to safer vehicles and/or those with higher levels of automation capabilities. Congestion pricing further exacerbates income inequality, particularly when it is reinvested in roadways and not into transit service and other lower-cost alternative modes such as walking and biking.

Vehicles, appliances, and lighting all become more efficient and more energy is created by solar, wind, and other clean energy sources. However, many HAV trucks continue to be powered by fossil fuels, offsetting some of the GHG emission reduction gains from EVs. Even so, there is an ongoing rise in atmospheric GHG due to increased consumption of all kinds of resources creating economic, societal, and environmental risks. In addition, electronic equipment lifespans remain short, leading to a deluge of e-waste.

While transportation data is increasingly plentiful, few companies are sharing data and little restrictions have been put on its use. This creates a variety of concerns:[70]

- Privileged social groups receive priority treatment, while everyone else often has to accept longer trips and travel times or surrender more personal data. This data is sometimes used for profiling purposes.
  - Service providers find additional business opportunities with the data they collect.
  - The elderly, children, and individuals with disabilities have been shown to have less transportation access in comparison to the general population.
  - The less well-off generally have to surrender more personal data, to provide more revenue to commercial services.
- Individuals concerned about privacy have been shown to reduce their travel activity due to less trust in the transportation system.
- Service providers collect massive amounts of data from their customers. There is not an anonymity or privacy guarantee available to consumers.
- Information and data are made available based on the users' ability to pay.[71]
- HAVs are used to collect more and increasingly sensitive private information, held as proprietary information, and used for commercial or societal control purposes.[72]
  - Very little of this data is made openly accessible to everyone or shared with public agencies—even data about HAV operating conditions and crash-contributing factors.

The lack of a strong data-rights infrastructure raises concern about the survival of an open and democratic society.[73] Cybersecurity services are thriving as they help to combat the privacy and hacking threats that emerge within the lightly regulated transport marketplace.

There is a fundamental change in the willingness to travel with increased trip lengths—due to Level 4 HAVs and EVs. At the same time, ubiquitous augmented reality and hologram technologies decrease the need to travel, especially for work. Level 5 HAVs remain out of technological reach, and still have not appeared on the region's streets by midcentury. With congestion getting worse, and Level 4 HAV functionality still somewhat limited, electric vertical take-off and landing vehicles

[70] National Academies of Sciences, Engineering, and Medicine, *Socioeconomic Impacts of Automated and Connected Vehicles.*
[71] Litman, *Autonomous Vehicle Implementation Predictions*.
[72] Litman, *Autonomous Vehicle Implementation Predictions*.
[73] Martin Tisne, "It's Time for a Bill of Data Rights," *MIT Technology Review*, December 14, 2018, www.technologyreview.com/s/612588/its-time-for-a-bill-of-data-rights/ (accessed December 17, 2018).

(eVTOL) begin to offer passenger services, threatening to disrupt HAVs before they achieve their full implementation. As congestion and infrastructure conditions hold HAVs back, automated eVTOL vehicles begin to disrupt the disruptor. eVTOL vehicles can pick up and drop off passengers at designated landing sites, called vertiports. Since they use electric propulsion, they do not have operational emissions and are quiet enough not to cause a disturbance. However, there are concerns that these operations will result in further loss of privacy, particularly when eVTOL vehicles fly over private property. There are also the questions of safety, particularly if vehicles fall out of the sky; affordability, which could raise more concern about growing inequality; and the visual effect of vehicles taking off, landing, and traveling in the sky. By making transportation work in all three dimensions, eVTOL services can bypass the worsening gridlock on the ground.

With more travel occurring in enclosed metal boxes, there is less and less life on the street.[74] As urban areas become even more auto-oriented, carmakers and technologists failed to learn from previous planning mistakes, which causes a full range of negative societal and environmental consequences.[75] In particular, as dispersed low-rise communities have replaced fixed, vertical cities, HAVs are steering us into a cul-de-sac with nowhere to go.[76] Serendipity and chance encounters—a major source of knowledge transfer and creative activity, and once routinely the best part of a day—now rarely happens.[77]

Inclusive Tech

In **Inclusive Tech**, a collaborative, networked, open source economy of abundance emerges from societal efforts to make technological advances more sustainable and equitable. The vision for transportation is to create an integrated, multimodal MaaS network that aims to achieve a Vision Zero goal of no traffic fatalities or serious injuries. Figure 11 highlights some of the key developing news stories for AVs and transportation in Inclusive Tech.

Figure 11. Inclusive Tech Developing News Stories

Year	How it Started	Year	How it's Going
2022	ADAPT Act Puts U.S. DOT in Charge of Guiding Highly Automated Vehicle Development	2027	Wide-Range of Safe, Non-Polluting Highly Automated Vehicles Hitting the Road
2022	ACT-ICE Act Creates Carbon Tax, Will Fund Transportation Infrastructure and More	2036	Push for Programmable Roads as Carbon Tax Dwindles
2026	Robotic "Road Butlers" Coming to Crash-Prone North Philly	2041	Vision Zero Safety Culture Changing How We View Risk and Priorities Across Society

Source: DVRPC, 2020.

Inclusive Tech Socioeconomic Overview

Technology is increasingly recognized as the hidden hand guiding the market. The capitalist system is being disrupted and the economy is increasingly directed by computerization, IT, Big Data, algorithms, automation, AI, and robotics; along with a handful of highly-skilled, technocratic human

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[74] Chenoe Hart, "Perpetual Motion Machines," *Real Life Magazine*, August 31, 2016, www.reallifemag.com/perpetual-motion-machines/ (accessed November 18, 2018).
[75] Hart, "Perpetual Motion Machines."
[76] Hart, "Perpetual Motion Machines."
[77] Hart, "Perpetual Motion Machines."

overseers. Digital fabrication democratizes the means of production, reducing scarcity and deconcentrating economic power, and allowing more people to work for themselves.

Healthcare technologies are dramatically extending lifespans, and 22 percent of the region's population is over 65 by 2050. Households become more self-sufficient, thanks to 3-D printing, though birthrates fall as more adults are caring for multiple older generations. People increasingly value experiences while the economy of abundance has counterintuitively reduced how acquisitive people are for goods, large and small. Job opportunities are becoming more limited, increasing by just five percent between 2015 and 2050 as technology does more and more of our work for us. Population movement has slowed around the world—though many of those who are able to are choosing to locate in smaller regions with good access to nature and outdoor recreation. The region's population continues to grow slowly as a result, up by just eight percent between 2015 and 2050. As work weeks shorten and people travel less for their job, they have more free time to use all portions of the transportation system and travel more than ever—even as different modes increasingly blur together into an integrated network. Walking and biking (+17 percent), transit ridership (+31 percent), and VMT (+21 percent) have all grown at much faster rates than jobs or population. While MaaS is fast becoming the primary way to get around, people are holding onto vehicles specialized for their needs, and the region's vehicle fleet has increased by +13 percent—more than population or jobs—despite the growth in shared mobility.

Inclusive Tech HAV Deployment

The COVID-19 crisis accelerates the move toward decentralized production and household autonomy. Working from home more or less becomes permanent in the wake of the pandemic.

Transportation activists help to bring about the 2022 Accelerating the Deployment of Automated Passenger-vehicles and Trucks (ADAPT) Act, which enables the U.S. DOT to guide transportation innovation. While not picking a specific technology or mode, it sets strong standards and leverages private-market funds for the reduction of fatalities and GHG emissions from the transportation sector—setting ambitious goals to reduce both to zero backed up by funding, attention, resources, and expertise. It committed to building out CV technologies that help vehicles communicate with other vehicles, infrastructure, and other things. It develops a gated certification process that includes putting automated vehicle hardware and software through objective safety criteria, simulations, road tests, and third-party review. It created guidelines to anthropomorphize vehicles, so they can better communicate with human road users and it set data and wireless communication standards for all vehicles.

Rather than using automated technologies to simply upgrade the car, the federal government sponsored a series of challenges to see how transportation and vehicles can be reinvented to better meet human needs. These challenges led to the emergence of all kinds of new low-emission vehicles. Government regulations are used to spur sustainable and equitable technological innovations, with a high carbon tax helping to provide further incentive. While critics contend that these regulations slow HAV deployment, manufacturers responded to the mandate by providing a variety of highly efficient, non-polluting vehicles.

The application of open source principles allows groups to collaboratively solve each problem only once, helping to advance Level 4 HAVs and the growth of a MaaS network.[78] Open source HAV

[78] "Open Source World," *Ted Radio Hour*, November 15, 2019, www.npr.org/programs/ted-radio-hour/?showDate=2019-11-15 (accessed November 19, 2019).

developers, such as Comma.ai, and non-profits, including public transit—which increasingly serves as the backbone of the transportation network—are among the most successful providers. An open source backend platform is accessible to any entity that wants to provide a front-end app connected to the MaaS network. A wide variety of HAVs, which look and function very differently from conventional cars and trucks start hitting the road in the late 2020s:

- Delivery Bots – small robots that travel along sidewalks at slow speeds, often delivering just a single package.[79]
- Kiosk Bots – similar concept to an Amazon locker, but they come to you and are particularly useful for returns.[80]
- Bus and Truck Platoons – use connected and automated technology to link a group of two or more buses or trucks together and let them travel in a convoy.
- Self-Balancing Automated Scooters – these devices roll on two wheels and can't be knocked over, even when rammed at high speeds.[81]
- Automated Shuttles – small 10 – 12 passenger vehicles that offer service in a loop connecting to mainline transit rail and bus rapid transit services as a first-mile and last-mile to transit solution.[82]
- Automated Pods – small, single passenger microvehicles that can be hailed on demand or hopped into at a multimodal transportation hub.[83]
- Self-Driving e-Bikes – can pick you up on demand, steer you to your destination, and then properly dock themselves.[84]
- Walking Cars – have legs that fold up inside the chassis, which can extend to transverse uneven terrain, move in any direction, and perform specialized and emergency response tasks.[85]
- Self-driving Hoverchairs – one of the few legalized uses for personal drone technology, these chairs can levitate over the ground, helping to overcome many Americans with Disabilities Act (ADA) challenges that remain in the built environment.[86]
- Rooms on Wheels – these vehicles have all-glass partition walls and are used as roving hotel rooms, office space, doctor's offices, mobile restaurants, shops, and in other ways.[87]
- Self-driving Microhouses – rolling high-tech, space efficient houses that some people live in full time, others use for itinerant work purposes, and still others use to travel around the country while on sabbatical or as part of their retirement.

What's really surprising is how unremarkable it is to travel in these vehicles. When individuals experience them the first time, there's some general excitement, but after just a few rides, HAVs feel more utilitarian, like a horizontal elevator, than anything particularly glamorous.[88] Figure 12 shows the progression of the region's vehicle fleet by SAE automation levels over time in Inclusive Tech along with key events shaping HAV deployment in this scenario.

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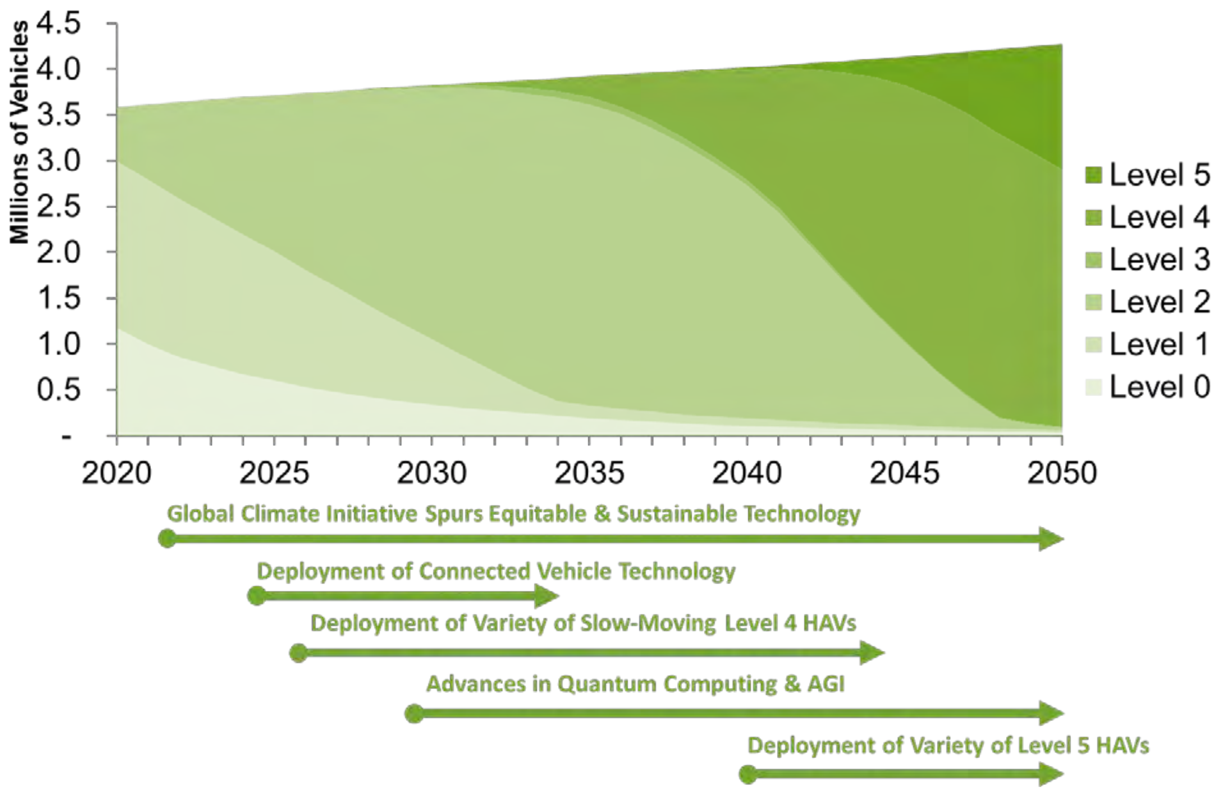
[79] Townsend, "Fables of the Driverless Revolution."
[80] Townsend, "Fables of the Driverless Revolution."
[81] Townsend, "Fables of the Driverless Revolution."
[82] Townsend, "Fables of the Driverless Revolution."
[83] Townsend, "Fables of the Driverless Revolution."
[84] Townsend, "Fables of the Driverless Revolution."
[85] Henry Payne, "Hyundai Green-Lights Development of a 'Walking Car' With 4 Dog-like Legs," *The Detroit News*, October 7, 2020, www.detroitnews.com/story/business/autos/foreign/2020/10/08/hyundai-green-lights-development-walking-car-four-dog-like-legs/5913689002 (accessed October 15, 2020).
[86] Townsend, "Fables of the Driverless Revolution."
[87] Elizabeth Stinson, "Ideo Imagines the Wild Future of Self-Driving Cars," *Wired*, November 11, 2014, www.wired.com/2014/11/ideo-imagines-self-driving-cars/ (accessed August 21, 2018).
[88] Litman, *Autonomous Vehicle Implementation Predictions*.

Figure 12. Inclusive Tech AV Pathways



Source: DVRPC, 2020.

Safety culture—which refers to how organizations and society view crash risk and prioritize road safety in decision-making—takes root throughout society. This creates more consumer demand for safety and leads to a virtuous cycle of ever-increasing carefulness. Government investments help to widely deploy CV technology along major roadway facilities in advance of HAVs hitting the road. This benefits safety and allows HAVs to develop in a highly cooperative environment. Enhanced traffic management systems improve traffic flow, reduce the potential for human error on roads, and help avoid secondary and tertiary collisions. CVs transmit real-time location, speed, and other data to traffic management systems that are significantly more precise and in-depth than what are currently available.[89] Connected technologies manage all traffic that is motorized and robotized, and utilize AGI to manage the huge database and computational requirements. Technology is critical to enhancing safety, as many traditional traffic calming techniques need to be rethought due to the changing nature of vehicle design and the wide variety of vehicle types on the road.

Most HAVs have programmed in a high level of cautiousness and courtesy as a result of federal government directives and safety standards. However, speed differentials between the wide variety of different modes and vehicle types within the same space creates safety risks, adds challenges in communications between different classes of HAVs, non-HAVs, and non-motorized users, and increases complexity and unpredictability. Road butler robots are deployed to help protect vulnerable road users from errant vehicles, whether they are ADS or human-driven, and also address non-transportation issues alongside roads. Most critically, they communicate with CVs to

[89] Federal Highway Administration, *The Smart/Connected City and its Implications for Connected Transportation* (Washington, DC: U.S. Department of Transportation, 2014) www.its.dot.gov/itspac/Dec2014/Smart_Connected_City_FINAL_111314.pdf.

completely and objectively detect all bikes, pedestrians, and animals without requiring a transponder or potentially costly and invasive technology just to be in public space. By the 2030s, it is clear, though, that roads need to be more programmable in order to help facilitate all the different movements on them in real time. Unfortunately, this occurs as carbon tax revenues are in steep decline, prompting the need to once again rethink transportation funding.

Dual-use freight and passenger business models emerge with positive impacts to safety and the environment, which leads to high public acceptance.[90] Goods movement is increasingly automated, while boundaries between firms are breaking down thanks to an open supply web managed by sophisticated data analytics and algorithms. This enables companies to ship products in real time using the most efficient manner possible, while vastly reducing the need for warehouse space.

Federal government research and development investments leads to major breakthroughs in quantum computing and AGI. This paves the way for Level 5 HAVs that can finally take a passenger between any two points without the need for human driver intervention starting in the early 2040s.

Inclusive Tech HAV Deployment Outcomes

The 2022 Accelerating Clean Technology Innovation for Climate and Equity (ACT-ICE) Act uses innovation to reduce GHG emissions, and leverage what its proponents hope to be considerable private funds, while avoiding favoritism toward a specific technology. It takes a three-pronged approach: first, through subsidies and low-interest government financing for carbon-neutral technologies; second, increasing regulation on goods and services to further stimulate investment around climate, equity, and health concerns; and third, by applying a carbon tax—set at a well above market rate of $150 per ton to price in risk—as a way to both fund investments and stimulate innovation.[91] Revenue from the carbon tax directly funds the subsidies for innovative technological advances toward carbon-neutral buildings, manufacturing, energy generation, transportation, agriculture, and other sectors. Carbon tax revenues are also used for building low-carbon infrastructure, such as EV charging stations, and for workforce retraining programs.[92] Last, they fund investments in environmental protection and the expansion of biodiversity, helping to prevent future pandemics.[93] Carbon tax revenues are used as a new source of funding for transportation infrastructure. This leads to much higher revenues throughout the 2020s, but funds start to taper off as carbon emissions quickly plummet. This creates new funding challenges to continuously update and maintain infrastructure in order to keep up with technological changes.

Despite government efforts to level the playing field, HAVs are still somewhat less affordable and available to low-income and minority communities—both in terms of ownership and access to shared mobility services. As a result, there are more older and less-safe vehicles in low-income neighborhoods. Though progress has been made, the technology still hasn't fully met the goal of improving access to jobs and services for the most vulnerable population groups.

The ACT-ICE Act creates a locally administered Community Jobs Program (CJP) that offers public service work to anyone who wants it. ACT-ICE enables the public sector to increase education funding and modernize curriculums, pay caretakers for their work and individuals for their data, and

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[90] National Academies of Sciences, Engineering, and Medicine, *Socioeconomic Impacts of Automated and Connected Vehicles*.
[91] David Roberts, "Greta Thunberg Is Right: It's Time to Haul Ass on Climate Change," *Vox*, October 4, 2019, www.vox.com/energy-and-environment/2019/10/4/20896541/greta-thunberg-panic-carbon-tax-price (accessed October 14, 2019).
[92] Roberts, "Greta Thunberg Is Right."
[93] Abraham Lustgarten, "How Climate Change is Contributing to Skyrocketing Rates of Infectious Disease," *ProPublica*, May 7, 2020, www.propublica.org/article/climate-infectious-diseases (accessed May 8, 2020).

work to broaden capital ownership. The Act also developed a national Climate Communications Network app to help individuals prepare for, and respond to, emergencies; and gently nudge more sustainable behavior.

ACT-ICE stimulates advances in nuclear fusion, leading to the expansion of a plentiful and clean, carbon-free energy source. This helps to facilitate a rapid uptake of EVs, and causes global demand for oil to peak in the late-2020s. The growth of rapid battery-swapping services makes recharging a vehicle as fast and easy as filling an old ICE-powered car with a tank of gasoline. Even as they are retired from service in EVs, large numbers of batteries are repurposed in residential and commercial applications.[94] This is critical to obtaining enough low-carbon energy to power the computing systems that Level 5 HAV systems need.

A federal 'Data Bill of Rights' (DBR), has major implications for the 2020s and beyond. The DBR attempts to thread the needle between protecting individual privacy and allowing for the collection and sharing of data, by enshrining the following principles.[95]

- The purpose of data is to enrich individual lives.
- It is up to the individual to decide what experiences should be captured with data.
- The individual is the sole arbitrator for how the data is used and/or shared.
- The right of the people to be secure against unreasonable surveillance shall not be violated.
- No person shall have his or her behavior surreptitiously manipulated.
- No person shall be unfairly discriminated against on the basis of data.

The DBR offers micropayments for those willing to be data generators.[96] Data-rights infrastructure also includes: boards, data cooperatives (which could enable collective action and advocate for users), ethical data certification programs, specialized data-rights litigators and auditors, and data representatives who serve as fiduciaries for the public with the ability to parse the complex impacts that data can have.[97] There have been challenges along the way, particularly as small details get implemented.[98] The DBR helps ensure data security for the transportation network.

People have more free time as work weeks begin to shorten in the 2030s. Those with means take frequent, short trips to Instagram-worthy travel destinations while remotely participating in the gig economy. It is challenging for some people to find fulfillment. Many others are finding new ways to enjoy their time by volunteering and being active in their community. Everyone is encouraged to take a two-week mental health break each year. Month-long Ashram residencies, Buddhist retreats, and wilderness adventures have also become popular for those looking for purpose.

As demand for office space declines, skyscrapers are being targeted by artists, similar to how they once moved into abandoned factory and warehouse buildings.[99] Those who take advantage of

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[94] Colin McKerracher, Stefan Knupfer, Itamar Orlandi, Jan Tijs Nijssen, Michale Wilshire, Erik Hannon, Swarna Ramanathan, and Surya Ramkumar, *An Integrated Perspective on the Future of Mobility* (London: McKinsey and Co. and Bloomberg New Energy Finance, October 2016) www.mckinsey.com/~/media/mckinsey/business%20functions/sustainability%20and%20resource%20productivity/our%20insights/an%20integrated%20perspective%20on%20the%20future%20of%20mobility/an-integrated-perspective-on-the-future-of-mobility.ashx.

[95] Shoshana Zuboff, *The Age of Surveillance Capitalism: The Fight for a Human Future at the New Frontier of Power* (New York, NY: Public Affairs, 2018); and Martin Tisne, "It's Time for a Bill of Data Rights."

[96] Tisne, "It's Time for a Bill of Data Rights."

[97] Tisne, "It's Time for a Bill of Data Rights."

[98] Tisne, "It's Time for a Bill of Data Rights."

[99] Levinson, "What Happened to Traffic?"

shared mobility options are more able to live car-free. If they have unused garage space as a result, they can convert it to workshops, small stores, or accessory dwelling units.[100] Despite there being more vehicles in the region, increased efficiencies have enabled some parking facilities and on-street spaces to be redeveloped. Nature and natural functions are being embedded into the fabric of our communities as they never have before. For example, miniature forests are planted on brownfield sites using a wide variety of native plants, which are allowed to grow quickly with minimal intervention.[101] This produces resilient and diverse ecosystems that can mature in as few as 20 years, absorb carbon dioxide, and act as an oasis for biodiversity.[102] These green urban spaces improve mental health, reduce air pollution, and counter urban heat islands.[103]

Self-driving microhouses are a combination of tiny homes and HAVs, which are often 3D printed using recycled materials. They provide an unprecedented low-cost housing option and prove popular with retirees and those on job sabbaticals who want to travel around the country. They allow workers to relocate as work opportunities arise and help to quickly evacuate in emergency situations—although road operators are concerned about how much road space they require. Urban areas experiment with high-rise rental spaces for these self-driving microhomes. They consist of a skeletal structure built around an elevator and emergency stairway shaft and holding pens for the unit. Mechanical arms automatically move the microhouses to an available dock.

AGI is employed to protect critical infrastructure, and defend against cyberattacks and network intrusions in the early 2040s. As wireless and cellular connectivity becomes central to transportation network operations, there is increasing vigilance on keeping these networks up and operating all the time, and more risk whenever they do go offline. There are concerns about growing dependence on technology, which could have serious consequences from cascading system failures, and the decline of all kinds of workforce and other skills from disuse.

A fundamental change in the willingness to travel increases travel frequency and a greater proclivity to share space—due to shared mobility services, HAVs, and all kinds of new vehicle types. The decline in commuting reduces peak period transportation network overloads, while a variety of shared, readily available vehicles means that a right-sized version is on-hand for every trip, making the system far more space efficient. Vehicle sharing enables more people to forego car ownership. More types of vehicle types require additional road space or careful design, and increases infrastructure use, complexity, and cost. The network increasingly looks like the vision for on-demand MaaS, where all kinds of different modes are integrated into a network that can readily meet immediate and ongoing travel, information, and payment needs. HAV scooters, bikes, and other small, shared vehicles are likely to lower costs and, therefore, may be more affordable and accessible to a wider segment of the population. Collaborative governments help ensure infrastructure investment focuses on equity and communities of need in development, including more subsidies for low-income populations.

By the late 2040s, HAVs are upending our notions of space and time, with time becoming more of an organizing principle than space.[104] Distance is seen as a block of time put into the day's

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[100] Levinson, "What Happened to Traffic?"
[101] Alex Thornton, "People are Planting Tiny Urban Forests to Boost Biodiversity and Fight Climate Change," *World Economic Forum*, July 3, 2020, www.weforum.org/agenda/2020/07/tiny-urban-forests-miyawaki-biodiversity-carbon-capture (accessed August 16, 2020).
[102] Thornton, "People are Planting Tiny Urban Forests to Boost Biodiversity and Fight Climate Change."
[103] Thornton, "People are Planting Tiny Urban Forests to Boost Biodiversity and Fight Climate Change."
[104] Hart, "Perpetual Motion Machines."

schedule, and the most noteworthy part of each trip is watching the progress bar update.[105] The distinction between vehicles and buildings, static and mobile space, and transportation and destination is blurring together.[106] In the ultimate linking of transportation and land use, a new transportation system is emerging where trips are no longer fixed to a location, but instead involve the coordination of various moving parts in order to facilitate an exchange.[107] For example, instead of taking a customer to a coffee shop, software directs a mobile coffee shop to a customer.[108]

Signposts

Signposts are actions, events, or indicators with specific thresholds that can help to determine if the future is more closely following one scenario's track than the others. Crossing a signpost suggests that relevant adaptive actions should be taken for that specific future.

Delayed Expectations Signposts

Signposts for this scenario could include unsuccessful road-testing trials, major AV developers cutting back on research and development or even shutting down operations, and no efforts from the public sector to pick up development as the private market pulls back.

People Power Signposts

Signposts for this scenario could include unsuccessful road-testing trials, major AV developers cutting back on research and development or even shutting down operations, and the public sector stepping in to advance development as the private market pulls back.

Technology in the Driver's Seat Signposts

Signposts for this scenario include a rapid rollout of HAVs in advance of government and general public readiness, and a hands-off role for federal HAV regulations.

Inclusive Tech Signposts

Signposts for this scenario include major advances in other technologies, such as AGI and quantum computing, and the federal government actively using regulations to enhance HAV safety, sustainability, equitable access, and to meet other high-level societal goals.

[105] Hart, "Perpetual Motion Machines."
[106] Hart, "Perpetual Motion Machines."
[107] Hart, "Perpetual Motion Machines."
[108] Hart, "Perpetual Motion Machines."

III. Crafting a Vision for HAV Deployment

Vehicle automation clearly presents an opportunity for systemic change in the transportation network. There are many potential benefits: a safer, more convenient and environmentally friendly transportation system with lower costs, which enables society to more productively use two limited, but highly valuable, resources: space and time. However, the technology comes with some potentially significant risks. The last major system change, motorization, as detailed in the 'Redesigning the Transportation Network' section of Appendix C, provides many cautionary tales about applying technology in urban areas—particularly in redesigning cities around the technology and the loss of community function for streets.

The recent interest in urban living creates an opportunity to modify behavior away from being centered on the automobile, which is also critical for responding to climate change. A more multimodal network can provide health benefits through active transportation, enhanced safety, reduced travel costs, and increased social opportunity. Doing this will require dedicating additional space to bicycles, pedestrians, and transit; along with a major emphasis on achieving Vision Zero. Technology alone will not solve challenges such as climate change, Vision Zero road safety, and creating a more just and equitable society. Behavioral change is needed. For transportation, good urban design, economic rules and regulations that guide more sustainable and equitable technology and innovation, process changes, and institutional reforms can all help to drive the necessary transformations.

The region needs to articulate a clear vision for how it wants HAVs to be deployed. That vision should guide the strategies and policies developed to prepare for them. Some options to consider, (see also Figure 13):

- **Privately-Owned HAVs** – A continuation of the existing private vehicle ownership model.
- **Shared Motorized Mobility** – A move to a MaaS type model where vehicle trips are purchased through a monthly subscription service or for an individual trip instead of vehicle ownership.
- **Multimodal Shared Mobility Network** – A move to a MaaS type model where trips are purchased through a monthly subscription or individual trip using an app that helps determine the best available mode instead of vehicle ownership.
- **Active Mobility** – Prioritizes walking, biking, and conventional and automated transit as the primary modes of transportation, and using HAVs to fill in the gaps for trips that are harder to make on foot or bike, or by transit. HAVs can supplement peak period demand. For example, if demand for a bus service exceeds capacity, automated shuttles could help to meet the need.

Different parts of the region may have a different vision. If MaaS is a key part of the vision, governance options should also be considered. Three primary options have been identified with different entities taking on the lead role: a local government or regional or transit agency, the private market, or a non-profit or cooperative entity. A key component of a MaaS network is an app that ties together trip planning, booking, and payment. There are different models for setting this up, such as both the publicly facing front end and back-end database being created by either the public sector or the private market.[109] Another approach is to have a publicly developed back-end that different private market providers can interface with for the front end.[110]

Figure 13. Some Different Visions for the Future of Transportation

Individual Mobility

Motorized Mobility

Multimodal Mobility

Privately-Owned HAVs – A continuation of the existing private vehicle ownership model.

Pros
- Ease of mobility.
- Continued individual expression through ownership.

Cons
- No reduction in parking demand.
- Limited reduction in transportation costs.
- Limited active mobility.
- Continuation of auto-oriented development patterns.

Multimodal Shared Mobility Network – A MaaS model where travel is purchased through subscriptions or by trip and uses an app to determine the best available mode.

Pros
- Reduced parking demand.
- Potential for lower transportation costs.
- Support of multimodal development patterns.
- More active transportation and safety for all road users.

Cons
- Lower travel speeds.
- Longer travel times.

Shared Motorized Mobility – A MaaS model where vehicle trips are purchased through subscriptions or by trip instead of vehicle ownership.

Pros
- Reduced parking demand.
- Potential for lower transportation costs.

Cons
- Less active transportation.
- Continuation of auto-oriented development patterns.

Active Mobility – Prioritizes walking, biking, and conventional and automated transit; HAVs fill hard to make trip gaps and supplement peak period demand.

Pros
- Reduced parking demand.
- Lower transportation costs.
- More walkable communities.
- More active transportation and safety for all road users.
- Reduced greenhouse gas emissions and energy use.
- Less reliance on complex technologies.

Cons
- Lower travel speeds.
- Longer travel times.

Shared Mobility

DVRPC, 2020.

Three of the *Dispatches* scenarios align closely with these visions. People Power closely tracks Active Mobility; Technology in the Driver's Seat resembles a Shared Motorized Mobility future; and Inclusive Tech reflects a Multimodal Shared Mobility Network.

[109] *Being Mobility-as-a-Service (MaaS) Ready* (Washington, DC: American Public Transportation Association, June 2019) www.apta.com/wp-content/uploads/MaaS_European_Study_Mission-Final-Report_10-2019.pdf.
[110] *Being Mobility-as-a-Service (MaaS) Ready*.

IV. Strategies to Achieve the Vision for HAV Deployment

How HAVs operate and the type of externalities they create will largely depend on the public policies put in place to guide their development and eventual deployment—but there may be a limited window for this. Strong, well-designed regulations can spur innovation. When government and the private sector work together, new technologies can be better tested and brought to the market sooner. However, it will be challenging to update municipal ordinances well in advance of any actual HAV rollout, meaning the region could be caught reacting to the technology instead of proactively preparing for it. Given that most local governments have limited resources with which to prepare for HAVs, the federal government needs to take the lead.

Typically, each level of government has focused on different aspects of transportation system regulations. NHTSA has regulatory authority over vehicle safety. States register and title vehicles, license drivers, establish and enforce traffic laws, and regulate vehicle insurance.[111] Local governments have authority over traffic law enforcement and infrastructure they own and operate. However, HAVs may blur the boundaries in some of these regulations by taking the driver out of the equation.[112] NHTSA has cautioned against states regulating vehicle performance.[113] Regulations can avoid entangling current technologies by specifying automation level(s).

In moving forward to a world with automated vehicles, we must appreciate the risks of human driving. More than 40,000 people die each year on our nation's roadways, and 1.25 million die in car crashes around the world. This is one of the leading causes of death both domestically and globally. Given that human error impacts driving safety, governments should raise the safety bar across the board and should not uniquely burden ADSs.[114] While HAVs have the potential to improve safety and solve other problems, they increase future uncertainty in a myriad of ways and are likely to cause new, unintended consequences. Reduced speed limits—which can be the difference between dying in a crash and walking away from it—can both improve safety and mitigate against some of the quandaries that arise when machines start making moral decisions.

What's Already Happening in Greater Philadelphia

There is already a lot going on to prepare for vehicle automation in the region. PennDOT has undertaken a number of initiatives to help prepare for an automated transportation world. Other state agencies do have regulatory power over certain aspects of automated vehicles. For instance, the Public Utilities Commission will determine when AV testers can charge for rides. PennDOT initiatives include:

- **PennStart** is a partnership between PennDOT, the PA Turnpike, and Penn State that will build a state-of-the-art training and testing facility to address the transportation safety and operational needs of Pennsylvania and the Mid-Atlantic Region. The facility will focus on six areas: Traffic Incident Management, Connected and Automated Vehicles, ITS/Tolling/Traffic Signal Testing, Commercial Vehicles, Work Zones, and Transit Vehicles.

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[111] Hedlund, PhD, *Preparing for Automated Vehicles: Traffic Safety Issues for States*.
[112] Hedlund, PhD, *Preparing for Automated Vehicles: Traffic Safety Issues for States*.
[113] *Autonomous Vehicles: A Policy Preparation Guide* (Washington, DC: National League of Cities, n.d.) www.nlc.org/sites/default/files/2017-04/NLC%20AV%20Policy%20Prep%20Guide%20web.pdf.
[114] Bryant Walker Smith, *How Governments Can Promote Automated Driving*, New Mexico Law Review, forthcoming, March 17, 2016, www.papers.ssrn.com/sol3/papers.cfm?abstract_id=2749375.

PennDOT and NJ DOT Perspectives on HAV Testing and Deployment

Both of the region's DOTs have been following HAV development and are carefully preparing for their testing and eventual deployment.

Pennsylvania takes a unique approach to authorizing AV testing by focusing on operator safety training and the safety culture of a company rather than the technology in the vehicle. Regardless of how advanced the technology is, if a tester is focused on safety and their operators are properly trained, there will be multiple safety nets in case the ADS fails.

New Jersey encourages the safe testing and deployment of HAVs through a welcoming policy environment that fosters collaboration, promotes public acceptance of automation, uses technology to improve the efficiency of the State's transportation system, and enhances the lives of the state's residents, workers, and visitors by expanding travel options and making travel safer, easier, and more affordable for all.[115]

- **The SmartBelt Coalition** is a collaborative effort between Pennsylvania, Michigan, and Ohio to advance truck platooning, with future plans to advance work zone mapping and V-2-I connectivity. The focus of the coalition is to ensure consistency and interoperability across jurisdictional boundaries to support the deployment of connected and automated vehicles.
  - The coalition recently successfully demonstrated a multistate automated two-truck platoon operation that carried donated food between food banks in Pittsburgh, PA, Toledo, OH, and Detroit, MI.[116]
- PennDOT has developed a ***Statewide Connected and Automated Vehicle Strategic Plan***.
- Multiple **CV deployments at 54 signalized intersections**.
- **Pennsylvania legislation** passed for AVs and CVs:
  - Act 101 of 2016 enables PennDOT to use up to $40 million in Green Light Go funds on Intelligent Transportation Systems (ITS), such as AV- and CV-related technology, in addition to other specified uses.
  - Act 117 of 2018 set platoon operations policy, tasks PennDOT with establishing regulations for platooning, and allows platoons of up to three vehicles on the Commonwealth's highways.[117] No company has submitted a platoon operations plan to date.
  - Act 106 of 2020 amends Title 75 of the Pennsylvania Consolidated Statutes, to provide for personal delivery devices (PDDs), in order to enhance delivery options in response to the coronavirus pandemic. These vehicles can weigh up to 550 pounds without any cargo, and can operate on the sidewalk at speeds up to 12 mph or along the road or a shoulder at speeds up to 25 mph.
    - It requires PDD operators obtain authorization from PennDOT to operate that needs to be renewed annually and maintain liability insurance.

[115] Jon Carnegie and David Aimen, *New Jersey Autonomous Vehicle Task Force, Final Report* (New Brunswick, NJ: Alan M. Voorhees Transportation Center, March 2020) www.senatenj.com/uploads/NJ-AVTaskForceFinalReport_v03042020.pdf.
[116] Liz Carey, "Pennsylvania Coalition Gives Automated Truck Platooning Demonstration," *Transportation Today*, October 29, 2020, www.transportationtodaynews.com/news/20180-pennsylvania-coalition-gives-automated-truck-platooning-demonstration/ (accessed November 13, 2020).
[117] More information is available on PennDOT's website at www.penndot.gov/ProjectAndPrograms/ResearchandTesting/Autonomous%20_Vehicles/Pages/Platooning.aspx.

    - Phase I operations occur during the first 90 to 180 days of a new service and require an operator to be within 30 feet and in line of sight of the PDD. After that, Phase II allows for remote monitoring with the ability to override control from the automated system.
    - PDDs must follow basic rules for their operation in the commonwealth, including requirements that they obey the rules that govern pedestrian-use of sidewalks—waiting at crosswalks, and yielding to vehicular traffic and foot traffic in front of them.
    - The legislation sets requirements to enhance public safety, such as unique ID numbers, a braking system, visible lights, and other features to enhance the visibility and awareness of the PDDs.
- The Pennsylvania legislature has also proposed:
  - Senate Bill 1268 would amend Title 75 (Vehicles) of the Pennsylvania Consolidated Statutes to provide for controlled AV testing, but not operations; allow flexibility and adaptability to changing technology; require testing companies to apply and provide proof of $5 million in general liability insurance; and support in-vehicle and remote-operator testing for 'full self-driving automation.'
- PennDOT has hosted an **Annual Pennsylvania AV Summit** since 2017.
- PennDOT was one of eight awardees for the $8.5 million **Automated Driving Systems Demonstration grant**. This four-year program will investigate the integration of automated vehicles in work zones. PennDOT will test automated crash-truck attenuators.
- An **AV Task Force** has been meeting since 2016, and has released a report with recommendations for AV testing policies.
- An **HAV Advisory Committee** was formed by Act 117, which will provide an annual report on HAV activities in the state. The task force will:
  - Develop technical guidance.
  - Evaluate best practices.
  - Review existing laws, regulations, and policies.
  - Engage in continued research and evaluation of CV and AV systems technology necessary to ensure safe testing, deployment and continued innovation in the commonwealth.
- **AV Testing Guidance** is a living document developed with stakeholders and AV developers. Version 2.0 was recently released with additional requirements. Any tester planning to use Pennsylvania roadways to submit a *Notice of Testing Application*, which asks for:
  - Background information about the testing entity, vehicle information, driver safety information, and location where testing is expected to occur.
  - Applicants must acknowledge the testing will follow all applicable federal and state laws and regulations; vehicle(s) have been tested under controlled conditions for their ODD; are capable of complying with applicable traffic and motor vehicle laws and traffic control devices within their ODD; that a safety driver will be present, actively monitoring, and ready to take over whenever necessary; that there is an accessible mechanism to engage and disengage the ADS; that the HAV will record data before a crash, which will be made available to PennDOT and other law enforcement agencies upon request; that quality controls are deployed and monitored to ensure safe operation; and other acknowledgments.
  - The tester must have a 'safety and risk mitigation plan,' including an overview of the ODD, a description of the disengagement technology and how it complies with standards; safety driver background and driving history records; a description of the safety driver training programs; and ways to prevent driver fatigue, inattention, and carelessness.
  - Operational requirements, including different criteria for testers that will operate under 25 miles per hour (mph) and those that will operate over 25 mph. Those operating over 25 mph must have a secondary safety backup associate in the vehicle or an enhanced driver-

    training program, which allows operations over 25 mph with only one safety driver in the vehicle. To date, no tester can operate with only one driver in the vehicle.
    - Terms by which PennDOT can suspend or revoke testing authorization, particularly if the tester is deemed to pose an unreasonable risk to the public, along with a process for reinstatement; and reserving the right to temporarily restrict or prohibit testing on specific facilities if the circumstances warrant it.
    - Semi-annual data reporting requirements.
    - Crash reporting requirements.
    - Version 2.0 requires more information for first responders, identification of AV passengers, restrictions for commercial vehicles, and more detailed data and location reporting.
- The Pennsylvania statewide Traffic Incident Management (TIM) program, PennTIME, is currently developing an **AV Incident Response Plan**. It will include lessons learned in preparing to respond to AV crashes, safely moving vehicles and ensuring they remain stopped, how to tow, common consistency, and developing training programs.
- Pennsylvania is one of eight states participating in **U.S. DOT's Automated Vehicle Transparency and Engagement for Safe Testing (AV TEST) program**, which will hold a series of public events with nine AV companies aimed at improving transparency and safety of ADS development and testing. The initiative will also create a platform for federal, state, and local governments to share standardized data and information.
- A partnership between SEPTA, PennDOT, DVRPC, and the Philadelphia Authority for Industrial Development (PAID)—a public authority under Philadelphia Industrial Development Corporation (PIDC)—has applied for **an Advanced Transportation and Congestion Management Technologies Deployment Initiatives (ATCMTD) grant to retrofit a standard transit bus with autonomous capabilities.** PAID/PIDC is the lead applicant. If successful, this grant would allow the Navy Yard to operate their internal shuttles 24 hours per day, supporting investments in the shipyard and new residential development at the Navy Yard. The partnership proposes to use an electric bus and experiment with inductive, wireless charging.
    - A similar proposal submitted to FTA's Mobility on Demand (MOD) Sandbox in 2019.

As of September 2020, there were nine known AV testers operating in the Commonwealth: Argo.ai, Aptiv, Aurora, Carnegie Mellon, Locomotion, Motional, Plus.ai, Qualcomm, and Uber. Carnegie Mellon, Nvidia, Qualcomm, and Plus.ai are authorized to test in the Greater Philadelphia region.

In New Jersey, the following preparations are underway for HAVs:

- Governor Murphy signed Senate Joint Resolution 105 legislation into law in March 2019, creating the **New Jersey Advanced Automated Vehicle Task Force**. The Task Force is made up of 11 members, including the DOT Commissioner, the Chief Administrator of the Motor Vehicle Commission, the Director of the Division of Highway Traffic Safety, and eight individuals appointed by the governor, including one individual from the Board of Public Utilities, five members of the public, one member of the public recommended by the President of the Senate, and another recommended by the Speaker of the General Assembly.
    - The task force has produced a report to the legislature with recommendations for how the State can safely integrate AVs on public roadways.
- The **New Jersey Transportation Agency Partnership (NJTAP)** has completed the *New Jersey Connected and Automated Vehicle Strategic Plan*.
- **NJDOT is developing a strategic plan for connected and automated vehicles**.
    - Staff and consultants presented on this Plan at the 2019 Pennsylvania AV Summit.

There is currently no known AV testing being conducted in New Jersey.

Recommendations

The general public has not been meaningfully consulted on a vision for HAVs. Preparing Greater Philadelphia for HAVs requires setting a vision and goals for their deployment and use, and then make policy and investment decisions that support the vision—which should be consistent with the region's long-range plan and based on continuous and ongoing dialogue with a diverse group of regional citizens and stakeholders. At a minimum, the vision's goals should consider safety, equity, climate and environment, jobs and the economy, and community walkability and bikeability impacts. It then requires identifying performance measures that can track how well the region is doing toward achieving the vision. The entire process needs to be evaluated regularly, and then amended as needed based on the findings of each evaluation.

Advanced Mobility Partnership in Denver, CO

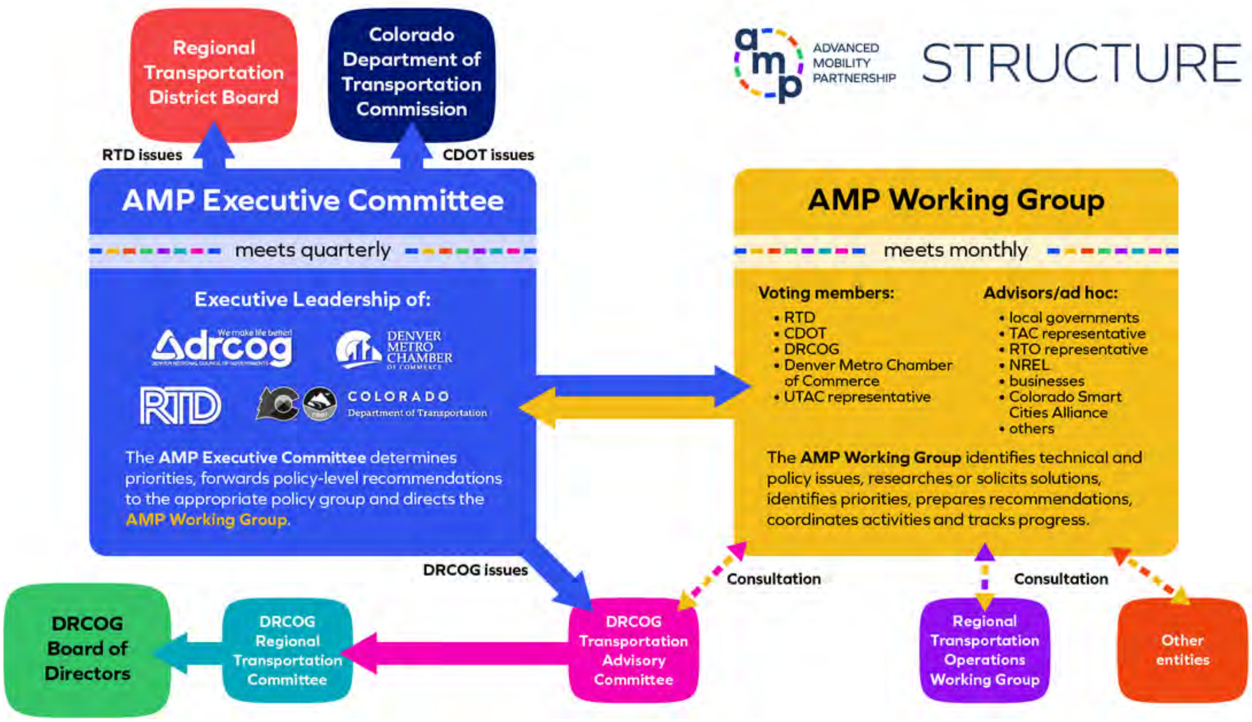
The Advanced Mobility Partnership (AMP) in Denver, CO brings together the region's MPO (DRCOG), transit provider (RTD), Colorado DOT, and the Chamber of Commerce to prepare for new transportation technologies. It was formed in 2019 based on a memorandum of understanding and has developed a *Mobility Choice Blueprint* to guide its work. The AMP has encouraged closer collaboration between the partners, and has given space for conversations about a regional vision for applying new transportation technologies. This ensures a coordinated planning process, instead of an individual agency ad-hoc one. It also centralizes dialogue with private-market actors and other public agencies conducting pilot projects—including a place to share results, findings, and lessons learned. The partners expect that the AMP will help strengthen applications for competitive funds.

The *Mobility Choice Blueprint* identified 34 tactical actions that the partners intend to pursue in order to improve transportation in the Denver region. While there are no employees working directly for the AMP, staff from each of the partner agencies meets as a working group each month, which is guided by an executive committee that meets each quarter and tracks progress on the tactical actions. The AMP has further prioritized 10 of its 34 tactical actions and has formed three steering committees around them. These three committees are system operations, shared mobility, and data and data sharing. Figure 14 illustrates the AMP governance structure.

Each of the agencies is pursuing projects related to AMP goals specific to its capabilities. For example, the Chamber of Commerce has strengths in policy development and private-market connections, particularly in bringing non-traditional tech companies to the table. Colorado DOT continues to lead preparations for HAVs and project implementation. RTD is exploring developing a shared mobility trip planning and fare payment app, creating a data sharing platform, and is working to integrate its services with private shared mobility providers. DRCOG undertakes transportation operations planning work, has a set aside in its Transportation Improvement Program (TIP) to fund projects that implement regional transportation operations and technologies, and helps facilitate many of the AMP's meetings and activities. The partnership is a test of how effectively public resources can be pooled in order to shape outcomes.

No single public agency has responsibility for all the actions needed to prepare Greater Philadelphia for HAVs. Many best practice recommendations are to find new ways to partner and collaborate across the public and private sectors than ever before. In light of this, the region should convene major agencies working on preparing for HAV deployment and other new technologies together to enable close collaboration through a new formal partnership on preparing for HAVs and deployment of other transportation technologies. Greater Denver's Advanced Mobility Partnership (AMP) can serve as a potential model for this. A 'Greater Philadelphia Advanced Mobility Partnership' could include PennDOT, NJ DOT, SEPTA, New Jersey Transit, DRPA-PATCO, the Greater Philadelphia Chamber of Commerce, and DVRPC. Additional working group level partners could include Department of Community and Economic Development, PIDC, counties, universities, and others. PIDC recently applied for an ATCMTD grant to operate an automated shuttle in the Navy Yard. Though it is a strong application, U.S. DOT prefers to award these projects to DOTs, cities, MPOs, transit authorities as the lead agency, or existing coalitions. A partnership could apply for federal grants and any member of the partnership could manage it, such as PIDC managing a shuttle service instead of SEPTA or the City of Philadelphia.

Figure 14. Advanced Mobility Partnership Governance Structure



Source: Advanced Mobility Partnership, 2018.

The AMP was informed and modeled on Smart Columbus, which emerged out of its 2016 win of the $50 million U.S. DOT Smart Cities Challenge. A major reason why Columbus won this grant was its plan for workforce training and using technology to improve connections from a low-income area, Linden, OH, to regional job opportunities. The grant enables Smart Columbus to have full-time staff working on three key issues: (1) setting up an open and integrated transportation operating system powered by EVs and CVs; (2) conducting demonstration projects that work closely with the public and transportation system users; and (3) embracing change by shifting minds and behaviors to improve the transportation ecosystem's ability to move people and goods.

The Greater Philadelphia commute shed extends over two states, nine counties, and more than 350 municipalities. Such a partnership could lead regional coordination efforts to ensure HAV interoperability across boundaries. Interoperability across all these jurisdictions will be critical to successfully rolling out HAVs. A partnership could coordinate actions taken to prepare for HAVs across federal, state, and local governments, and could include stakeholders and a diverse public in decision making processes. By including local transit agencies, the partnership could keep them informed on potential HAV-related infrastructure or policy changes that could affect the transit service and help make local governments aware of transit agency plans or ideas for deploying HAVs as part of their service. A partnership would need to determine the scope of its mission, as in whether it would specifically focus on HAVs or broader transportation technologies that could include CVs, EVs, shared mobility, and upgrading infrastructure. A broader approach may make sense given how interrelated these issues are. It could present an opportunity to think about multifunctional infrastructure delivery, and the potential use of air rights, co-development of different types of infrastructure, and other innovative approaches. Without such a partnership, the region’s transportation agencies are likely to have a much more difficult time in approaching issues in HAV deployment than in a united front that delivers the best outcomes for the public good.

A partnership could be tasked with working with the public to develop the vision and critical long-term universal and adaptive strategies to guide HAV deployment. Strategy development needs to consider short-term and medium-to-long term universal strategies that can work across a variety of potential HAV deployments; along with adaptive strategies that reflect different ways in which HAVs may be rolled out in the future. Given the uncertainties of HAV deployment, designing for the transportation needs of the future must address how a network may look and operate under conditions where Level 4 HAVs are operating on the region's streets within a year, but Level 5 HAVs may not appear for 50 or more years and consider a large range of plausible deployment scenarios in between. Identifying champions for a partnership within the executive-level agencies is critical to it being an effective change agent.

Appendix D develops an initial vision, set of related goals, and strategies to achieve the vision based on DVRPC’s *Connections 2045* Plan. The analysis starts to identify some potential longer-term and adaptive strategies geared toward specific futures, but there is still more research to be done. In lieu of a defined vision, there are many low-hanging fruit strategies that the region can begin implementing to prepare for HAV deployment. Many of these strategies have co-benefits that will still be useful even if HAVs don’t appear on the region’s roads before 2050. For instance, Vision Zero notes that speed is the top contributing factor to fatal crashes. A pedestrian struck by a vehicle at 20 mph has a 90 percent chance of surviving the collision, where one hit at 40 mph has just a 10 percent chance of surviving. Reduced speeds can help alleviate the concerns about HAVs making life or death decisions, by lowering the number of life and death situations in the first place.

- ☐ Study transportation technology actions from around the world and learn from best practices.
- ☐ Conduct extensive public engagement to raise awareness of, educate about, gather input on the vision for HAV deployment, and train on interacting with.
  - ▷ Work with state governments to advocate at the federal level for public input and involvement into the legislative process around HAVs.
  - ▷ Make extra effort to include communities with low-income, minority population groups, and areas with other potential disadvantages to identify their needs, preferences, ways that HAVs can improve access to opportunity and better quality of life, and develop policies consistent with these findings.
- ☐ Work with state DOTs on HAV plans and pilot projects for safe testing and deployment.
- ☐ Prioritize roadway state-of-good repair and maintenance and meet basic HAV infrastructure needs including: lane markings, standardized road signs, roadway geometry standards,

transportation systems management and operations, connected vehicle technologies, and work zone locations updated in real time.

- ▷ Follow forthcoming revisions to *The Manual on Uniform Traffic Control Devices* (MUTCD) and state guidance on roadway lane marking widths, broken line length and gaps, dotted lines on all exit and entrance ramps, and use chevrons to create clear demarcation of marked pavement areas where edge lines on highway mainline through lanes converge or diverge with ramp lanes.[118] Fully remove old lane markings and ensure that 'ghost' markings aren't left behind, potentially confusing AVs.

- ☐ Enhance safety by reducing speed limits for all vehicles, incorporating pedestrian- and bike-only phases into intersection controls, and pursuing other Vision Zero strategies.[119]
- ☐ Use governmental procurement power at all levels to advance EV, ADAS, and eventually HAV technologies.
- ☐ Expand shared mobility options and fully integrate them with transit.
  - ▷ Create mobility hubs that combine a transit station with carsharing, bikesharing, scooter sharing, and TNC and taxi pick-up and drop-off areas.
  - ▷ Dedicate curb space for pick-up and drop-off zones to ensure safe vehicle and building egress as more trips become door-to-door. Consider use of geofencing to improve curb management and pricing curb space. Measure use and program effectiveness, and use data to optimize space management.
  - ▷ Reduce or eliminate parking minimums in municipal zoning codes and encourage shared parking strategies.
  - ▷ Develop an open source digital, real-time multimodal travel information, booking, routing, and payment platform. This may consist of either a uniform backend server that is maintained by a public or nonprofit entity and accessible by any party that wants to connect to it; or a public or non-profit app that contains both the backend server and the public-facing frontend.
- ☐ Equitably distribute infrastructure and technology improvements across the region.
- ☐ Work with states to determine local government data needs.
  - ▷ Require all mobility service providers to collect and seamlessly share data in order to use it to enhance the transportation network's performance. Create open data standards for HAV operations and regulation with oversight and/or storage capabilities. Tie data sharing agreements to operating permits.
  - ▷ Build local government data management and processing capacity.
  - ▷ Identify who among law enforcement, insurers, and others should have access to ADS data, and how that access will be granted.
  - ▷ Track automation levels in state vehicle registration databases, on crash forms, and in other relevant records.

The private market isn't going to wait for the public sector to get organized to grant permissions. This creates urgency to act because decisions we collectively make—or don't make—now will determine what options are available to us in the future.

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[118] Robert Dingess, "Driverless Cars are Stuck in a Traffic Jam," *LinkedIn*, October 15, 2019, www.linkedin.com/posts/robert-dingess-3a851a6_driverless-cars-are-stuck-in-a-jam-activity-6588508664875880448-B8Ec (accessed October 15, 2019).
[119] National Association of City Transportation Officials, *Blueprint for Autonomous Urbanism* (New York, NY: National Association of City Transportation Officials, Fall 2017) www.nacto.org/publication/bau/blueprint-for-autonomous-urbanism/.

V. Conclusion

HAVs could someday, possibly very soon, be the biggest transformation in urban mobility since the rise of the automobile. Thus, it is critical to gain a better understanding of the technology and its implications. The goal of this report is to be informative about HAV development, different ways it could be deployed, and potential outcomes from deployment. One report alone will not be able to capture everything about HAV development, deployment, and outcomes from deployment. More understanding will be needed as the technology continues to evolve, along with its implications for transportation infrastructure and safety, community design, the economy, the environment, and other key aspects of society. From here, the region needs to start thinking about how to prepare for safe and effective HAV deployment. Continuing the dialogue around HAVs and how to respond to them would be best done through a partnership between key transportation agencies and their planning partners that meets regularly. Greater Denver's Advanced Mobility Partnership can serve as a potential model.

The degree of uncertainty surrounding HAVs make scenario planning a critical tool for analyzing and preparing for a range of potential impacts and outcomes. This report further utilized DVRPC's *Dispatches* scenarios to game out different ways HAVs could roll out and consider their broader implications. This will create major challenges and generate considerable debate over their merit and fairness. While these challenges are vast, there are pathways forward where HAVs offer the potential opportunity to greatly improve quality of life, equitable access to transportation and the opportunity that mobility brings, and environmental sustainability. However, it is unlikely that HAVs will yield these benefits on their own. Achieving these goals will require governments to work together in order to look out for the public good.

Successfully preparing Greater Philadelphia for HAVs will require setting a vision and goals for their deployment and use, and then make policy and investment decisions that support the vision—which should be consistent with the region's long-range plan and based on continuous and ongoing dialogue with a diverse group of regional stakeholders and citizens. At a minimum, the vision's goals should consider safety, equity, climate and environment, jobs and the economy, and community walkability and bikeability impacts. That vision should then guide the strategies and policies that are developed to prepare for them. Some key themes to choose from for developing a vision:

- **Privately-Owned HAVs** – a continuation of the existing private vehicle ownership model.
- **Shared Motorized Mobility** – A move to a MaaS type model where vehicle trips are purchased through a monthly subscription service or for an individual trip instead of vehicle ownership.
- **Multimodal Shared Mobility Network** – A move to a MaaS type model where trips are purchased through a monthly subscription or individual trip using an app that helps determine the best available mode instead of vehicle ownership.
- **Active Mobility** – prioritize walking, biking, and conventional and automated transit as the primary modes of transportation, and using HAVs to fill in the gaps for trips that are harder to make on foot or bike, or by transit. HAVs can supplement peak period demand.

Developing a vision and strategies highlights the need for transportation agencies to coordinate and collaborate in ways that go well beyond business as usual, which furthers the need to create new partnerships focused on technology deployment. This new advanced mobility partnership should be tasked with working with the public to develop the vision and critical long-term universal and adaptive strategies that guide regional HAV deployment. Appendix D in this report identifies a draft vision for HAV deployment consistent with the vision and goals of the *Connections 2045* Plan, which can be reacted to and refined by the public and key stakeholders. More public dialogue is needed to refine the vision and the strategies, particularly more outreach to low-income and Black and Brown communities that are often underrepresented in public engagement around transportation issues. The ultimate vision for HAV deployment and other emerging technologies should be consistent with DVRPC's long-range plan.

The vision should then guide strategy development. Appendix D also documents potential initial short-term and medium-to-long-term universal strategies that can be applied successfully across a variety of potential HAV deployments. Additionally, it proposes a series of adaptive strategies that reflect different ways in which HAVs may be rolled out in the future—based on the *Dispatches* scenarios and signposts for them that attempt to show if the future is heading in that direction. This effort should also identify performance measures that can track how well the region is doing toward achieving the vision. The entire process needs to be evaluated regularly, and then amended as needed based on the findings of each evaluation.

Even in lieu of a vision or more fully developed set of strategies, HAVs present an opportunity to more aggressively pursue short-term, low-regret actions that will be beneficial even if they do not become a reality during the lifetime of the long-range plan: focusing on a state-of-good repair for transportation infrastructure, dedicating lanes to bikes and high-capacity uses such as transit, creating more pedestrian-only areas, making communities more livable, and clearly delineating pavement markings. These investments are good regardless of whatever future comes about, while beginning to support potential HAV deployment. Given that, Greater Philadelphia should purse the short-term no- or low-regrets actions that build on its rich history of walkable, dense urban areas.

Learning from Alternate Futures

Scenario planning is an opportunity to learn from the future. Some key findings emerge from the individual scenarios and form common themes across scenarios.

- Delayed Expectations: will require finding solutions to big transportation problems without vehicle automation.
- People Power: will require political will and public investment to advance long-promised, but hard to deliver automated technologies.
- Technology in the Driver's Seat: The challenge is to not rush headlong into the future, but rather to do things deliberately by setting goals and taking incremental steps.
- Inclusive Tech: there will be considerable design challenges to adapting existing infrastructure to incorporate a wide variety of new vehicle types and travel speeds, and safely move all modes.

Some common themes that emerge across multiple scenarios:

- There is a good chance that Level 4 HAVs could arrive on the region's roads within the next five to ten years, and it's not out of the realm of possibility that they could arrive within a year. They are likely to be both owned and operated by private individuals much like the cars driven today, and operated in new shared mobility services. Getting to Level 5 HAVs remains technologically daunting, and they could be decades away from commercial readiness.[120]

- Many of the benefits associated with HAVs—such as improved safety, reduced congestion, and increased mobility—don't really kick-in until the vast majority of the fleet is largely made up of Level 4 and 5 HAVs. Even so, the arrival of HAVs within the complex adaptive transportation ecosystem means they are unlikely to be a silver bullet that solves all problems. Instead they will improve transportation in many ways, but could make some aspects worse off.
- Some of the strongest business cases for Level 4 HAVs come from middle-mile trucking and automated shuttles, where a vehicle can focus on traveling the same route again and again. Low-speed personal delivery devices may also advance sooner. It's not clear how big the market will be for personal ownership of Level 4 HAVs, this will depend on how expensive they are to own and operate and how big their ODDs are. If consumers balk at paying extra for Level 4 automation and there is a long lag time between Level 4 deployment and the arrival of Level 5 HAVs, then there may be a strong opportunity to advance shared mobility and MaaS concepts during this period.

- The private market seems poised to play a larger role in transportation services and potentially even infrastructure provision in the future.
  - Successful business models may be hard to develop until Level 5 is achieved. Level 2 AVs provide driver assistance, but only limited self-driving capabilities. Level 3 vehicles require continuous monitoring of the roadway, and may not provide much in terms of consumer benefits. Level 4 HAVs may be able to operate without a safety driver within their ODD, but there is some uncertainty about whether this will be the case. Any trip going outside an ODD would require a driver to take over. This could greatly limit their appeal for personal HAV ownership; and reduce it only to a lesser extent for shared mobility and freight applications since specific vehicles can be set up and programmed to operate on a fixed route or within a designated area.
  - Even if Level 5 HAVs do arrive in the nearer-term, they will generate substantial uncertainty that will challenge long-range plans and planning processes.
  - The Boring Company has developed a test 'Loop' AV tunnel project in Los Angeles and is nearing completion of its first project in Las Vegas. It had won a bid to construct an 18-mile tunnel project in Chicago, but that project seems to have been put on hold by a mayoral change. A 35-mile AV Loop has been proposed between Baltimore and Washington, DC.
- AVs and EVs are likely to speed up the obsolescence of the gas tax, while increasing demand for investment in transportation infrastructure. The gas tax's replacement must carefully consider long-term implications for equity, unintended consequences, ability to generate stable and growing revenue over time, ease of implementation, revenue yield, and economic efficiency.
- Technology and data may be on the cusp of bringing about major changes to the structure of the economy—and therefore demand for the transportation network and the types of transportation infrastructure needed. Because there is a range of plausible outcomes, it is hard to know what the results will be or precisely when this will happen—though changes will probably be gradual. The extent of data being collected will likely make protecting personal privacy a bigger concern and also risks a major societal backlash against technology.

[120] John Moavenzadeh and Nikolaus S. Lang, *Reshaping Urban Mobility with Autonomous Vehicles: Lessons from the City of Boston* (Washington, DC: World Economic Forum and Boston Consulting Group, 2018) www.weforum.org/reports/reshaping-urban-mobility-with-autonomous-vehicles-lessons-from-the-city-of-boston.

Short-Term, Low-or No-Regrets Strategies

Even in lieu of a defined vision, there are strategies that the region can begin implementing to prepare for HAV deployment. These are unlikely to set the region on any sort of path dependence or technological lock-in that could cause future regret. Many of these strategies have cobenefits that will still be useful even if HAVs don't appear on the region's roads before 2050.

- ☐ Learn from technology deployment **best practices** from around the world.
- ☐ Conduct extensive public **engagement and education** on HAVs, with extra focus on reaching historically marginalized and disenfranchised communities.
- ☐ Work with state DOTs on **plans for safe HAV testing and deployment**.
- ☐ **Prioritize roadway state-of-good repair** and maintenance needs, particularly for lane markings, standardizing road signs, updating roadway geometry standards, transportation system management and operations, connected vehicle technologies, and work zone locations updated in real time.
- ☐ **Reduce speed limits** and pursue other Vision Zero strategies.
- ☐ Use governmental **procurement to advance vehicle technologies**.
- ☐ Expand and **integrate shared mobility options with transit** through mobility hubs, dedicated pick-up / drop-off curb space, reduced parking minimums, and an open source, real-time trip information, booking, routing, and payment platform.
- ☐ Pursue **transit-first strategies**: transit signal priority, off-board fare payment, and dedicated bus lanes.
- ☐ **License private shared mobility services** to operate if they: serve everyone, share data, integrate with transit and other transportation providers, follow curb regulations, and meet safety standards. Renew licenses if requirements are met.
- ☐ **Equitably distribute infrastructure improvements** across the region.
- ☐ Work with state and local governments to determine **data** needs, create open data standards for shared mobility providers, and build local government data management and processing capacity.

Appendices

Appendix A. Glossary

5G: The fifth generation of cellular technology, designed to increase speed, reduce latency, and improve flexibility of wireless services.

Accelerating Clean Technology Innovation for Climate and Equity (ACT-ICE) Act: A fictional piece of legislation set in an Inclusive Tech future. ACT-ICE uses innovation to reduce GHG emissions through subsidies and low-interest government financing for carbon-neutral technologies; increasing regulation on goods and services to further stimulate investment around climate, equity, and health concerns; and by applying a carbon tax set at a well above market rate of $150 per ton to price in risk, which funds investments and stimulates innovation. It also creates a locally administered Community Jobs Program (CJP) that offers public service work to anyone who wants it.

Accelerating the Deployment of Automated Passenger-Vehicles and Trucks (ADAPT) Act: A fictional piece of legislation set in an Inclusive Tech future. The ADAPT Act empowers the U.S. DOT to guide transportation innovation. It sets strong standards and leverages private-market funds for the reduction of fatalities and GHG emissions from the transportation sector—including goals to reduce both to zero backed up by funding, attention, resources, and expertise. It commits to building out CV technologies and infrastructure. It develops a gated certification process that includes putting automated vehicle hardware and software through objective safety criteria, simulations, road tests, and third-party review.

Advanced-Driver Assistance Systems (ADAS): Support human steering, braking, and acceleration over a period of time within Level 1 and Level 2 AVs.

American Transportation Infrastructure Act of 2021: A fictional piece of legislation set in a Delayed Expectations future.

Artificial General Intelligence (AGI): Computer programs with an equal or greater level of intelligence than the human brain.

Artificial Intelligence (AI): The theory and development of computer programs able to perform tasks that normally require human intelligence, such as visual perception, speech recognition, decision making, and translation between languages.

Automated Driving System (ADS): An AV's software, which is capable of operating without driver control for a duration under specific conditions.

Automated Vehicles (AVs): Use hardware and both remote and on-board software systems to perform the functions needed to either assist with the driving task or drive a vehicle.

Cellular Vehicle-to-Everything (C-V2X): A connected vehicle communications system that uses cellular networks and the 5.9 GHz band to facilitate short-range and long-range vehicle to vehicle, vehicle to infrastructure, and vehicle to everything data transmissions.

Climate Communications Network: A fictional government platform for sharing climate change mitigation strategies in an Inclusive Tech future.

Community Jobs Program (CJP): A fictional government program focused on sustainable community investment in an Inclusive Tech future.

Complex Adaptive Systems (CASs): Are made up of a set of parts or things that work together as a unified whole or interconnected network, where random events and individual actions shape outcomes. CASs respond to changes in their operating environment, and can also cause changes to the operating environment itself. As a result of this two-way adaptation it is hard to predict outcomes, and predictability is even more difficult when human behavior is added to the loop.

Connected Vehicles (CVs): Vehicles that use cellular vehicle-to-everything (C-V2X) and possibly dedicated short-range communications (DSRC) through licensed wireless networks, cellular technologies, satellites, the internet, and telematics to connect cars, trucks, buses, motorcycles, bicyclists, pedestrians, and infrastructure.

Dedicated Short-Range Communications (DSRC): Previously operated on the 5.9 GHz spectrum to facilitate vehicle-to-vehicle (V-2-V) and vehicle-to-infrastructure (V-2-I) communication, and could supplement navigation systems in dense urban areas, where the canyon effect can be a limiting factor, and in sparse geographic areas where other systems are not as strong. A November 2020 Federal Communications Commission repartition of the 5.9 GHz bandwidth, which will render this technology obsolete if it isn't overturned by the incoming Biden administration or overruled by expected industry lawsuits.

Digital Revolution: Began with the emergence of computers, digital data storage, and the internet, which have collectively shifted how humans communicate; changed the primary function of the economy from product manufacturing to information; and enabled software, automation, robotics, and outsourcing to replace low-skill jobs with high-skill ones.

Electric Vehicles (EVs): Are powered by an electric motor using electrical energy stored in rechargeable batteries or other storage devices (such as a hydrogen fuel cell). EVs include plug-in hybrid electric vehicles—which have a supplementary internal combustion engine (ICE)—and all-electric vehicles.

Electric Vertical Take-Off and Landing (EVTOL) Vehicles: Electric propulsion aircraft that can take-off, hover, and land vertically.

Fair New Deal (FND): A fictional future piece of legislation set in a People Power future. The FND is a series of federal bills that strengthen the social safety net, antitrust measures, and personal privacy. Other parts of the legislation use existing technologies to reduce GHG emissions; shifts many independent contractors back onto company payrolls; and increases transportation funding through a fee based on how many vehicle miles traveled each real estate property generates and a tradable driving credits system.

Funding an Equitable, Accessible, and Sustainable Transportation Infrastructure Act (FEASTIA): A fictional piece of transportation legislation set in a Delayed Expectations future. In this future, this legislation is passed in 2028 as a six-year, $480 billion bill. It leads to sweeping changes to financing the nation's roads, bridges, and transit systems. The legislation eliminates the federal gas tax (18.4 cents per gallon for regular and 24.4 cents for diesel) and replaces it with a mileage-based user fee (MBUF) of 2.0 cents per mile traveled for light-duty cars and trucks, and 2.5 cents per mile for medium- and heavy-duty trucks.

General Purpose Technology (GPT): Major innovations that can completely reorganize national and/or global economies; they have long and persistent impacts in productivity across industries.

Greenhouse Gases (GHGs): Are gases that absorb infrared radiation emitted from the surface of the Earth, which prevents their heat from escaping into outer space. Once trapped, they reradiate the heat back into the planet's surface. These gases include carbon dioxide, methane, water vapor, ground-level ozone, nitrous oxides, and fluorinated gases.

High Definition (HD) Maps: Are detailed 3-D data layers that provide precise location—within centimeters—for roadways, lane markings, curbs, traffic signs, poles, landmarks, and other appurtenances. An ADS uses this data to provide context to the data its sensors are recording. HD maps need to be continuously updated to reflect the ever-changing conditions of the built environment.

Highly Automated Vehicle (HAV): A vehicle with an automated driving system that does not need a safety driver when operating on specific facilities (Level 3 AV), within a specifically defined operational design domain area (Level 4 AV), or at any place and time (Level 5 AV).

Infrastructure Owner Operators (IOOs): Are entities responsible for the design, build, maintenance and operation of transportation infrastructure.

Internet of Things (IoT): A system of interrelated computing devices, mechanical and digital machines, objects, animals, or people that are provided with unique identifiers and the ability to transfer data over a network without requiring human interaction.

Latency: The time between making a request and having a network execute it.

Machine Learning: A branch of artificial intelligence based on the idea that systems can learn from data, identify patterns, and make decisions with minimal human intervention.

Micromobility: Includes a range of low-speed (15 mph), lightweight vehicles (less than 1,000 pounds) designed to be operated by a single rider. Transportation modes that fit into the micromobility category generally include bicycles and E-bikes, electric scooters, electric skateboards and other rideable devices.

Mileage-Based User Fee (MBUF): Charges for the use of roads more like a utility, based on system use. Is assessed at a specific rate per mile driven and can be imposed on either all vehicle miles traveled or only on specific facilities.

Mobility-as-a-Service (MaaS): A shift away from privately-owned vehicles and toward transportation solutions that are delivered as a service. Transportation services from public and private transportation providers are combined through a unified gateway that creates and manages each trip, and facilitates payment across modes all through a single account. Users can pay per trip (single-trip MaaS program) or a monthly fee for a limited distance (subscription MaaS program).

National Highway Traffic Safety Administration (NHTSA): A U.S. government agency within the Department of Transportation charged with advancing transportation and vehicle safety, saving lives, preventing injuries, and reducing economic impacts from traffic crashes, through education, research, safety standards, and enforcement.

National Traffic Safety Board (NTSB): U.S. Federal Government Agency within the Department of Transportation charged with keeping people safe on U.S. roads by enforcing vehicle performance standards and creating partnerships with state and local governments.

Operational design domain (ODD): Defines the conditions in which an ADS is designed to operate, including geographic area (urban places, mountains, deserts, etc.), types of roadways (interstate, local, etc.), speeds, conditions (day or night, weather, etc.), and other constraints.

Quantum Computing: Computers use combinable qubits, which can be any combination of value of 0s and 1s, and may be able to enable computational speed and possibilities far beyond classical computing capabilities, which are based on non-combinable bits that can be either 0 or 1.

Regulatory Capture: A situation where agencies that are charged with protecting the public interest instead act in ways that benefit the industry they are supposed to regulate.

Roadway Auto and Safety Advocates: A fictional organization working toward safer roads in a Technology in the Driver's Seat future.

Safe Connected and Automated Trucks and Vehicles (SCATV) Act: A fictional piece of legislation set in a People Power future. SCATV sets tough standards for HAV safety and performance, which must be satisfied before granting any commercial licensing, while increasing federal investment in truck platoons, automated vehicles, and connected vehicles.

Safety Driver: A person who has been specifically trained to actively monitor conditions, and is ready to take over whenever necessary when a Level 2.5, Level 3, or Level 4 automated driving system is operating within its operational design domain.

Southeast Pennsylvania Regional Transportation Funding Authority (SPARTA): A fictional regional government agency set in a People Power future, charged with collecting local taxes and distributing them to transportation agencies in the region.

Truck Platoon: Use connected and automated technology to link a group of two or more trucks together and let them travel in a convoy.

Vision Zero: A transportation planning philosophy that aims to end fatal and serious injury crashes by protecting all roadway users through equitable engineering, education, and enforcement while prioritizing speed control.

Appendix B. Key Related Technologies

There are several key technologies that are developing at the same time as vehicle automation, which may help shape the future of transportation. These include connected vehicles, electric powertrains, shared mobility providers, and real-time information and communications.

Connected Vehicles

Connected vehicle (CV) technologies are a separate innovation from automation. CVs use licensed wireless and cellular networks, satellites, the Internet, and telematics to connect cars, trucks, buses, motorcycles, bicyclists, pedestrians, and infrastructure through cellular vehicle-to-everything (C-V2X) technologies and possibly dedicated short-range communications (DSRC)—depending on the final outcome of the Federal Communication Commission's November 2020 decision to reallocate a portion of the 5.9 GHz spectrum to wireless devices.[121] CVs create machine awareness and enhance communications between vehicles (V-2-V) and between vehicles and infrastructure (V-2-I) by transmitting precise and in-depth real-time location, speed, acceleration, fault conditions, and other data.[122] External CV sensors can use real-time data to monitor for roadway hazards such as ice, sharp curves, or other vehicles, and issue warnings to the driver.[123] CVs can verify that vehicles are aware of each other, advance warnings about hazards and intentions between vehicles, help with maneuvering. and can overcome range, sight, and data interpretation problems with sensors.[124] They can also enable system coordination, cooperation, and smooth traffic flow by connecting with traffic management systems.

By cooperating with each other, CVs are often forecast to reduce crash and fatality rates for non-impaired drivers by up to 80 percent.[125] Telematics integrate telecommunication and information technologies for enhanced vehicle safety and mobility.[126] Connected and wireless technologies may increase potential hacking and cybersecurity risks. In the longer-term, CV technologies could relocate much road information—signs, speed limits, even traffic signals—to the vehicle dashboard, reducing roadside clutter and lowering maintenance costs.

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[121] Abbas Mohaddes and Peter Sweatman, *Transformational Technologies in Transportation: State of the Activities* (Transportation Research Board, May 2016), www.trb.org/Main/Blurbs/174370.aspx.
[122] Federal Highway Administration, *The Smart/Connected City and its Implications for Connected Transportation.*
[123] Federal Highway Administration, *The Smart/Connected City and its Implications for Connected Transportation.*
[124] Steven Schladover, "Progress toward Automated Driving," *Halmstad Colloquium* (video), February 12, 2012, www.youtube.com/watch?v=4wfpUSTG9zU (accessed June 7, 2016).
[125] "U.S. DOT Advances Deployment of Connected Vehicle Technology to Prevent Hundreds of Thousands of Crashes," *National Highway Traffic Safety Administration*, December 13, 2016, www.nhtsa.gov/press-releases/us-dot-advances-deployment-connected-vehicle-technology-prevent-hundreds-thousands (accessed November 13, 2017).
[126] Peter Jin, *Emerging Transportation Technologies White Papers* (Austin, TX: The University of Texas at Austin Center for Transportation Research, May 2015), www.library.ctr.utexas.edu/ctr-publications/0-6803-P2.pdf.

Electric Vehicles

Electric vehicles (EVs) are powered by an electric motor using electrical energy stored in rechargeable batteries or other storage devices (such as a hydrogen fuel cell). EVs include plug-in hybrid electric vehicles—which have a supplementary internal combustion engine (ICE)—and all-electric vehicles.

Shared Mobility

Shared mobility providers offer service through digital networks, which are typically accessed through a smartphone app that uses real-time data to match supply and demand.[127] Services that include vehicle sharing can vary by whether they are one-way—meaning the vehicle can be picked up in one location and dropped off at another—or round trip—meaning the trip must end at the same location where it started. In Greater Philadelphia, Indego Bikeshare is an example of a one-way trip, which generally ends at a different station from where it started. Typically, carsharing providers require round-trips, where the vehicle must be returned to the same location where it was picked up. Free-floating or dockless systems break away from station infrastructure altogether and aim to move vehicles and bicycle pick-up and drop-off locations closer to trip origins and destinations.[128] In peer-to-peer networks, an individual can rent their personal vehicle (or bike, scooter, etc.) to someone else. Ideally, a common platform will emerge that allows these services to be jointly booked and paid for through a single app that also connects with public transit. Common types of shared mobility services include:

- Bikesharing services set up publicly accessible bicycles for short-term use. They can fill in gaps in transit service and can accommodate overflow of peak-period transit ridership. Bikesharing programs are often operated municipally through a Public-Private Partnership (P3), but can be found on corporate and university campuses, on residential properties, and in hotels. Removing dock infrastructure can reduce costs and expand service areas, allowing bikesharing to be more financially feasible for public and private operators. Services are increasingly offering electric bicycle (e-bike) options. Bikesharing programs can help improve first- and last-mile connections to transit.
- Electric-scooter (e-scooter) sharing are generally dockless programs that allow individuals to rent these rideable vehicles for a short duration. E-scooter programs generally have designated parking areas and can be located and booked through a smartphone app. Concerns about these programs include cluttering sidewalks, being left in inappropriate locations, and causing accessibility issues when they are left in places that block the sidewalk.
- Carsharing allows an individual to rent a car on an hourly or daily basis. Reservations are usually made in advance but often can be done with very short (30 minutes or less) notice. Each carsharing vehicle is generally estimated to replace 9–13 personally-owned vehicles.
- Courier networking services offer on-demand pick-up and/or delivery of goods, groceries, and take-out foods. By delivering needed, and potentially bulky or heavy goods to a household, these services can enable individuals to live car-free or car-lite lifestyles.

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[127] "Episode 2—Shared Mobility Conversation with Susan Shaheen." *ITE Talks Transportation Podcast Series*, www.spreaker.com/user/ite-talks-transportation/episode-2-shared-mobility-conversation-w (accessed June 28, 2016).
[128] *New Mobility* (Toronto: WSP, August 2016 update), www.wsp-pb.com/Globaln/WSP-Canada/In%20the%20media/Project%20News/2016/16-08-31%20-%20New%20Mobility/WSP%20Metrolinx%20New%20Mobility%20Report%20July%202016.pdf.

- Transportation Network Companies (TNCs) facilitate rides through a digital network using independent contractors or professional drivers, depending on the form.
  - Microtransit services generally combine trips to move multiple passengers simultaneously on demand. These services often create partnerships with charter bus companies, which supply the vehicles, drivers, and insurance. By combining passenger trips, microtransit may be able to reduce traffic volumes and road congestion.
  - Ridehailing uses an app to electronically hail a driver, who “contracts” with the service. The cost of the trip is indicated before the request is finalized. The app guides the driver to pick up the passenger and then take them to their desired destination. Payment is handled electronically within the app, so the driver has no need to carry cash. Ridehailing services have generally increased car trips and congestion to date.
  - Ridesplitting combines aspects of ridehailing and microtransit. These services may use larger vehicles, which are owned by independent contractor drivers, to simultaneously pick up and drop off multiple passengers for a discounted price. This may increase vehicle occupancy rates and could help to alleviate congestion.

A key question is whether or not AVs will be made available through shared mobility services. Sharing is generally seen as beneficial from environmental, congestion, and cost viewpoints. Future AV scenarios often consider two implausible extremes: either a fully shared or entirely privately-owned fleet. Any plausible future is likely to have some degree of both sharing and private ownership. The amount of AV sharing that actually occurs will depend on a number of factors including: supportive land use and infrastructure, such as mobility hubs; the economics of sharing and ownership; public policy; how inclusive and accessible the services and vehicles are; and human behavior.

Real-Time Information and Communications

The ability to access information and communicate in real-time through a variety of digital devices and automated data collection systems is critical to shared mobility services and offers the potential to transform the transportation network. Real-time information is available through traffic navigation tools and apps, such as Google Maps, INRIX, Waze, and SEPTA and NJ TRANSIT apps. They help to use the transportation network more efficiently in several ways. First, mode optimization can determine the most efficient transportation mode based on travel time, cost, and available modal options. Once a mode is chosen, route optimization can identify the quickest and most direct route. Second, navigation tools route people and vehicles away from congested facilities and onto less congested ones. This lets individuals make faster trips while also benefiting society with reduced congestion. While facility optimization can balance vehicle volumes throughout the system and reduce congestion, it may increase VMT, particularly on roads with historically lower traffic volumes. Some vehicles may use residential streets that are not designed for high volumes or speeds to bypass congestion. Several different types of applications are improving the travel information we have at our fingertips and changing how we get around the region:

- Dynamic carpooling or ridesharing apps enable real-time carpooling by connecting drivers and potential passengers.
- Freight apps are digital goods movement platforms that allow small trucking carriers to transact directly with shippers. Real-time, on-demand routing programs can promote efficiencies and reduce congestion through fewer empty truck legs and decreased truck VMT.
- Multimodal apps provide real-time travel and cost information for a variety of modes, allowing the user to select the best option for them.

- Parking apps provide better space availability information or easier payment options to make parking in the region more efficient.
- Taxi apps operate within the traditional taxi medallion framework. Users are able to access the technology through a handheld device to summon a licensed taxi driver, and in some apps the passenger can electronically pay for the trip.
- Micromobility apps help individuals locate and book shared bikes and e-scooters.
- Transportation network company apps enable the digital hailing of on-demand rides (pooled or individual) or microtransit services.
- Courier network and delivery apps provide real-time delivery of all kinds of food and goods.

Appendix C. HAV Deployment Uncertainties

This appendix documents background research conducted on HAVs. This is an exploration of key issues, and is not intended to develop a consistent coherent take on HAV development, deployment, and deployment outcomes. The contradictions found within should be seen as showing the uncertainty in predicting how HAVs will ultimately be deployed, the conflicting opportunities and challenges they bring, and reflect a range of plausible outcomes as a result. This research reflects a variety of viewpoints that don't necessarily reflect any official DVRPC stance or policy, and were consulted to reflect an array of opinions and perspectives. The research highlights the following major first-degree uncertainties in HAV development and deployment:

1. HAV safety.
2. Developing profitable business models.
3. Additional infrastructure investment needs.
4. Cybersecurity and other technical challenges.
5. Regulating HAVs.
6. Artificial Intelligence and reliance on technology.
7. COVID-19 and Black Lives Matter protests effects on HAV development.

The above uncertainties may serve as limitations and challenges to deployment. The research also highlights a second-degree set of uncertainties related to outcomes that may arise once HAVs are deployed.

1. Impacts to jobs and the economy.
2. Mobility and congestion.
3. Energy use and greenhouse gas emissions.
4. Maintaining urban vitality and open space.
5. Achieving equitable access.
6. Redesigning the transportation network.
7. Data and privacy.

In many ways, each of these uncertainties will also add new layers of complexity to the transportation network. The research did not focus as heavily on some specific well documented uncertainties, such as the timing for the deployment, or whether HAVs will be privately owned or shared. These issues were considered in the development of the *Dispatches* scenarios.

I. First-Degree Uncertainties for Developing and Deploying HAVs

These uncertainties may impact HAV deployment by potentially serving as limitations or challenges to be overcome.

1. HAV Safety

Greater safety is often stated as the primary opportunity and need for vehicle automation. HAV deployment may be slowed by the difficulty of proving to a skeptical public that they are safer than conventional human drivers. Once deployed, HAVs are also likely to have a second-degree impact on transportation safety and crashes.

The expectation that HAVs will be safer assumes that machine precision and attentiveness can deliver more consistent operations, especially since an ADS won't be driving while distracted, impaired, or fatigued. Speeds could be lowered by vehicle programming that follows all the rules of the road. HAVs could more safely interact with pedestrians and bicyclists, and improve night-time driving for everyone—particularly for the elderly. Removing human error in decision-making around traffic incidents can increase safety for traffic controllers, first responders, and road workers; and reduce secondary and tertiary collisions. In a 2017 peer-reviewed article, researchers Eric R. Teoh and David G. Kidd from the Insurance Institute for Highway Safety found that Google/Waymo's AVs had a police-reportable crash rate that was nearly a third (2.19) that of human-drivers (6.06) per million vehicle miles traveled between 2009 and 2015, though their findings were not statistically significant.[129] The most common crashes involving Google/Waymo's AVs were being rear-ended by a human-driven vehicle, and the company's vehicles were responsible for only one crash during this period.[130]

Once deployed, HAVs could have second-degree safety benefits in the form of lowering insurance costs, providing alternatives to high-risk drivers, and allowing for lighter-weight vehicles—which could further reduce costs.[131] However, lighter-weight vehicles may have a difficult time overcoming path dependence, (where future options are limited by past decisions) as conventional vehicles and HAVs may share the road for a long time and ADSs will still be vulnerable to being crashed into by human drivers as long as they share the road. Until Level 5 HAVs are alone on the road, many of the vehicle safety features included in vehicles today will remain necessary, and even then, safety features may remain as Level 5 HAVs will still need to take evasive maneuvers to avoid collisions.[132] In the meantime, shared HAVs could help to reduce the overall crash rate by providing alternatives to high-risk drivers. Reducing high-risk driving through graduated driver's licenses, testing senior drivers, and anti-impaired driving campaigns can be made more feasible if affected individuals have other travel options.[133]

Often overlooked is the possibility that AVs could cause new types of crashes and safety risks. It may be surprisingly difficult to prove that an ADS is safer than a human driver. Within the region, there is an opportunity to use HAVs to focus on safety culture and to achieve the Vision Zero goal of no traffic fatalities or serious injuries.

New Types of Crashes and Safety Risks

Research by Schoettle and Sivak has found that HAVs may not provide any safety benefits compared to the average driver, and may increase crashes when human and self-driving vehicles operate in mixed traffic.[134] Groves and Kalra make the case that HAV deployment is defensible if it

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[129] Eric R. Teoh and David G. Kidd, "Rage Against the Machine? Google's Self-Driving Cars Versus Human Drivers," *Journal of Safety Research,* December. 2017, https://pubmed.ncbi.nlm.nih.gov/29203024/ (accessed November 4, 2020).
[130] Teoh and Kidd, "Rage Against the Machine? Google's Self-Driving Cars Versus Human Drivers."
[131] Daniel Fagnant and Kara M. Kockelman, *Preparing a Nation for Autonomous Vehicles: Opportunities, Barriers and Policy Recommendations* (Washington, DC: Eno Center for Transportation, 2013), www.enotrans.org/etl-material/preparing-a-nation-for-autonomous-vehicles-opportunities-barriers-and-policy-recommendations/.
[132] Smith, *How Governments Can Promote Automated Driving*.
[133] Litman, *Autonomous Vehicle Implementation Predictions*.
[134] Brandon Schoettle and Michael Sivak*, A Preliminary Analysis of Real-World Crashes Involving Self-Driving Vehicles* (Anne Arbor, MI: Transportation Research Institute, University of Michigan, 2015, Report # UMTRI-2015-34) www.umich.edu/~umtriswt/PDF/UMTRI-2015-34.pdf.

reduces crash rates, but note that total crashes may increase due to the rebound effect.[135] For example, if AVs reduce the crash rate by 10 percent, but increase total VMT by 15 percent, then total crashes will be higher.[136] The best way to mitigate these risks is through policies that lower speed limits and VMT, particularly in urban areas.

Beyond increasing risk exposure through more vehicle travel there are any number of new types of crashes that could occur with HAV deployment. These include active and passive hacking, complex human-machine interactions, sensor failures, software bugs, and other risks that are unknowable in the present. Sensors are critical to safe operations but also highly delicate. For example, AVs can't use a commercial car wash out of fear that it could damage sensor systems.[137]

It is difficult, if not impossible to prepare HAVs for all possible situations involving bad drivers—whose actions may or may not be intentional.[138] The current approach to automation takes the human out of the loop, even though humans and machines are very complementary in their skills.[139] Humans are really good in complex situations, while machines are really good at staying vigilant.[140]

There are many examples of over trusting ADAS technology and the dangers of on-road Level 2.5 testing. Josh Brown was the first person to be killed in an AV crash on May 7, 2016 when the Tesla he was driving with Autopilot on slammed into an oncoming truck.[141] The National Transportation Safety Board (NTSB) released computer logs from Brown's vehicle showing he was warned to keep his hands on the wheel seven times.[142] Each time he did so, just long enough to stop the warnings. Brown's death shows that there are risks to the gradual path of bringing AVs to the market with increasingly sophisticated ADAS features.[143] The more people use the technology, the more they may overly trust it and stop watching the road.[144] The industry's response has been to constantly nag drivers to pay attention to the road, often by mounting a camera in the windshield or rearview mirror, in order to test whether a driver is watching the road.[145] Ironically, ADAS vehicles could ask drivers to pay more attention to the road, not less.[146] Early research has shown that as people master use of ADAS technologies, they begin to overtrust it and let their guard down.[147] So while ADAS can reduce crashes when properly used, it could be less safe when drivers are less vigilant and less focused on the driving task.[148]

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[135] David G. Groves and Nidhi Kalra, *Enemy of Good: Autonomous Vehicle Safety Scenario Explorer* (Santa Monica, CA: Rand Corporation, 2017); at www.rand.org/pubs/tools/TL279html.
[136] Litman, *Autonomous Vehicle Implementation Predictions*.
[137] Ed Finn, "Phoenix Will no Longer be Phoenix if Waymo's Driverless-Car Experiment Succeeds," *MIT Technology Review*, June 26, 2018, www.technologyreview.com/s/611420/phoenix-will-no-longer-be-phoenix-if-waymos-driverless-car-experiment-succeeds/amp/ (accessed July 19, 2018).
[138] Schladover, "Progress Toward Automated Driving."
[139] Evan Ackerman, "Toyota's Gill Pratt on Self-Driving Cars and the Reality of Full Autonomy," *IEEE Spectrum*, January 23, 2017, www.spectrum.ieee.org/cars-that-think/transportation/self-driving/toyota-gill-pratt-on-the-reality-of-full-autonomy (accessed September 22, 2017).
[140] Ackerman, "Toyota's Gill Pratt on Self-Driving Cars and the Reality of Full Autonomy."
[141] Timothy B. Lee, "Car Companies' Vision of a Gradual Transition to Self-Driving Cars has a Big Problem," *Vox*, July 5, 2017, www.vox.com/new-money/2017/7/5/15840860/tesla-waymo-audi-self-driving (accessed September 22, 2017).
[142] Lee, "Car Companies' Vision of a Gradual Transition to Self-Driving Cars has a Big Problem."
[143] Lee, "Car Companies' Vision of a Gradual Transition to Self-Driving Cars has a Big Problem."
[144] Lee, "Car Companies' Vision of a Gradual Transition to Self-Driving Cars has a Big Problem."
[145] Lee, "Car Companies' Vision of a Gradual Transition to Self-Driving Cars has a Big Problem."
[146] Lee, "Car Companies' Vision of a Gradual Transition to Self-Driving Cars has a Big Problem."
[147] "Safety First: Concerns Raised About New Vehicle Safety Features," *AASHTO* (video), August 26, 2020, www.youtube.com/watch?v=YAoTAGoGwXE&feature=youtu.be (accessed August 26, 2020).
[148] "Safety First: Concerns Raised About New Vehicle Safety Features."

Another example occurred when a Tesla suspected to be operating with Autopilot active followed the exit ramp lane marking off a highway in California, ran a red light, and crashed into another vehicle, killing two people.[149] At least four Teslas using Autopilot have run into stopped firetrucks, and once into a stopped police cruiser, causing one death.[150] Radar detects many things alongside the highway that it doesn't need to worry about—such as overhead highway signs, loose hubcaps, and road signs—these systems are programmed to detect moving objects, and to ignore stationary ones.[151] This may not be much of a problem if every human occupant closely followed the automakers' instructions to watch the road at all times and take back control if there is a stationary vehicle ahead. LiDAR combined with sensors and higher levels of computing power will eventually be the solution to this issue.[152] LiDAR will be able to build a detailed rendering of the vehicle's environment and be able to tell if that is a hubcap or a police cruiser up ahead.[153] But this technology is still being developed, is currently very expensive, and not able to survive potholes, rain, or snow.[154] Sam Schwartz has noted that warnings from a 2019 Toyota Camry's vehicle sensor system may have a hard time detecting a wide variety of different types of individuals, including those:[155]

- Shorter than 3.2 ft. or taller than 6.5 ft.
- Wearing oversized clothing.
- Carrying large baggage, holding an umbrella, or carrying other unusual items.
- Bending forward or squatting.
- Pushing a stroller, wheelchair, or bicycle.
- Walking closely in groups.
- Wearing white or extremely bright colors.
- Walking in the dark, such as at night or in a tunnel.
- Wearing clothing nearly the same color as surroundings.
- Walking near walls, fences, guardrails, or large objects.

While these gaps are likely to be overcome as AVs reach higher-level capabilities, they also suggest that some hidden gaps are likely to remain that may only become evident when the ADS systems fail. Mixed vehicle fleets and greater diversity of roadway users will increase complexity, and may exacerbate the challenging nature of human-machine interactions. Standards, voluntarily developed or otherwise, between manufacturers may be necessary to ensure compatibility and that human–computer interaction functions in a similar method in all types of AVs.[156] Some industry insiders—such as Andrew Ng, a Drive.AI board member—have suggested that the public should be trained to

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[149] Tom Krisher, "3 Crashes, 3 Deaths Raise Questions About Tesla's Autopilot," *Star Tribune*, January 3, 2020, www.startribune.com/3-crashes-3-deaths-raise-questions-about-tesla-s-autopilot/566680301/ (accessed January 10, 2020).
[150] Jack Stewart, "Why Tesla's Autopilot Can't See a Stopped Firetruck," *Wired*, August, 27, 2018, www.wired.com/story/tesla-autopilot-why-crash-radar/ (accessed November 21, 2018); and Krisher, "3 Crashes, 3 Deaths Raise Questions About Tesla's Autopilot."
[151] Stewart, "Why Tesla's Autopilot Can't See a Stopped Firetruck."
[152] Stewart, "Why Tesla's Autopilot Can't See a Stopped Firetruck."
[153] Stewart, "Why Tesla's Autopilot Can't See a Stopped Firetruck."
[154] Stewart, "Why Tesla's Autopilot Can't See a Stopped Firetruck."
[155] Sam Schwartz, "No One at the Wheel," Presentation to DVRPC Futures Group, June 19, 2019.
[156] James M. Anderson, Nidhi Kalra, Karlyn D. Stanley, Paul Sorensen, Constantine Samaras, and Oluwatobi A. Oluwatola, *Autonomous Vehicle Technology: A Guide for Policymakers* (Rand Corporation, 2014) www.rand.org/pubs/research_reports/RR443-2.html.

anticipate AV behavior.[157] However, this thinking risks that untrained pedestrians and bicyclists may be considered at fault in the event of an AV crash where they are the victim.

Robo-taxi services, where a single party of one or more people makes a trip, seems likely to be offered in the future. A service used by multiple parties, who are otherwise strangers to each other, could create personal safety and security concerns if there is not an authority figure in the vehicle who is responsible for maintaining order.

Other concerns may increase from riskier behavior due to perceived greater safety—as already seen in the Josh Brown example—platoons, system failures, skill erosion, and changes in criminal and law enforcement practices. Individuals tend to increase risk taking when they think their travel is safer, such as reduced seat belt use or being less cautious as pedestrians.[158] System failures by personal smartphones, computers, and other digital devices are annoying, but rarely fatal, whereas with HAVs they can be both annoying and deadly to vehicle occupants and other roadway users.[159] Manually driven cars travel about two million hours between fatalities and 50,000 hours between injuries.[160] HAVs will need to top these values, but computers and cell phones 'crash' much more frequently than this; and ADSs will operate in much more extreme temperature and weather conditions than computing systems currently do.[161] The software doesn't need to crash to cause problems. Major roadway risks can occur if the software becomes hung up or delayed by as little as one-tenth of a second.[162] Vehicles operating closer together in high-speed platoons may have increased crash severity when something goes wrong.[163] Debris and litter on road surfaces and shoulders can confuse ADSs.[164] Being overly focused on HAVs could cause readily available vehicle design strategies—such as crash-avoidance systems and intelligent speed adaptation—that can make our roads safer in the here and now to be overlooked.[165]

Level 2 and 3 AVs have a major potential safety concern in that they rely on the driver being ready to take over at a moment's notice when it encounters problems. Research by the University of Southampton published in the *Journal of Human Factors* found it took drivers up to 25.7 seconds to look up in response to a command to take control back from the AV computer system.[166] If an automated system works 99 percent of the time, drivers may become complacent and assume it works 100 percent of the time.[167] This could further reduce vigilance and readiness to take over in an emergency situation. Human driving skills will erode with less practice, which may create safety

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[157] Russell Brandom, "Self-Driving Cars are Headed Toward and AI Roadblock," *The Verge*, July 3, 2018, www.theverge.com/2018/7/3/17530232/self-driving-ai-winter-full-autonomy-waymo-tesla-uber (accessed July 5, 2018).
[158] Litman, *Autonomous Vehicle Implementation Predictions*.
[159] Litman, *Autonomous Vehicle Implementation Predictions*.
[160] Schladover, "Progress Toward Automated Driving."
[161] Schladover, "Progress Toward Automated Driving."
[162] Schladover, "The Truth About Self-Driving Cars."
[163] Litman, *Autonomous Vehicle Implementation Predictions*.
[164] Smith, *How Governments Can Promote Automated Driving*.
[165] Hillary Smith, "David Ward on Self-Driving Cars: 'Don't Put the Autonomous Cart Before the Horse," *The City Fix*, December 10, 2018, www.thecityfix.com/blog/david-ward-self-driving-cars-dont-put-autonomous-cart-horse-hillary-smith/ (accessed January 2, 2019).
[166] Victoria Allen, "Drivers Could Take 25 Seconds to take Control of a Self-Driving Car if Something Goes Wrong, Warn Experts," *The Daily Mail*, updated January 26, 2017, www.dailymail.co.uk/sciencetech/article-4161240/Driverless-cars-cause-havoc-roads.html (accessed September 22, 2017).
[167] Schladover, "Progress Toward Automated Driving."

challenges in situations where human interaction, decision-making, and cognitive thinking is required.[168]

Given the amount of time it could take to orient oneself to the situation, there needs to be a plan for what an ADS will do when its capabilities are compromised. Some HAV developers have suggested that they could pull over to the side of the highway, but this assumes there is a shoulder.[169] Other manufacturers are planning to use remote drivers, but this assumes the Internet is working, there aren't hackers, and there isn't an urgent situation, such as a natural disaster.[170]

Pedestrians may realize they can step out into the street and HAVs will stop, making it difficult to move vehicles through urban areas.[171] The term jaywalking was invented by the auto industry in the 1930s to keep pedestrians out of the way of fast-moving vehicles by criminalizing their behavior. It is fairly easy to imagine dystopian ways of prioritizing HAV movement, such as automated enforcement of jaywalking laws with facial recognition technology;[172] or using fencing to delineate pedestrian and vehicle space, with cattle shoots that open up only when pedestrians have the right to cross the road.[173]

Transportation for America has noted that almost every fatal crash has one thing in common: high vehicle speeds. As long as motorized vehicles are in use, streets must be designed to manage and restrict their speed. Backup systems, such as radar and satellite, and redundancy must also be part of the system design due to both machine and human fallibility.

Safety testing is currently being conducted in a world where AVs share the road with human-driven vehicles, but they aren't being tested alongside ADSs developed by other AV companies. There is uncertainty in how HAVs will perform in these types of mixed fleets.

Radio-signal spoofers could be used to send false location data to a vehicle's GPS and change turn-by-turn navigation directions.[174] The device costs less than $250 and only needs to be located within 1,600 feet of a vehicle, so potentially an attack could come via drone flying above the target or by a trailing vehicle.[175] HAVs may be more vulnerable to this sort of attack, if they rely on GPS, since there isn't a driver watching where the vehicle is going—though an attacker would need a high-expertise level and an idea of the vehicle's intended destination.[176] Encrypting GPS or using computer-vision techniques to compare real world markers and signs with digital maps could be potential solutions to this challenge. In 2017, more than 20 ships in the Black Sea were found to have their GPS spoofed, showing their location as more than 32 miles inland in what may have been a Russian test

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168 "Hands-Free, Mind-Free: What We Lose through Automation," *National Public Radio*, September 29, 2014. www.npr.org/sections/alltechconsidered/2014/09/29/352496605/hands-free-mind-free-what-we-lose-through-automation (accessed September 29, 2014).
169 Ackerman, "Toyota's Gill Pratt on Self-Driving Cars and the Reality of Full Autonomy."
170 Ackerman, "Toyota's Gill Pratt on Self-Driving Cars and the Reality of Full Autonomy."
171 "Autonomous Vehicles: Separating the Hype from Reality."
172 "Autonomous Vehicles: Separating the Hype from Reality."
173 Sam Schwartz, "No One at the Wheel," Presentation to DVRPC Futures Group, June 19, 2019.
174 Dan Goodin, "A $225 GPS Spoofer can Send Sat-Nav-guided Vehicles into Oncoming Traffic (Some Restrictions Apply)," *Ars Technica*, July 18, 2018, www.arstechnica.com/information-technology/2018/07/a-225-gps-spoofer-can-send-autonomous-vehicles-into-oncoming-traffic/ (accessed July 20, 2018).
175 Goodin, "A $225 GPS Spoofer can Send Sat-nav-guided Vehicles into Oncoming Traffic."
176 Goodin, "A $225 GPS Spoofer can Send Sat-nav-guided Vehicles into Oncoming Traffic."

of electronic warfare capabilities using a GPS-spoofing system.[177] Jamming or spoofing GPS signals shouldn't be a problem if HAVs rely only on on-board maps and don't need GPS.[178]

HAVs could be used for, or be the target of criminal activity. Thieves could try to block an ADS and then rob its passengers once it stops.[179] ADSs could be used to deliver drugs, illicit goods, or explosive materials.[180] Certain tasks will require identification of a driver, such as school pickups (positive IDs to prevent kidnapping) and courier pickups (legal documents).

The vehicle will need to know when everyone has gotten in and is ready to go before starting to drive. Shared vehicles are likely to use a smartphone app, similar to what is currently available from TNCs such as Uber and Lyft. Waymo's approach to shared vehicle design has a screen that hangs above each seat that displays the passengers name along with a start button.[181] Each passenger must press their start button before the trip can start.[182]

The Difficulty of Proving ADS Safety

How much safer will HAV systems need to be in order to deploy them?[183] Is 10 percent better than human drivers good enough, or should HAVs be kept off roads until they are 10 times better?[184] Most people are empathetic with human driver errors, recognizing that it could have just as easily been themselves who made a mistake.[185] Since machines are expected to be perfect, there will likely be less empathy for them.[186] The Rand Corporation has suggested that an AV needs to travel 275 million VMT without a fatality to prove it is safer than human drivers.[187] Another Rand analysis suggests 11 billion miles of travel are needed before reliable statistics on HAV safety can be generated.[188] If HAVs are indeed safer, however, then slowing their roll out could have a number of negative costs, most prominently lives lost unnecessarily to vehicle crashes.

It is impossible to test every possible driving situation that an ADS will encounter. NHTSA'S *Federal Automated Vehicle Policy*,[189] published in September 2016, identified 28 core behavioral competencies that represent common situations that an ADS will need to navigate:[190]

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[177] David Hambling, "Ships Fooled in GPS Spoofing Attack Suggest Russian Cyberweapon," *New Scientist*, August 10, 2017, www.newscientist.com/article/2143499-ships-fooled-in-gps-spoofing-attack-suggest-russian-cyberweapon/ (accessed November 13, 2019).
[178] Neil J. Rubenking, "Self-Driving Cars are Surprisingly Secure," *PC Mag*, August 10, 2018, www.pcmag.com/article/363045/self-driving-cars-are-surprisingly-secure (accessed August 16, 2018).
[179] Hedlund, PhD, *Preparing for Automated Vehicles: Traffic Safety Issues for States*.
[180] Hedlund, PhD, *Preparing for Automated Vehicles: Traffic Safety Issues for States*.
[181] Wilson, "The Fate of Self-Driving Cars Hangs on a $7 Trillion Design Problem."
[182] Wilson, "The Fate of Self-Driving Cars Hangs on a $7 Trillion Design Problem."
[183] Ackerman, "Toyota's Gill Pratt on Self-Driving Cars and the Reality of Full Autonomy."
[184] Ackerman, "Toyota's Gill Pratt on Self-Driving Cars and the Reality of Full Autonomy."
[185] Ackerman, "Toyota's Gill Pratt on Self-Driving Cars and the Reality of Full Autonomy."
[186] Ackerman, "Toyota's Gill Pratt on Self-Driving Cars and the Reality of Full Autonomy."
[187] Nidhi Kalra, "With Driverless Cars, How Safe is Safe Enough?" *USA Today*, January 31, 2016, www.usatoday.com/story/opinion/2016/01/31/driverless-cars-autonomous-vehicles-safety-innovation-death-accidents-column/78688584/ (accessed November 1, 2019).
[188] Kyle Wiggers, "Self-Driving Cars Face a Long Road to Becoming Transportation's Future," *Venture Beat*, August 25, 2018, www.venturebeat.com/2018/08/25/self-driving-cars-have-a-long-road-to-becoming-transportations-future/ (accessed November 21, 2018).
[189] This report has since been superseded by since superseded by *A Vision for Safety; Automated Driving Systems 2.0: A Vision for Safety; Preparing for the Future of Transportation: Automated Vehicles 3.0*; and *Ensuring American Leadership in Automated Vehicle Technologies, Automated Vehicles 4.0*. The 28 competency areas have not been carried through with these newer federal guidance documents.
[190] *Federal Automated Vehicle Policy: Accelerating the Next Revolution in Roadway Safety* (Washington, DC: U.S. Department of Transportation and National Highway Traffic Safety Administration, September 2016), www.hsdl.org/?view&did=795644.

1. Detect and respond to speed limit changes and speed advisories.
2. Perform a high-speed merge, such as entering a highway.
3. Perform a low-speed merge.
4. Move out of the travel lane and park, such as on the shoulder for minimal risk fallback condition.
5. Detect and respond to encroaching oncoming vehicles.
6. Detect passing and no passing zones and perform passing maneuvers.
7. Perform car following (including stop-and-go).
8. Detect and respond to stopped vehicles.
9. Detect and respond to lane changes.
10. Detect and respond to static obstacles in the path of the vehicle.
11. Detect traffic signals and stop and yield signs.
12. Respond to traffic signals and stop and yield signs.
13. Navigate intersections and perform turns.
14. Navigate roundabouts.
15. Navigate a parking lot and locate spaces.
16. Detect and respond to access restrictions (one-way, no turn, ramps, etc.).
17. Detect and respond to work zones and people directing traffic in unplanned or planned events.
18. Make appropriate right-of-way decisions.
19. Follow local and state driving laws.
20. Follow police and first responder controlling traffic (overriding or acting as traffic control device).
21. Follow construction zone workers controlling traffic patterns (slow/stop sign holders).
22. Respond to citizens directing traffic after a crash.
23. Detect and respond to temporary traffic control devices.
24. Detect and respond to emergency vehicles.
25. Yield for law enforcement, EMT, fire, and other emergency vehicles at intersections, junctions, and other traffic-controlled situations.
26. Yield to pedestrians and bicyclists at intersections and crosswalks.
27. Provide safe distance from vehicles, pedestrians, bicyclists on the side of the road.
28. Detect and respond to detours and/or other temporary changes in traffic patterns.

FHWA's *Automated Driving Systems 2.0: A Vision for Safety* provided voluntary guidance to ADS developers that should be resolved prior to deployment using their own, industry, and other best practices. It identifies 12 safety design elements that apply to both ADS original equipment, replacement equipment, and updates, including software updates and upgrades. NHTSA recommends ADS developers consider:[191]

1. System Safety – follow a robust design and validation process using a systems-engineering approach, while setting a goal to design ADSs that are free of unreasonable safety risks within the system's ODD.
2. Operational Design Domain (ODD) – delineates the conditions where an ADS is intended to operate: geographic area (urban places, mountains, deserts, etc.), types of roadways (interstate, local, etc.), speeds, conditions (day or night, weather, etc.), and other constraints.

[191] *Automated Driving Systems 2.0: A Vision for Safety* (Washington, DC: National Highway Traffic Safety Administration, September 2017), www.nhtsa.gov/sites/nhtsa.dot.gov/files/documents/13069a-ads2.0_090617_v9a_tag.pdf.

3. Object and Event Detection and Response (OEDR) – address a wide variety of foreseeable but unusual roadway encounters: emergency vehicles, temporary work zones, police manually directing traffic, construction worker traffic flaggers, etc.
4. Fallback (Minimal Risk Condition) – may vary depending on the type and extent of a given failure, but could include bringing the vehicle to a safe stop, preferably outside of an active traffic lane. Strategies should anticipate that, despite laws and regulations, human back up drivers and occupants may be inattentive, drowsy, under the influence of alcohol or other substances, or otherwise impaired.
5. Validation Methods – simulation, test-track, and on-road testing should be used to demonstrate that an ADS performs competently during normal operations, in crash avoidance situations, and while performing fallback strategies relevant to the ADS's ODD. These tests could be performed by an independent third party. Developers should work with NHTSA, SAE, International Organization for Standards (ISO), and others to develop test criteria and facilities for conducting validation.
6. Human-machine Interface – at a minimum, an ADS should be able to inform a human operator or occupant whether or not it is: functioning properly, currently engaged in ADS mode, available for use, experiencing a malfunction, or requesting control transition from the ADS to the operator. Developers should also consider voluntary guidance, best practices and design principles for the automation level and expected driver engagement needs as established by SAE, ISO, NHTSA, the American National Standards Institute (ANSI), the International Commission on Illumination (CIE), and other relevant organizations.
7. Vehicle Cybersecurity – developers are encouraged to incorporate best practices, voluntary guidance, and design principles established by the National Institute of Standards and Technology (NIST), NHTSA, SAE, the Alliance of Automobile Manufacturers, the Association of Global Automakers, the Automotive Information Sharing and Analysis Center (Auto-ISAC), and other relevant organizations.
8. Crashworthiness – AV developers should anticipate that ADS-driven vehicles will operate on public roadways with human-driven vehicles for a long time. Thus, each AV needs to consider how it will protect vehicle occupants in a situation where it is involved in a crash.
9. Post-crash ADS Behavior – AV developers should consider how each ADS will return to safe state after being involved in a crash, which may include: shutting off the fuel pump, removing motive power, and moving to a safe location off the roadway, and disengaging electrical power. If available, the ADS should be able to communicate and share relevant crash data, particularly any information that can reduce the harm resulting from the crash. Developers are also encouraged to document appropriate maintenance and repair facilities, and the equipment and processes required in order to ensure safe operation post repair.
10. Data Recording – collect data associated with fatal, non-fatal personal injury, or crashes that require towing in order to facilitate continuous learning. In order to reconstruct crash circumstances, ADS data should be stored, maintained, and available for retrieval, standard with current practice, from crash data event recorders. At a minimum, all available information relevant to the crash should be recorded, including the status of the ADS—and any human interventions—leading up to, during, and immediately after the crash. NHTSA is working with SAE to establish uniform data elements for crash reconstruction.
11. Consumer Education and Training – develop and maintain training programs for employees, dealers, distributors, and consumers that address anticipated differences in the use and operation of each ADS relative to the conventional vehicles widely owned and operated today.

AV developer staff, including those in marketing and sales, should understand the technology well enough to educate and train dealers, distributors, and consumers. Topics should include an ADS's functional intent, operational parameters, system capabilities and limitations, and mechanisms that could alter its behavior while in service. These programs could include on-road or on-track demonstrations of ADS operations and human-machine interface functions before they are made commercially available.

12. Federal, State, and Local Laws – account for all federal, state, and local traffic laws within an ODD. In some foreseeable events, such as crossing a double line to pass a vehicle stopped in the road, the ADS may violate motor vehicle driving laws in safety-critical situations. It is anticipated that an ADS will have the capability to handle such events, and that there is documentation, independent assessment, testing, and validation for all plausible scenarios. AV developers should create a process to update and adapt an ADS to address new or revised legal requirements.

AV developers are advised to document how the ADS assesses, tests, incorporates, and validates its response to each safety design element. AV developers are encouraged to submit voluntary safety self-assessments to NHTSA. The agency also requests to be the sole regulator of ADS technology safety design and performance in order to avoid conflicting federal and state laws and regulations, which could slow deployment. There are still many other concerns to be determined, such as: will the public accept the voluntary approach being taken by NHTSA; if it will be able to produce the safest possible vehicles; will it address possible equity concerns in crash disparities (if, for instance, pedestrians are put at greater risk than fellow vehicle occupants); and whether NHTSA's stance risks missing out on innovative regulatory policies, such as when the states act as "laboratories" for federal policy.

Plus.ai will have an independent third party auditor, the Transportation Research Center (TRC) in Ohio, test the capabilities of its Level 2 automated trucks.[192] TRC will design and conduct the tests at highway speeds without input from Plus.ai using a 7.5-mile oval track.[193] The testing will include multiple vehicle scenarios that simulate complex, realistic driving conditions: steering, braking, accelerating, changing lanes, and a combination of all of these driving in free-flow conditions, stop-and-go conditions, work zones, and around disabled vehicles and bicycles; conditions will also include a range of weather conditions, visibility, and lighting.[194]

Preparing First Responders for Safe AV Incident Management

In advance of HAV testing or operations, state DOTs and local agencies should establish cross-jurisdictional approaches and work with first responders and law enforcement to update practices and response plans.[195] New procedures may be needed for the police to be able to pull ADS-equipped vehicles over and verify that they are being used appropriately and operated within the law.[196] All types of responders—police, fire, emergency medical services, and towing operations—will need to be trained on safe interactions with partially or fully disabled ADS-vehicles, especially at

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[192] Richard Bishop, "In an Industry First, Plus.ai to Submit Their Self-Driving Trucks to Independent Test," *Forbes*, July 21, 2020, www.forbes.com/sites/richardbishop1/2020/07/21/in-an-industry-first-plusai-to-submit-their-self-driving-trucks-to-independent-testing/#63033e3b6254 (accessed July 30, 2020).
[193] Bishop, "In an Industry First, Plus.ai to Submit Their Self-Driving Trucks to Independent Test."
[194] Bishop, "In an Industry First, Plus.ai to Submit Their Self-Driving Trucks to Independent Test."
[195] U.S. Department of Transportation, *Preparing for the Future of Transportation: Automated Vehicles 3.0*.
[196] U.S. Department of Transportation, *Preparing for the Future of Transportation: Automated Vehicles 3.0*.

crash scenes.[197] For instance, how to assure that an HAV won't move until it has been authorized to do so, and how to disable and restart the ADS.[198]

Waymo has released a law enforcement emergency response guide which details how police, firefighters, and paramedics can interact and respond to its AVs.[199] These guidelines include:

- Instructions for disabling the automated driving mode, turning the vehicle off, and disconnecting the battery or disabling electric power if responders can't get inside the car; as well as how to safely pry open and deactivate an AV if passengers are unconscious and need help.
- A toll-free, 24-hour hotline, which can also be accessed by pushing the 'Live Help' button on the vehicle's ceiling, to talk with a trained specialist and identify the best solution for the situation.
- An overview of the vehicle's parts and their capabilities, as well as details on how to make sure it doesn't drive off while first responders are trying to access it.
- Once turned off, a Waymo AV can be towed just like any other vehicle.

If an HAV is involved in a crash, first responders will need to know that it is ADS equipped and where the disengagement mechanism is. On some vehicles, the button might be behind the driver's seat, in others in the center console. Standardization could help to ensure that every model doesn't end up with different features and locations. If this happens, responders may have a difficult time finding the disengagement mechanism, especially if at an incident under less than ideal circumstances. Responders will want to know if the ADS was in control at the time of the crash; whether the ADS informed the human operator that they should take control; why other road users thought the car's ADS would stop for them; why the ADS didn't recognize the danger and avoid it; and ultimately, whether the crash was the fault of the ADS, the driver, the other party, or all three.[200] Responders will also want to know how to access data as evidence in the crash investigation process. If this data is not stored on the vehicle, will manufacturers be obligated to hand over the data, especially if it is considered proprietary?

Vision Zero

Vision Zero and Toward Zero Deaths are planning policies that aim to end fatal and serious injury crashes by protecting all roadway users through equitable engineering, education, and enforcement, while prioritizing speed control—although, many Vision Zero advocates and cities are rethinking enforcement in light of the Black Lives Matter racial justice protests. Both New Jersey and Pennsylvania are Toward Zero Death states, and Philadelphia is a Vision Zero city. Traditional road safety engineering has emphasized reducing crashes and the role of personal responsibility. Vision Zero shifts the focus to eliminating deaths and serious injuries through transportation network design and understanding kinetic energy and the human body's tolerance.[201]

The combination of HAVs and Vision Zero represent an opportunity to largely reset the transportation system and redesign it with more focus on its safe use. The starting point for redesigning a complex system, such as transportation, matters a lot. A commonly cited statistic states that 94 percent of crashes are caused by human error. This is often presented as a case for

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197 U.S. Department of Transportation, *Preparing for the Future of Transportation: Automated Vehicles 3.0*.
198 Hedlund, PhD, *Preparing for Automated Vehicles: Traffic Safety Issues for States*.
199 The guidelines are available at: https://storage.googleapis.com/sdc-prod/v1/safety-report/waymo-emergency-response-guide-law%20-enforcement-interaction-plan.pdf.
200 Hedlund, PhD, *Preparing for Automated Vehicles: Traffic Safety Issues for States*.
201 Ann-Catrin Kristianssen, Ragnar Andersson, Matts Åke Belin, and Per Nilsen, "Swedish Vision Policies for Safety—A Comparative Policy Content Analysis," *Safety Science*, 103 (2018) 260-269, May 24, 2017.

why AVs are needed. The source for this claim is likely NHTSA's 2015 report on *Critical Reasons for Crashes Investigated in the National Motor Vehicle Crash Causation Survey*. This report states: "The critical reason, which is the last event in the crash causal chain, was assigned to the driver in 94 percent (+/-2.2%) of the crashes." This statement considers only the last event in the crash causal chain, and not all of the events leading up to that point.[202] It doesn't examine whether the road's design factors into the human error, or flaws in vehicle engineering or road design or maintenance.[203] Police reports don't identify whether headlights were operating, the brakes were working properly; or if turning radii, lane width, lack of high-visibility crosswalks, ADA non-compliance, or inoperable pedestrian signal buttons were factors.[204] Engineers usually work during the day, so they don't investigate a crash scene during night hours, when visibility may be an issue.[205] A different statistic is used in Sweden's Vision Zero philosophy: "research has found that 63 percent of all deaths have the roadway environment or vehicle system as the main cause of fatalities."[206] When an issue is addressed starting with a statement like this, as opposed to the 94 percent of crashes are caused by human error, a very different set of solutions is likely to emerge.[207]

Protecting Bicyclists and Pedestrians

Better protecting the most vulnerable roadway users—bicyclists and pedestrians—is central to the tenets of Vision Zero. William Riggs and Michael R. Boswell have proposed a set of principles for HAV developers and policymakers to use in order to ensure the technology improves bicyclist safety:[208]

1. HAVs should be able to detect bicyclists and understand all signage and lane markings dedicated to bicycles.
2. HAVs should be able to detect and understand bicyclists' hand signals.
3. HAVs should cede the right-of-way to bicyclists.
4. HAVs should be able to visibly and audibly signal basic intentions.
5. When unable to pass, HAVs should follow bicyclists at a safe distance.
6. HAVs should exceed the four-foot minimum passing rule, especially when traveling at higher speeds.
7. HAVs should leave an ample margin of safety when turning, passing, ceding right-of-way, and other interactions with bicyclists.
8. HAVs should detect and prevent the 'dooring' of approaching bicyclists.
9. HAV design should minimize bicyclists injury in the event of a collision.
10. HAVs should travel at appropriate urban speeds to facilitate safe travel for non-motorized users.
11. HAVs should minimize use of streets designated as bicycle boulevards, or have high bicycle use but no separated facilities.
12. Companies deploying shared HAVs should adequately supply vehicles equipped with bicycle racks or carriers to meet demand.

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[202] Dan Kostelec, "On the 9th Day of Safety Myths, my DOT Gave to me...94 Percent!" *Kostelec Planning Blog*, December 19, 2018, www.kostelecplanning.com/on-the-9th-day-of-safety-myths-my-dot-gave-to-me-94-percent/ (accessed January 2, 2019).
[203] Kostelec, "On the 9th Day of Safety Myths, my DOT Gave to me...94 Percent!"
[204] Kostelec, "On the 9th Day of Safety Myths, my DOT Gave to me...94 Percent!"
[205] Kostelec, "On the 9th Day of Safety Myths, my DOT Gave to me...94 Percent!"
[206] Kristianssen et al., "Swedish Vision Policies for Safety."
[207] Kostelec, "On the 9th Day of Safety Myths, my DOT Gave to me...94 Percent!"
[208] William Riggs and Michael R. Boswell, "The Bicyclists' Manifesto for an Autonomous Vehicle Future," *Planetizen*, September 13, 2016, www.planetizen.com/node/88564/bicyclists-manifesto-autonomous-vehicle-future (accessed October 12, 2016).

13. HAV companies should record and share all crash data with local, state, and national law enforcement and regulatory agencies.

These should be the starting point of a wider conversation about HAVs, bicyclists, and safety. Other analysts expect that some of today's most effective safety strategies—separated bike lanes, lighting improvements, pedestrian crossing islands, and gateway treatments—will make it easier to detect or predict the presence of pedestrians and bicyclists.[209]

Connected technologies could also improve vehicle detection of pedestrians and bicyclists, potentially preventing many crashes that occur due to limited sight distances or from being obscured by objects such as trees, utility poles, or parked vehicles.[210] However, CV technologies suffer from poor locational accuracy—especially in urban canyons—inability to predict intentions, identification of false positives and false negatives, privacy, and issues when non-motorized users don't carry an active beacon due to cost, choice, or device failure.[211] ADSs will need advanced detection, prediction, and avoidance capabilities to steer safely around bicyclists, who may have unpredictable weaving behaviors, can legally ride in the middle of a traffic lane at a slower speed, and how to navigate around bicyclist crashes.[212] If ADSs are designed to always yield to pedestrians, then pedestrians may game the system in response—such as crossing the street in front of an HAV and expecting it to stop—or overly trust the technology.[213] Either of these could increase the risk for conflict and crashes, especially in mixed fleets. Zones with high levels of pedestrian activity may make HAV travel inefficient and unworkable.[214]

There may be a need to limit when and where an ADS can operate in order to protect bicyclists and pedestrians.[215] This could potentially include no operations at night, on shared streets, in pedestrian districts, school zones, and other areas of heightened bicyclist and pedestrian concern.[216] School zones may be particularly unsuited to Level 2 or 3 AV operations, due to the presence of children, pedestrians, and bicyclists, who are all extremely vulnerable and more likely to make unpredictable actions.[217] Other situations where higher amounts of unpredictability is expected may also be unsuitable for lower level AVs, such as street festivals, group running or cycling events, residential streets, or any non-limited-access facility where shared-use space exists and a volume of bicyclists or pedestrians may overwhelm sensor capabilities.[218]

Safety Culture

Traffic safety culture is a belief system shared by a group of people that influences our behavior and actions, as well as our perceived control over situations. Our shared belief systems thus influence our transportation behavior. There is a fundamental need to shift culture within agencies, organizations, and communities to accept the premise that traffic fatalities are unacceptable and preventable if we are to achieve the Vision Zero goal. Even as the U.S. has experienced a general decline in highway fatalities, several behaviors continue to contribute to a significant portion of fatal crashes, including: aggressive driving, speeding, failure to use safety equipment, driving under the

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[209] Sandt, PhD, and Owens, *Discussion Guide for Connected and Automated Vehicles, Pedestrians, and Bicyclists*.
[210] Sandt, PhD, and Owens, *Discussion Guide for Connected and Automated Vehicles, Pedestrians, and Bicyclists*.
[211] Sandt, PhD, and Owens, *Discussion Guide for Connected and Automated Vehicles, Pedestrians, and Bicyclists*.
[212] Sandt, PhD, and Owens, *Discussion Guide for Connected and Automated Vehicles, Pedestrians, and Bicyclists*.
[213] Sandt, PhD, and Owens, *Discussion Guide for Connected and Automated Vehicles, Pedestrians, and Bicyclists*.
[214] Sandt, PhD, and Owens, *Discussion Guide for Connected and Automated Vehicles, Pedestrians, and Bicyclists*.
[215] Sandt, PhD, and Owens, *Discussion Guide for Connected and Automated Vehicles, Pedestrians, and Bicyclists*.
[216] Sandt, PhD, and Owens, *Discussion Guide for Connected and Automated Vehicles, Pedestrians, and Bicyclists*.
[217] Sandt, PhD, and Owens, *Discussion Guide for Connected and Automated Vehicles, Pedestrians, and Bicyclists*.
[218] Sandt, PhD, and Owens, *Discussion Guide for Connected and Automated Vehicles, Pedestrians, and Bicyclists*.

influence of alcohol or drugs, and distracted driving. This suggests that U.S. culture accepts an inherent level of risk. As long as this cultural risk acceptance exists, we are unlikely to eliminate traffic fatalities and serious injuries.

If HAV technology achieves its safety promises market adoption should increase—resulting in reduced vehicle crashes, injuries, and fatalities. If the technology does not improve safety, market adoption would likely slow on its own, but with significant potential for adverse outcomes while that runs its course. Education and data will be critical. Education to ensure a safety culture framework informs consumer demand in ways that incentivize HAV developers to achieve safety promises. Data will be critical to understanding how exposure to HAVs impacts safety, and confirming that these vehicles have, in fact, increased safety.

2. Artificial Intelligence and Technological Reliance

Artificial Intelligence (AI) powers much of the software under the hood of AVs, and its capabilities are key to the viability of developing vehicles that can drive themselves. AI is a set of algorithms that aim to handle unforeseen circumstances, and can function with unstructured data.

Algorithms are the building blocks of AI, but they are built from code developed by human programmers. Algorithms have their own set of concerns, separate from AI. Without going into detail, Greenfield notes some key considerations for algorithmic design.[219]

- How does one know if the information and data that goes into the algorithm is correct? Algorithm developers rarely take responsibility for prejudicial decisions based on bad data.
- How do we show that an algorithm complies with the law? The FTC's Equal Credit Opportunity Rights explicitly prohibits discrimination based on race, color, religion, national origin, sex, marital status, age, or being a recipient of public assistance.
- How do we know if an algorithm's recommendations correlate with real world outcomes? For instance, does an algorithm that determines whether someone should receive a loan actually indicate that person's likelihood of repaying it?

AI systems use algorithms to write their own code, which often reaches a complexity well beyond human comprehension.[220] There are two ways of classifying AI programs. The first identifies the three levels of theoretical AI capabilities (see Figure C-1):

1. Artificial Narrow Intelligence (ANI), which is task specific and is essentially a Big Data pattern recognition software. This is as far as AI has advanced to date.
2. Artificial General Intelligence (AGI), which would mimic human intelligence at an equal or higher level. This would enable intelligent machines—but may be decades away.
3. Artificial Conscious Intelligence (ACI), which would give us sentient machines. It's not clear whether conscious machines are even possible.

ANI has high levels of capability within very narrow subject areas. ANI excels at things that are hard for people—playing championship level Go, Chess, or poker—but it struggles with things that are easy for people—such as communicating or making sense of the surroundings.[221] Yuval Noah Harari

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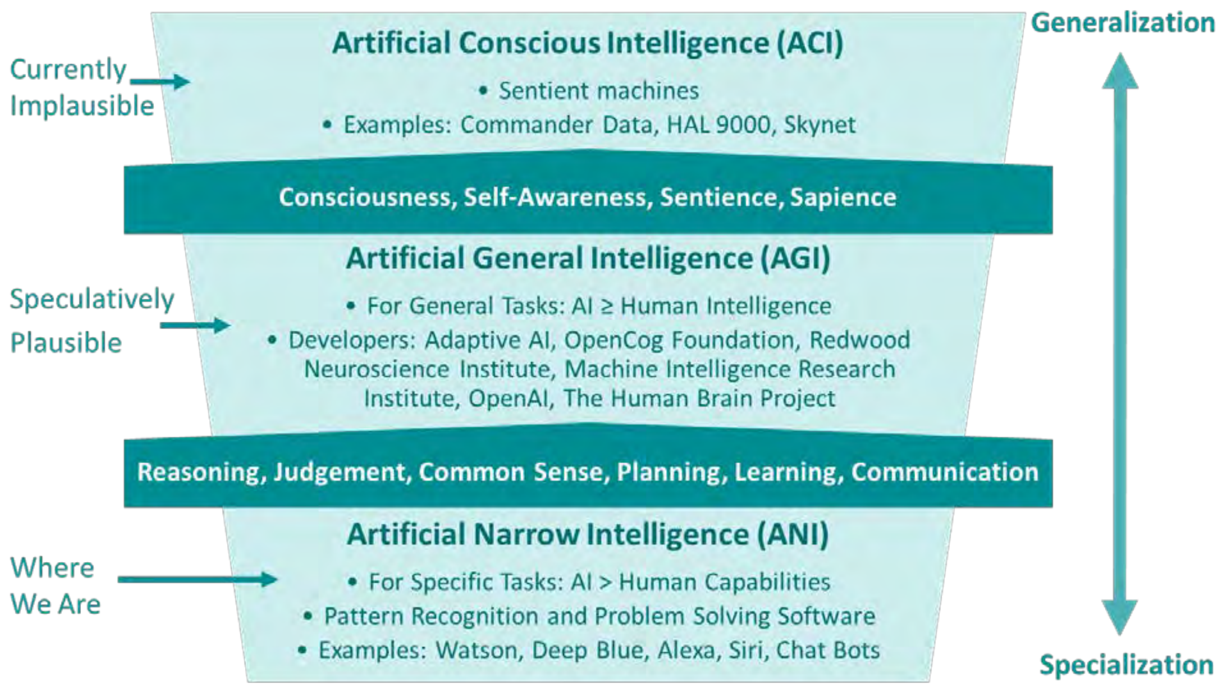
[219] Greenfield, *Radical Technologies* (London: Verso, 2017).

[220] Aarian Marshall, "The Maddening Struggle to Make Robot-Cars Safe—And Prove It," *Wired*, December 15, 2018, www.wired.com/story/zoox-self-driving-cars-safety/ (accessed December 20, 2018).

[221] Kate Baggerly, "There are Two Types of AI, and the Difference is Important," *Popular Science*, February 23, 2017, www.popsci.com/narrow-and-general-ai/ (accessed July 5, 2019).

has noted that ANI, and in the future AGI, are causing intelligence and consciousness to diverge.[222] This is important to recognize, as most movie and television representations are of ACI, a level of technological advancement that no one has any idea how to create. Without consciousness, it is implausible that intelligent machines will rise up against us—a common AI theme from popular entertainment.

Figure C-1. Different Theoretical Levels of Artificial Intelligence Capabilities



Source: Adapted from "Artificial General Intelligence," Wikipedia, last edited October 11, 2019, www.en.wikipedia.org/wiki/Artificial_general_intelligence (accessed October 18, 2019).

While this classification system is useful for understanding different levels of AI, the degree to which a system can do things it isn't programmed to do is a continuum. In some cases, there won't be a distinct easily understood differentiation between ANI and AGI.

The second classification system identifies a pathway for overcoming the barriers between humans and machines to build broadly intelligent and sentient AI systems. These systems build off each other, meaning one can't be achieved without the level below it being available.

- **Reactive machines** are the most basic AI systems.[223] They perceive the world directly and act on what is seen, and do not form memories or use previous experiences to inform their decisions. One example is IBM's Deep Blue, which beat Garry Kasparov by eliminating most possibilities based on how it rated the outcome and focusing on just a few possible moves.[224] Google's AlphaGo is another example, which uses a neural network to evaluate game development. While these techniques enable AI systems to play games better, they can't easily be applied to other

[222] Yuval Noah Harari, *Homo Deus: A Brief History of Tomorrow* (New York, NY: Harper Collins, 2017).
[223] Arend Hintze, "Understanding the Four Types of Artificial Intelligence," *Governing*, November 14, 2016, www.govtech.com/computing/Understanding-the-Four-Types-of-Artificial-Intelligence.html (accessed July 11, 2019).
[224] Hintze, "Understanding the Four Types of Artificial Intelligence."

situations as they have no concept of the wider world.[225] Some AI researchers argue that we should only build reactive AI machines because people aren't able to program accurate simulated representations of the world.[226]

- **Limited memory systems** can consider past experience.[227] These systems include machine learning and deep learning approaches. Concern about humans building simulated worlds can be avoided by letting machines create their own representations.[228]
- **Theory of mind machines** form representations about the world as well as about other agents and entities in the world to understand how people, creatures, and objects can have thoughts and emotions that shape their behavior.[229]
- **Self-awareness systems** could build their own representations about themselves.[230] Though doing this will require AI researchers to both understand the human mind and its consciousness and then be able to build machines with it.[231]

It may be tempting to align the two classification systems into a grand unified theory. This works at the lower levels where ANI aligns nicely with reactive machines and limited memory systems. However, it begins to break down at the higher levels. There is overlap between AGI and theory of mind systems, but they are not a one-for-one match.[232] For example, a machine that is considered to have general intelligence could still fail the theory of mind test.[233] At the highest levels of each classification, self-awareness is only a subset of the consciousness envisioned by ACI.[234] This further recognizes the potential implausibility of ACI, and sets a more reasonable highest-level target for AI.

Machine learning and deep learning are approaches currently being used to train limited memory AI programs. These are tools that can take huge amounts of data and use it to make complex computations.[235] Machine learning is a process by which algorithms are taught to recognize patterns in the world through automated analysis of large, structured datasets.[236] This is an expensive, time-intensive process where humans draw boxes around objects in images and label what is inside the highlighted area.[237] The program then uses these cues to extrapolate and recognize other images.

Deep learning is an unprompted algorithm that brings about order through analyzing vast quantities of data in an unsupervised process.[238] The name deep learning comes from stacking of neural networks.[239] Neural networks contain thousands of simulated neurons, arranged in intricately

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225 Hintze, "Understanding the Four Types of Artificial Intelligence."
226 Hintze, "Understanding the Four Types of Artificial Intelligence."
227 Hintze, "Understanding the Four Types of Artificial Intelligence."
228 Hintze, "Understanding the Four Types of Artificial Intelligence."
229 Hintze, "Understanding the Four Types of Artificial Intelligence."
230 Hintze, "Understanding the Four Types of Artificial Intelligence."
231 Hintze, "Understanding the Four Types of Artificial Intelligence."
232 Arend Hintze, e-mail dated October 21, 2019.
233 Arend Hintze, e-mail dated October 21, 2019.
234 Arend Hintze, e-mail dated October 21, 2019.
235 Berend Berendson, "What's the Difference Between Artificial Intelligence, Machine Learning, and Algorithms?" *WidgetBrain*, November 15, www.widgetbrain.com/difference-between-ai-ml-algorithms/ (accessed October 8, 2019).
236 Greenfield, *Radical Technologies.*
237 Evan Ackerman, "How Much can Autonomous Cars Learn from Virtual Worlds," *IEEE Spectrum*, June 8, 2017, www.spectrum.ieee.org/cars-that-think/transportation/self-driving/how-much-can-autonomous-cars-learn-from-virtual-worlds (accessed September 22, 2017).
238 Greenfield, *Radical Technologies.*
239 Greenfield, *Radical Technologies.*

connected layers.[240] The network's learning consists of input units that represent things such as pixels or words, through multiple layers—the more there are the deeper the network is—that map connections and relationships between inputs and outputs.[241] The first layer receives an input, and then performs a calculation before outputting a new signal, which is fed into the next layer's neurons, and the process is repeated until a final output is created. The program learns by clustering to develop a sense about what is important in its environment through gradually increasing its understanding.[242] For example, a series of images, each of three different types of cars, could be analyzed and sorted by a deep learning program as Cluster_1, Cluster_2, and Cluster_3.[243] Within all these layers is a process that tweaks the findings of individual neurons in ways that allows the network to learn to produce the desired output.[244] These layers enable the network to recognize all kinds of things at different levels of abstraction.[245] Deep neural networks automate perception, and have demonstrated increasing capability to recognize language, perform translation, and enable computers to see.[246] This is where machine learning meets Big Data, with a goal of having an algorithm identify what is important in the world without anyone telling it what to look for.[247]

Machine learning systems are brittle. Since they learn only from existing data, they struggle when encountering a new situation.[248] Some of the specific shortcomings recently noted with the machine learning approach include:

- Object detection and categorization – the ability of an AV to recognize a pedestrian pushing a stroller, carrying a plant or an umbrella, or even a pedestrian that doesn't look like a pedestrian.[249]
- Interpreting and predicting human behavior – anticipating what other drivers, cyclists, and pedestrians are going to do, and even communicating with them. AVs must understand when they are in another vehicle's blind spot, and need to see and react to emergency vehicles.[250]
- Decision making – human drivers make a lot of subtle signals to each other—such as for right-of-way—that a computer currently has a hard time deciphering.[251]
- Sensor snags – AVs combine three different sensor systems: LiDAR (for 3-D vision), cameras (provide color and detail), and radar (long distance detection of objects and their velocities). LiDAR is particularly costly, and the vehicles must combine the data from all three of these sensor systems together, extract what they need to operate, and discard what they don't need.[252]

As a result of machine learning's limitations, deep learning has come to be seen as the Holy Grail for enabling HAVs and other automated systems to operate in real world conditions.[253] ADSs identify objects and monitor them over time. These objects are compared with pre-programmed

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[240] Will Knight, "The Dark Secret at the Heart of AI," *MIT Technology Review*, April 11, 2017, www.technologyreview.com/s/604087/the-dark-secret-at-the-heart-of-ai/ (accessed September 22, 2017).
[241] Gary Marcus, *Deep Learning: A Critical Appraisal* (New York: New York University, undated) www.arxiv.org/ftp/arxiv/papers/1801/1801.00631.pdf.
[242] Greenfield, *Radical Technologies*.
[243] Greenfield, *Radical Technologies*.
[244] Knight, "The Dark Secret at the Heart of AI."
[245] Knight, "The Dark Secret at the Heart of AI."
[246] Knight, "The Dark Secret at the Heart of AI."
[247] Greenfield, *Radical Technologies*.
[248] "Driverless Cars are Stuck in a Jam," *The Economist*.
[249] "Autonomous-Driving Disruption: Technology, Use Case, and Opportunities," *McKinsey*, November 2017.
[250] Aarian Marshall, "After Peak Hype, Self-Driving Cars Enter the Trough of Disillusionment," *Wired*, December 29, 2017, www.wired.com/story/self-driving-cars-challenges/ (accessed September 9, 2018).
[251] "Autonomous-Driving Disruption: Technology, Use Case, and Opportunities."
[252] Marshall, "After Peak Hype, Self-Driving Cars Enter the Trough of Disillusionment."
[253] Greenfield, *Radical Technologies*.

representations of the world: lane markings, traffic lights, digital maps. The ADS uses these representations to help with decision making, such as changing lanes or avoiding crashes. Machine learning and deep learning can then use experiences that are recorded by the ADS to learn from; this enables these programs to study millions of hours of driving and learn more as they go.[254] But key outcomes could be different depending on where the AI learning programs are applied. If they are at the fleet level, then an entire fleet could learn at once and be routinely updated. If it is at the vehicle level, two vehicles from the same production run could spend years encountering different traffic conditions that may result in very different behavior.[255] Lag time and latency issues suggest that an HAV is not likely to be operated through a centralized network in the Cloud.

Gary Marcus' critical appraisal of deep learning raises questions about whether this technology will be able to deliver Level 5 HAVs.[256] Deep learning is useful for optimizing complex systems and mapping the inputs and outputs of large data sets and works best when there are huge numbers of labeled examples. However, it may struggle with generalizing and is overly reliant on large numbers of labeled examples which may lead to exponential inefficiencies that cause failures.[257] While humans can learn abstract relationships quickly, deep learning lacks such capabilities. It is not an ideal solution for situations where data is limited. This is particularly relevant for edge cases, which occur at extreme minimum or maximum operating parameters. For example, an HAV operating on a road with unexpected objects in its path. Corner cases occur when multiple environmental parameters are operating at extreme levels. For example, an HAV operating on a road with unexpected objects in its path during a severe weather event. These are rarely-occurring situations that HAVs still must be prepared for.

Deep learning needs massive amounts of data to train with, and needs to incorporate nearly every possible scenario it will encounter.[258] Google Images is great at recognizing animals as long as it has the training data to show what each type of animal looks like.[259] It learns through interpolation—estimating values based on other known values. For example, deep learning programs can be shown thousands of pictures of a leopard, and then determine if it is looking at a picture of a leopard by deciding if it looks like the other ones it has seen.[260] Data serves as a limitation in how good a deep learning algorithm is.[261] An image recognition program doesn't recognize a leopard as somewhere between a housecat and a jaguar.[262] This is a different skill set, called generalization. Researchers had thought that AI could improve its generalization skills with the right algorithms, but research has found AI is even worse at generalizing than previously thought.[263] One study found it had a hard time generalizing across different frames of the same video.[264]

The key question is whether AVs will keep improving like interpolation programs? Or will they run into the generalization problem?[265] The unpredictability of driving is central to this question.[266] Nothing has ever been automated to this level before, so we don't know what kind of task it is. If it's

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[254] Schladover, "The Truth About Self-Driving Cars."
[255] Schladover, "The Truth About Self-Driving Cars."
[256] Marcus, *Deep Learning: A Critical Appraisal*.
[257] Marcus, *Deep Learning: A Critical Appraisal*.
[258] Brandom, "Self-Driving Cars are Headed Toward and AI Roadblock."
[259] Brandom, "Self-Driving Cars are Headed Toward and AI Roadblock."
[260] Brandom, "Self-Driving Cars are Headed Toward and AI Roadblock."
[261] Brandom, "Self-Driving Cars are Headed Toward and AI Roadblock."
[262] Brandom, "Self-Driving Cars are Headed Toward and AI Roadblock."
[263] Brandom, "Self-Driving Cars are Headed Toward and AI Roadblock."
[264] Brandom, "Self-Driving Cars are Headed Toward and AI Roadblock."
[265] Brandom, "Self-Driving Cars are Headed Toward and AI Roadblock."
[266] Brandom, "Self-Driving Cars are Headed Toward and AI Roadblock."

just identifying familiar objects and following a set of rules, existing technologies can make automation happen. However, safe driving in extreme circumstances may be quite challenging.[267] The more surprising things that happen with driving, the harder it will be to overcome the generalization problem.[268] Without generalization capabilities, each new situation that an HAV encounters could risk a fluky crash, the occurrence of which won't become less common or less dangerous with more data.[269]

Current machine learning and deep learning approaches are largely leading to higher degrees of specialization, while getting HAVs to reach Level 5 capable driving may require a more generalized skillset.[270] Deep learning may not work as well with current road situations such as where there are limited amounts of training data (such as in edge cases), when actual roads are different enough from those used to train the system, or when the road space has broad levels of activity or is filled with novelty (as they often are).

AGI may be a necessary technology for achieving Level 5 HAVs that can go to and from anywhere and safely respond to any situation it encounters on roads around the world. Lack of computing power is one of the challenges behind achieving AGI. Quantum computing is seen as a potential solution. The critical difference is the use of probability in decision making, which AGI can do, but ANI cannot.[271] Machine intelligence will be needed to ensure HAVs understand their operating environment even when it is passively hacked—such as if a vandal removes a stop sign from a four-way intersection, creating a risk that an ADS won't realize it needs to stop and continues directly through the intersection. An ANI-powered, or deep-learning-based HAV may not know to stop without the sign.[272] An AGI-powered HAV will understand its surrounding context and stop, as the vast majority of humans would do in this situation.[273]

AGI needs background knowledge about the world, common sense, and a memory of what it has been exposed to.[274] Most scientists agree that this level of machine intelligence is at least 25 years away.[275] While current deep learning approaches are unlikely to achieve AGI, new approaches in developing neuro evolution through 'Markov brains' and population-based deep learning, which combines neuro evolution with traditional deep learning approaches, may speed up this timeline.[276] Markov brains neuro evolution is being developed with a superset of all neural networks optimized with genetic algorithms, in what can be called a combination of deep learning and reinforcement learning.[277] Other potential techniques include hybrid artificial intelligence, which combines neural networks and symbolic AI to give deep learning the ability to deal with abstractions; system 2 deep learning, which uses a pure neural network approach to enable deep learning to manipulate symbols;

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[267] Brandom, "Self-Driving Cars are Headed Toward and AI Roadblock."
[268] Brandom, "Self-Driving Cars are Headed Toward and AI Roadblock."
[269] Brandom, "Self-Driving Cars are Headed Toward and AI Roadblock."
[270] Baggerly, "There are Two Types of AI, and the Difference is Important."
[271] Colin Colter, "The 'Car Wrecks' Ahead in the World of Artificial Intelligence and Transportation," *Duke Today*, June 13, 2019, www.today.duke.edu/2019/06/car-wrecks-ahead-world-artificial-intelligence-and-transportation (accessed June 20, 2019).
[272] Colter, "The 'Car Wrecks' Ahead in the World of Artificial Intelligence and Transportation."
[273] Colter, "The 'Car Wrecks' Ahead in the World of Artificial Intelligence and Transportation."
[274] Baggerly, "There are Two Types of AI, and the Difference is Important."
[275] Baggerly, "There are Two Types of AI, and the Difference is Important."
[276] Arend Hintze, e-mail dated October 23, 2019.
[277] Arend Hintze, e-mail dated October 23, 2019.

and self-supervised learning, which explores the world on its own without much human help or instruction.[278]

In 2016, NVIDIA may have been the first company to use AI to help an ADS learn to drive by watching humans drive.[279] While getting AI to drive a car is a considerable feat, it's not entirely clear how it works.[280] This could create a big problem if it crashes into specific objects, sits through green lights, or has other operating errors. Engineers and programmers won't be able to determine what in the code is causing the problem as it will be difficult to isolate the reasoning behind any individual action. The challenge is so difficult that some companies, particularly those in China, think it may be easier to reengineer cities to support limited HAVs than to build Level 5 HAVs.[281]

There are two different schools of thought as to how understandable and explainable AI should be. The first thinks machines should be built to use rules and logic, and make their inner workings transparent to anyone who wanted to examine the code it produces.[282] The second prefers that machines learn by observing and experiencing, which turns computer programming on its head as the program generates code using data and desired outputs.[283]

This second school has taken off in the 2010s thanks to refinements to large, 'deep' neural networks.[284] Since we've never built machines that operate in ways we can't fully understand, some AI experts are making the case that the ability to interrogate an AI system on how it reached its conclusions should be a fundamental legal right.[285] Daniel Dennet, a renowned philosopher and computer scientist, suggests there may be no perfect answer to making AI explainable, which means "if it can't do better than us at explaining what it's doing, then don't trust it."[286]

Ethical Decisions Made by Machines

As we take moral decision making away from people and put it into the hands of machine programmers, we may be losing something that is essential to the human experience.[287] A common safety concern is how to algorithmically program ethical decision making into HAVs. Emergency situations sometimes require a choice between bad outcomes. How will HAVs make decisions when a crash is inevitable? Will it risk injuring the vehicle occupant(s) by running off the road, or harm the pedestrian in the way? Codifying these quandaries into an algorithm brings up very serious moral issues.[288]

The trolley problem asks what course of action someone should take if they see a runaway trolley careening down tracks that would kill five people who are unable to get out of the way. There is a lever that can be pulled to switch the trolley onto another set of tracks, but doing so would kill a worker who is standing alongside this second set of tracks. The key question is would you intervene to save five peoples' lives at the cost of another person's life. There has not been a satisfying philosophical answer to the trolley problem, which makes it difficult for HAV developers to know

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[278] Ben Dickson, "Why Deep Learning Won't Give Us Level 5 Self-Driving Cars," *Tech Talks*, July 29, 2020, www.bdtechtalks.com/2020/07/29/self-driving-tesla-car-deep-learning/ (accessed August 5, 2020).
[279] Knight, "The Dark Secret at the Heart of AI."
[280] Knight, "The Dark Secret at the Heart of AI."
[281] "Driverless Cars are Stuck in a Jam," *The Economist*.
[282] Knight, "The Dark Secret at the Heart of AI."
[283] Knight, "The Dark Secret at the Heart of AI."
[284] Knight, "The Dark Secret at the Heart of AI."
[285] Knight, "The Dark Secret at the Heart of AI."
[286] Knight, "The Dark Secret at the Heart of AI."
[287] Hands-Free, Mind-Free: What We Lose through Automation."
[288] Hands-Free, Mind-Free: What We Lose through Automation."

how to deal with these concerns.[289] Harari has suggested that different HAV programming versions should be offered. An altruist could choose to kill the car occupants in an emergency situation, while an egoist could pick an option that would kill the non-passengers in danger.[290] Alternatively, a driver could choose who to prioritize—their self as the passenger, those in other vehicles, or other non-motorized road users.[291] However, the case could be made that it is immoral to give HAV occupants the right to prioritize their lives over those of other, more vulnerable road users. Lower speeds—which are the difference between surviving a crash and dying from one—are a potential way around these ethical driving dilemmas.[292]

Interoperability between the IoT, HAVs, and CVs will be another challenge.[293] The Internet, energy grid, and other infrastructures are highly interdependent on each other. As a result, a technology glitch could trigger a series of interconnected incidents leading to a cascading failure of systems, potentially knocking key components of an ADS offline as well.[294]

3. Developing Profitable Business Models

AV developers have already invested considerable sums into ADS technologies, but are only now considering the challenge of creating a profitable business model.[295] Google started its AV project out of its 'X' program, which aims to solve difficult technological problems first and figure out commercialization later.[296] Commercializing ADS technologies may also be difficult due to the need for government certification, building public trust, branding, scaling up manufacturing, and managing fleets in ways that are cost competitive with TNCs and conventional human-driven vehicles.[297]

Google and a handful of other companies have been taking the moonshot approach, which would jump straight to Level 5 HAVs. Given the daunting challenges of achieving this level of automation, there is a lot of risk in the moonshot approach. Other companies are taking a more incrementalist path, with a goal to get a less demanding technological application to the market quickly by experimenting with automated trucks and shuttles and sidewalk delivery robots.[298] These projects have speeds under 25 miles per hour and only operate in limited areas. The incremental approach risks running into a dead-end when scaling these services to wider areas or higher speeds.

The timing at which different levels of HAVs become technologically feasible will shape the ability to develop profitable business models, and will test out whether shared or individually-owned HAVs make the most sense for individuals and households. Vehicles are typically fast-depreciating assets that are a worthwhile investment for households due to the access to opportunity they grant. A shared model that can still give as much or more access to opportunity at lower costs could be highly valuable to individual consumers. Level 5 autonomy would provide the most benefits, but increasingly looks out of reach, at least with current technology. Ride-hailing and goods movement companies would like to remove the cost of drivers, but haven't yet figured out who will pay for

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[289] Yuval Noah Harari, *21 Lessons for the 21st Century* (New York, NY: Speigel & Grau, 2018).
[290] Harari, *21 Lessons for the 21st Century*.
[291] Harari, *21 Lessons for the 21st Century*.
[292] National Association of City Transportation Officials, *Blueprint for Autonomous Urbanism*.
[293] Federal Highway Administration, *The Smart/Connected City and its Implications for Connected Transportation.*
[294] Federal Highway Administration, *The Smart/Connected City and its Implications for Connected Transportation.*
[295] Raphael Orlove, "One Big Problem With Driverless Cars: Figuring Out How They Make Money," *Jalopnik*, November 26, 2019, www.jalopnik.com/one-big-problem-with-driverless-cars-figuring-out-how-1840046314 (accessed December 5, 2019).
[296] Timothy B. Lee, "Why Some Self-Driving Startups Reject Google's 'Moonshot' Approach," *Ars Technica*, July 21, 2020, www.arstechnica.com/cars/2020/07/slow-progress-on-self-driving-is-putting-startups-in-a-bind/ (accessed July 28, 2020).
[297] Lee, "Why Some Self-Driving Startups Reject Google's 'Moonshot' Approach."
[298] Lee, "Why Some Self-Driving Startups Reject Google's 'Moonshot' Approach."

automation.[299] Level 3 and 4 HAVs could operate within geofenced areas, but may require back up drivers, limiting potential cost savings for automation.[300]

Tesla has shown that some drivers will pay for Level 2 technologies—even if they require constant attention and require acceptance of the risk of catastrophic failure—but it's not clear there's enough consumers out there to make these systems profitable.[301] A recent *Consumer Reports* review of Tesla's suite of self-driving technologies—including Autopark, Auto Lane Change, Summon / Smart Summon, Navigate on Autopilot, and Traffic Light and Stop Sign Control—found that significant driver attention is needed to ensure these new features don't increase safety risks.[302] *Consumer Reports* suggests drivers should not rely on these safety features to make driving safer or easier, and even questions whether these technologies, which add $8,000 to the sticker price, provide any consumer benefit at all.[303] In the meantime, other automakers are highly focused on rolling out EVs, an equally capital-intensive undertaking that is closer to being profitable.[304] Simultaneously implementing two major revolutions in transportation may prove cost-prohibitive.

Middle-mile trucking, where an automated truck travels along the same limited access facility route, and personal delivery devices may be the best business case pathways for moving automation forward.[305] Delivering goods instead of people reduces the challenge, as there is less concern for passenger comfort and safety, and HAVs can take less direct, lower traffic-volume routes.[306] Already a couple of notable automated truck deliveries have been completed along the nation's highways. In October 2016, the 'beer run' was a 120-mile trip by the now defunct Otto delivering Anheuser-Busch beer from Fort Collins, CO to Colorado Springs, CO along I-25. In November 2019, Plus.ai took 40,000 pounds of Land O'Lakes butter 2,800 miles from Tulare, CA to Quakertown, PA along I-15 and I-70 in three days without a single disengagement.[307] The truck was able to successfully handle a variety of terrains along with rain and low visibility.[308] There was both a safety driver and a safety engineer on board.[309] Another automated truck maker, Gatik, has partnered with Walmart to help with middle-mile deliveries.[310] Its vehicles are box trucks and vans between 11 and 20 feet long and carry ambient, cold, and frozen goods.[311] Its business model connects with emerging micro distribution centers that retailers are setting up to meet increasing demand for online orders due to the COVID-19 pandemic.[312] It has completed more than 15,000 runs as of May 2020 with a safety driver in

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[299] Jay Ramey, "Here's Why Our Gleaming Self-Driving Future Has Been Delayed Indefinitely," *Autoweek*, June 8, 2020, www.autoweek.com/news/technology/a32782600/why-level-5-autonomous-driving-has-not-happened/ (accessed July 27, 2020).
[300] Jay Ramey, "Here's Why Our Gleaming Self-Driving Future Has Been Delayed Indefinitely."
[301] Jay Ramey, "Here's Why Our Gleaming Self-Driving Future Has Been Delayed Indefinitely."
[302] Mike Monticello, "Tesla's 'Full Self-Driving Capability' Falls Short of its Name," *Consumer Reports*, September 8, 2020, www.consumerreports.org/autonomous-driving/tesla-full-self-driving-capability-review-falls-short-of-its-name/ (accessed September 8, 2020).
[303] Monticello, "Tesla's 'Full Self-Driving Capability' Falls Short of its Name."
[304] Kalea Hall, "Coronavirus Presents Obstacles for Autonomous Vehicles," *Government Technology*, May 26, 2020, www.govtech.com/fs/transportation/Coronavirus-Presents-Obstacles-for-Autonomous-Vehicles.html (accessed July 16, 2020).
[305] Rachel Binder, "The Future of Transportation: Impact of COVID-19 on Mobility," *CB Insights* (webinar), June 25, 2020, www.cbinsights.com/research/briefing/webinar-future-transportation-mobility/recording/ (accessed July 25, 2020).
[306] Binder, "The Future of Transportation: Impact of COVID-19 on Mobility."
[307] Levi Sumugaysay, "Spread the News: Self-Driving Truck Makes Cross-Country Butter Delivery," *The Cupertino Courier*, December 10, 2019, www.ttnews.com/articles/spread-news-self-driving-truck-makes-cross-country-butter-delivery (accessed January 17, 2020).
[308] Sumugaysay, "Spread the News: Self-Driving Truck Makes Cross-Country Butter Delivery."
[309] Sumugaysay, "Spread the News: Self-Driving Truck Makes Cross-Country Butter Delivery."
[310] Kirsten Korosec, "Gatik Adds Autonomous Box Trucks to its 'Middle-Mile' Game Plan," *Tech Crunch*, May 6, 2020, www.techcrunch.com/2020/05/06/gatik-adds-autonomous-box-trucks-to-its-middle-mile-game-plan/ (accessed August 3, 2020).
[311] Kirsten Korosec, "Gatik Adds Autonomous Box Trucks to its 'Middle-Mile' Game Plan."
[312] Kirsten Korosec, "Gatik Adds Autonomous Box Trucks to its 'Middle-Mile' Game Plan."

place.[313] The company intends to eventually remove these drivers by using repeatable routes, where they don't make multiple lane changes and only perform right turns.[314]

Viscelli has envisioned the construction of automated truck ports (ATPs) along highway exit ramps that serve as a transfer station between ADS highway driving and a human driver that makes the first-mile and last-mile portion of a freight trip between the origin and the highway and then the highway and the destination. Given current difficulties with finding locations for truck parking in the region, it will be challenging to develop the ATPs needed for large scale AV truck movement. Land use patterns around ATPs, which would act similar to intermodal facilities, will also likely change significantly. Such an investment probably makes the best sense if there is a continuing use case for Level 5 trucks, or if Level 5 automation appears likely to arrive decades after Level 4. These issues are discussed further in the People Power scenario and later in this appendix.

A second promising business model exists in the personal delivery devices being developed by Starship Technologies, Nuro, and others. These low-speed vehicles make last-mile deliveries using the sidewalk, roadway shoulder, or through lanes.

Automakers and supportive services will seek both profit from their operations and a return on investment in research and development—though scaling up these supportive technologies at the same time may prove challenging. Once a company does develop a profitable model, it may become easier to apply to other markets, especially by learning from experience and scaling up from it.[315] For this reason, HAV technology is likely to be rolled out region by region, and perhaps even neighborhood by neighborhood, as a nationwide, and possibly even regionwide, approach will be cost prohibitive.

The longer AV developers go without a commercial product, the more skeptical investors may become.[316] These challenges were compounded by the stay-at-home orders due to COVID-19, which have cost automakers billions as plants shut down and left dealerships unable to sell vehicles.[317] A prolonged economic downturn as a result from the pandemic could significantly delay the HAV timeline and alter the industry's landscape. If investments and venture capital funding decline, it's possible that AVs will only be remembered as a heavily hyped concept.[318] Though, private companies seeking to unlock an estimated $6 trillion industry are likely to find some way to do so.

Overcoming Public Skepticism

Surveys have not found a warm initial public reaction to HAVs:[319]

- Many are skeptical about sharing the road with ADS vehicles.
- Many are unconvinced that ADS vehicles will bring about major safety benefits.
- Many are unwilling to ride in an ADS vehicle, and very few have interest in buying one.
- Drivers want to be able to retain control over vehicle operations when desired.

However, support is likely to grow as people learn more about ADS vehicles and experience them for themselves. A 2017 survey of 321 Bike Pittsburgh members, where there is active AV testing, found

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313 Kirsten Korosec, "Gatik Adds Autonomous Box Trucks to its 'Middle-Mile' Game Plan."
314 Kirsten Korosec, "Gatik Adds Autonomous Box Trucks to its 'Middle-Mile' Game Plan."
315 Lee, "Why Some Self-Driving Startups Reject Google's 'Moonshot' Approach."
316 Lee, "Why Some Self-Driving Startups Reject Google's 'Moonshot' Approach."
317 Hall, "Coronavirus Presents Obstacles for Autonomous Vehicles."
318 Orlove, "One Big Problem with Driverless Cars: Figuring Out How They Make Money."
319 Hedlund, PhD, *Preparing for Automated Vehicles: Traffic Safety Issues for States*.

42 percent of their members felt safe sharing the road with an ADS, whereas only 18 percent felt safe sharing the road with human drivers.[320]

Other individuals may be unwilling to give up driving and vehicle control. A survey conducted by the World Economic Forum and the Boston Consulting Group of a representative sample of 2,400 Bostonians asked about travel choices for specific trips using eight different potential modes in 2030. It found that age was a bigger factor in AV adoption than income and that older people are simply less likely to try new technologies.[321] To build comfort with the technology, the City of Boston hosted an AV petting zoo just outside its city hall to allow the public to see and interact with these vehicles.[322]

A 2015 consumer survey of 5,550 residents in 27 countries found respondents most valued HAVs for eliminating the need to find parking, followed by the ability to multitask and be productive while traveling, and not having to drive in traffic jams.[323] However, there may be increased anxiety in not being able to reach one's destination, especially if vehicle operations are out of the passenger's control.[324] The public may become more skeptical if testing fails to show increased safety, particularly if there is a major crash or series of crashes where an ADS is at fault.

Discontent with an automated future can be seen in the attacks on AVs in Arizona. It is also expressed in gatherings such as Radwood, which bring fans of pre-computerized cars—essentially vehicles built before 2000—together and celebrates an era when regular people could maintain their own cars using relatively simple tools.[325] The Human Driving Association has formed around protecting freedom of movement and the individual right to own and drive cars. It advocates for every car produced, even HAVs, to still be drivable under full human control with necessary steering wheels and pedal controls and calls for a constitutional amendment that enshrines the right to drive.[326] These events and organizations go beyond nostalgia, they are also resisting a technologically determined future.[327] The ability to repair the things we own and use is becoming harder and harder in the digital age, as proprietary software is embedded into everything.[328] Political philosopher Matthew B. Crawford argues that knowing how to repair things helps people better understand the world and provides meaningful work and purpose.[329]

The Tech Backlash

A societal focus on inclusivity and equity may result in a backlash against technology. The tech industry has been lightly regulated, in order to promote innovation, but recent concerns over the spread of misinformation has led to increased scrutiny on the sector. Stricter regulations could set HAVs back technologically—but without more regulations HAVs could suffer from a more negative public opinion. Prior to COVID-19, there were many indications that a backlash was happening. A 2020 Gallup and Knight Foundation survey found:[330]

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[320] Hedlund, PhD, *Preparing for Automated Vehicles: Traffic Safety Issues for States*.
[321] Hedlund, PhD, *Preparing for Automated Vehicles: Traffic Safety Issues for States*.
[322] Moavenzadeh and Lang, *Reshaping Urban Mobility with Autonomous Vehicles: Lessons from the City of Boston.*
[323] Moavenzadeh and Lang, *Reshaping Urban Mobility with Autonomous Vehicles: Lessons from the City of Boston.*
[324] Litman, *Autonomous Vehicle Implementation Predictions*.
[325] M.R. O'Connor, "The Fight for the Right to Drive," *The New Yorker*, April 30, 2019, www.newyorker.com/culture/annals-of-inquiry/the-fight-for-the-right-to-drive (accessed May 5, 2019).
[326] O'Connor, "The Fight for the Right to Drive."
[327] O'Connor, "The Fight for the Right to Drive."
[328] O'Connor, "The Fight for the Right to Drive."
[329] O'Connor, "The Fight for the Right to Drive."
[330] *Techlash? America's Growing Concern with Major Technology Companies* (Washington, DC: Gallup and Knight Foundation, 2020).

- Americans have largely negative views on how major technology and Internet companies impact society.
- Across the demographic and political spectrum, the public believes that technology and Internet companies have too much power.
- Americans distrust social media companies to make the right decisions about content, but are divided on what role the government should play in regulating them.
- 59 percent of Americans across demographic and political groups, believe political leaders are not paying enough attention to technology and tech companies.

The EU imposed the General Data Protection Regulation, levied multi-billion dollar fines against Big Tech, and published a paper calling for new restrictions on the use of personal data for Artificial Intelligence programs; while California passed the Consumer Privacy Act.[331] Right before the pandemic, the *New York Times* ran a series of scathing articles about smartphone surveillance, and 2020 Democratic presidential candidates were competing to have the toughest rhetoric and how far to go with regulations against big tech companies.[332]

COVID-19 transformed this critical conversation practically overnight. The pandemic is causing regulators to rethink how data governance, and policymakers are being pressured to reopen economies as soon as possible—meaning governments are more likely to weaken privacy protections than strengthen them—at least in the short-term.[333] Dialogue around technology's role in society will be even more critical if Big Tech emerges from this crisis more powerful than ever.[334]

4. Additional Infrastructure Investment Needs

While most AV developers intend for the technology to be able to operate on existing infrastructure, fast paced innovation could require more frequent redesign and upgrading of infrastructure. This could include more advanced communications technologies and active roadway management. Safe and effective HAV operations also require maintaining infrastructure in good repair, so as to not cause sensors to misalign due to rough pavement. Affording these additional costs will be difficult when simply maintaining the system as it has been built remains out of reach without coming up with new funding sources.

As of 2017, more than 1,800 state-maintained lane miles of road in Greater Philadelphia were in poor condition, about 35 percent of all roads. There is a lack of funding to address both maintaining existing infrastructure and upgrading with additional digital technologies needed for AV operations. On the positive side, HAVs could reduce pavement distress by being programmed to avoid deficiencies, collecting data on pothole locations and transmitting them to the maintenance agency, and through smoother traffic flow. However, closer vehicle spacing—especially through truck platooning—increased VMT, and if all vehicles travel in the same path they could increase the rate at which pavement wears out.

Beyond the basics of pavement and bridge condition, infrastructure owners and operators will need to ensure policies for signs, signals, lane markings, and maintenance are consistent, clear, and sensible across jurisdictions; and then ensure that existing infrastructure conforms to these

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[331] Chris Meserole, "COVID-19 and the Future of 'Techlash,'" *Brookings*, April 27, 2020, www.brookings.edu/techstream/covid-and-the-future-of-techlash/ (accessed May 7, 2020).
[332] Meserole, "COVID-19 and the Future of 'Techlash.'"
[333] Meserole, "COVID-19 and the Future of 'Techlash.'"
[334] Meserole, "COVID-19 and the Future of 'Techlash.'"

standards.[335] AVs and CVs may cause existing ITS infrastructure to become obsolete, and reduce or shift transit demand and parking needs.[336] It's not clear whether these technologies will decrease or increase the existing shortage in roadway capacity, and they may require changes in basic road design and geometry—but it's not currently clear what those design changes would entail.[337]

There are other challenges to maintaining infrastructure, which is highly energy intensive in an era where we must find ways to use far fewer fossil fuels than we do today. Other resources are becoming constrained in supply as well, such as construction sand, which further points to a need to completely rethink how infrastructure is designed, built, and operated.[338] 3D printing and other technologies may offer opportunities to completely revise infrastructure delivery, while meeting the challenges of reducing greenhouse gas (GHG) emissions and overcoming potential resource shortages and limited funding.

Integrated Corridor Management

Integrated corridor management (ICM) is a first step toward automating roads, as HAVs may require managed lanes for operations.[339] ICM applies technology, robust planning and preparedness, and inter- and intra-agency coordination to facilitating the movement of people and goods. Successful approaches to ICM will view the transportation system as an integrated network, use technology to obtain accurate real-time transportation data, and to share information between agencies and with the public. That information can guide real-time decision making around managed lanes and of transportation system users—alerting travelers to different available travel routes or modes. ICM is an important strategy being implemented on the I-76 Schuylkill Expressway in Montgomery County.

Building out Connected Vehicle Technologies

Cellular vehicle-to-everything (C-V2X) technologies provide both short-range and long-range communications through both 5G networks and the 5.9 GHz frequency band to send information between vehicles, infrastructure, and other road users information about traffic and road conditions beyond the driver's line of sight.[340] CV-enabled transportation networks will generate considerable amounts of data.[341]

5G may be a limiting factor for future ODDs and Level 5 HAV deployment if this cellular network takes a considerable amount of time to fully build out. 5G continues to struggle over data ownership questions, as the network will be largely built by private cellular network companies. CV technology can provide a platform for generating revenue from a mileage-based user fee and could provide roadside tolling infrastructure, with less need for overhead gantries.[342]

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[335] Smith, *How Governments Can Promote Automated Driving*.
[336] Johanna Zmud, Ginger Goodin, Maarit Moran, Nidhi Kalra, and Eric Thorn, *Advancing Automated and Connected Vehicles: Policy and Planning Strategies for State and Local Transportation Agencies* (Washington, DC: National Cooperative Highway Research Program; Transportation Research Board, National Academies of Sciences, Engineering, and Medicine, 2017) www.nap.edu/24872.
[337] Zmud et al., *Advancing Automated and Connected Vehicles*.
[338] Vince Beiser, "Why the World is Running Out of Sand," *BBC Future*, November 17, 2019, www.bbc.com/future/article/20191108-why-the-world-is-running-out-of-sand (accessed December 5, 2019).
[339] Schladover, "Progress Toward Automated Driving."
[340] "Cellular Vehicle-to-Everything (C-V2X) – Why Does it Matter?" *Robotics Biz*, August 25, 2020, www.roboticsbiz.com/cellular-vehicle-to-everything-c-v2x-why-does-it-matter/ (accessed November 9, 2020).
[341] Baker, "Infrastructure is Next Big Thing in AV Investment."
[342] Zmud et al., *Advancing Automated and Connected Vehicles*.

Even if competing technologies, such as cellular or satellite networks, become the primary CV communications technology, DSRC can still be used to collect macro-level transportation data.[343] Applying DSRC technologies through roadside units (RSUs) to the region's roads will require local and state governments to deploy, operate, and maintain CV infrastructure. RSUs aggregate, process, and distribute information to and from vehicles. RSUs need to be spaced roughly one mile apart along roadways to ensure consistent signal broadcasting to vehicles using the facility. The potential societal crash reduction benefits of CVs are not likely to be achieved without this public investment.[344] Testing can develop invaluable institutional knowledge, skill, and expertise and help to facilitate adoption. PennDOT has 54 connected intersections in the commonwealth, but none of them are in the DVRPC region.

Relying on local governments to deploy DSRC will likely lead to a great deal of disparity due to their varying capabilities, from financial resources to technical abilities. If local deployment is highly fragmented, some of the benefits of CVs may be limited. As it is, many municipalities have a hard time simply maintaining traffic signals, and it is not uncommon to go 10 or more years without updating or even maintaining this equipment. Each RSU is estimated to have annual costs of $1,950 to $3,050 per year (in 2017 dollars), accounting for electricity, traditional maintenance, license and maintenance agreements, security credential management system (SCMS) certification, and annualized replacement costs (every 5 to 10 years).[345]

NHTSA has long been expected to mandate CV technology equipment be included with all new vehicles, but this key step has yet to happen. Transportation agencies can dedicate funds to testing CV systems, even in the absence of such a mandate. Standards need to be developed for V-2-V, V-2-I, and vehicle-to-everything (V-2-X) communications.[346] Other needs include backhaul communications, CV data analytics, CV-equipped traffic signals and other infrastructure.[347] States could also experiment with 5G wireless networks to facilitate CV systems, though data ownership remains a key unanswered question with these networks. DOTs may need to identify which data will be made freely available, and whether some of it can—and should—be used to offset the cost of developing CV infrastructure.[348] Measuring the return on investment for CV infrastructure is difficult, which also makes it hard to identify the locations that would provide the greatest returns (such as sharp curves, signalized intersections, and corridors with unique data needs).[349]

Maintaining the 5.9 GHz Band for Transportation-Only Use

Both C-V2X and its former competitor technology, DSRC, were intended to utilize the 75 MHz of 5.9 GHz bandwidth that was set aside for transportation safety technologies in 1998. The slow rollout of V-2-V, V-2-I, and V-2-X communications led to calls for opening up this spectrum to other connected device uses as part of the Internet of Things (IoT), which has already connected tens of billions of items to the internet and plans to connect hundreds of billions more. This is because the Internet is running out of licensed spectrum to handle all the traffic it is carrying.

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343 Linda Baker, "Infrastructure is Next Big Thing in AV Investment," *FreightWaves*, July 29, 2020, www.freightwaves.com/news/infrastructure-next-big-thing-in-av-investment (accessed July 31, 2020).
344 Zmud et al., *Advancing Automated and Connected Vehicles.*
345 Zmud et al., *Advancing Automated and Connected Vehicles.*
346 Baker, "Infrastructure is Next Big Thing in AV Investment."
347 Baker, "Infrastructure is Next Big Thing in AV Investment."
348 Baker, "Infrastructure is Next Big Thing in AV Investment."
349 Baker, "Infrastructure is Next Big Thing in AV Investment."

In September 2018, the Federal Communications Commission (FCC) proposed the Facilitate American Superiority in 5G Technology plan (5G FAST plan), which would open up the lowest 40 MHz of the 5.9 GHz bandwidth to IoT uses, continue to reserve the highest 20 MHz for transportation uses only, and asks for public comment on which way to go with the other 10 MHz. Following that, the FCC's Office of Engineering and Technology released the results of 1,450 tests with more than a million data points showing how prototype devices can share the 5.9 GHz spectrum with CVs.[350] It tested two different approaches to spectrum sharing: detect and vacate and rechannelization.[351] In November 2020, the FCC approved the plan to redirect the lower 45 MHz from the 5.9 GHz spectrum to wireless applications, and reserve the upper 30 MHz to C-V2X applications.[352] This despite all 50 state DOTs along with a number of transportation and safety advocacy groups being opposed to these changes to the 5.9 GHz spectrum.[353] This decision will effectively render DSRC to be unusable.[354] This decision could slow or halt investments in C-V2X infrastructure, and put lives at risk if CVs are not part of the future of transportation. It could also limit HAV capabilities, as these vehicles will need every bit of communication bandwidth available.[355] Satellite networks remain another potential source of CV and HAV communications bandwidth.

The incoming Biden administration can still potentially reverse this reallocation of the 5.9 GHz spectrum, and industry lawsuits are being filed against the FCC to challenge it. The outcomes of these motions will determine if DSRC will be a viable technology going forward.

Truck Platooning

Truck platooning and closer vehicle spacing can increase road throughput capacity and relieve congestion. C-V2X can enhance communications within truck platoons, help to facilitate cooperative driving—where drivers work together to optimize available road space and reduce disruptions from lane changes and sudden braking by conveying intentions to other road users.[356] Reduced braking, smoother acceleration, and drafting can further reduce fuel consumption and vehicle emissions. Platooning could reduce driver fatigue, enable more rest, and potentially allow drivers to stay closer to home.[357] Economic incentives from truck platooning may make it one of the most commercially viable pathways to higher levels of vehicle automation.

There are many challenges that must be overcome. Truck platoons will likely be limited initially to designated facilities and could require truck-only lanes. As the number of trucks allowed in a platoon increases, so will the need to construct stronger pavement and bridges. Though truck only lanes could provide an opportunity to reduce road construction costs by building thick, strong concrete

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[350] Hill, "To DSRC or not to DSRC?"
[351] Hill, "To DSRC or not to DSRC?"
[352] David Shepardson, "U.S. Telecoms Regulator to Vote to Split Key Spectrum Block Between Autos, Wi-Fi," *Reuters,* October 27, 2020, www.reuters.com/article/us-usa-spectrum/u-s-telecoms-regulator-to-vote-to-split-key-spectrum-block-between-autos-wi-fi-idUSKBN27C31N (accessed October 28, 2020).
[353] "Pushback Begins Against FCC Proposal to Share 5.9 GHz Wireless Spectrum," *AASHTO Journal*, November 22, 2019, www.aashtojournal.org/2019/11/22/pushback-begins-against-fcc-proposal-to-share-5-9-ghz-wireless-spectrum/ (accessed December 4, 2019).
[354] Benjamin Preston, "FCC Plan Puts V2X Safety Technology at Risk," *Consumer Reports*, October 28, 2020, www.consumerreports.org/car-safety/fcc-plan-puts-v2x-car-safety-technology-at-risk/ (accessed November 1, 2020).
[355] Preston, "FCC Plan Puts V2X Safety Technology at Risk."
[356] "Cellular Vehicle-to-Everything (C-V2X) – Why Does it Matter?"
[357] Lauren Fletcher, "Pros and Cons of Truck Platooning," *Work Truck*, September 13, 2017, www.worktruckonline.com/160056/pros-and-cons-of-truck-platooning (accessed May 17, 2019).

lanes for trucks and less thick, and therefore less expensive, lanes for other vehicle types.[358] Platooning is dependent on both connected and automated technologies, which are still being tested and will increase the cost of new trucks.[359] There are many unknowns with these technologies, including how they will handle crashes and other incidents.[360] Until more vehicles have the needed technology, there will be limited availability for platooning.[361] There will also be operating challenges that could also cause safety risks: longer platoons may impede traffic, or limit the ability to access exit ramps; and platoons may break up if another vehicle tries to wedge itself in between the vehicles in it.[362] Fleets will need to develop platooning agreements, and may not want to platoon with another company's vehicles without an agreement in place.[363]

Potential Loss of Public Revenues

Even as investment needs may rise, local governments may lose critical parking and traffic ticket revenues if HAVs greatly reduce violations. As the number of HAVs on the road increases over time, there should be fewer traffic violations and crashes, which would drastically reduce policing needs and court loads. In the meantime, however, with a mix of ADS and human-driven vehicles, there may be need for even more police presence on the road.[364] Local government may gain other responsibilities, such as stopping pedestrians from jaywalking in front of HAVs.

States could see a decline in a number of revenue streams related to automobile use: drivers' license fees, gas taxes, vehicle sales taxes, ticketing and enforcement, transit fares, federal funding for transit ridership subsidies, and others.[365] On the other side of the ledger, HAVs could lower government expenses. For example, school bus transportation currently costs nearly $1,000 per student each year, which could potentially be reduced by automated buses.[366]

5. Cybersecurity and Technical Challenges

Vehicle cybersecurity is the protection of automotive electronic systems, communications networks, control algorithms, software, and underlying data from malicious attacks, damage, unauthorized access, or manipulation.[367] Responsibility for ensuring vehicle system and component security falls across the automotive supply chain and throughout the development cycle.[368] Automakers define core design requirements, including those for the software system, to parts suppliers.[369] In turn, parts suppliers assemble subcomponents and rely on lower-level suppliers, such as chip manufacturers, to obtain the specific parts—or hardware.[370] Each supplier is responsible for testing, validating, and certifying that its product meets the automakers specifications.[371] Automakers

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[358] Shawn Dubravac, Ph.D. *Digital Destiny: How the New Age of Data Will Transform the Way We Work, Live, and Communicate* (Washington, DC: Regnery Publishing, 2015).
[359] Dubravac, Ph.D. *Digital Destiny*.
[360] Fletcher, "Pros and Cons of Truck Platooning."
[361] Fletcher, "Pros and Cons of Truck Platooning."
[362] Fletcher, "Pros and Cons of Truck Platooning."
[363] Fletcher, "Pros and Cons of Truck Platooning."
[364] Hedlund, PhD, *Preparing for Automated Vehicles: Traffic Safety Issues for States*.
[365] Zmud et al., *Advancing Automated and Connected Vehicles*.
[366] Bits and Atoms, *Taming the Autonomous Vehicle: A Primer for Cities* (Long Island City, NY: Bloomberg Philanthropies and Aspen Institute Center for Urban Innovation, March 2017) www.bbhub.io/dotorg/sites/2/2017/05/TamingtheAutonomousVehicleSpreadsPDF.pdf.
[367] *Vehicle Cybersecurity: DOT and Industry Have Efforts Underway, but DOT Needs to Define Its Role in Responding to a Real World Attack* (Washington, DC: Government Accountability Office, March 2016) www.gao.gov/products/GAO-16-350.
[368] *Vehicle Cybersecurity.*
[369] *Vehicle Cybersecurity.*
[370] *Vehicle Cybersecurity.*
[371] *Vehicle Cybersecurity.*

assemble the vehicle using components from many different suppliers, and are ultimately responsible for validating that safety-critical systems meet performance requirements and operate as intended.[372]

In April 2019, a white hat hacker, who works on behalf of consumers, was able to infiltrate a network of GPS tracking apps—iTrack and Protrack—found in vehicles produced by many different prominent automakers.[373] Once inside the network, he found that more than 27,000 apps used the default password '123456.'[374] This password gave him access to the app and then to the vehicles' electronic systems that interact with the engine.[375] With this access he was able to remotely turn off the engine of any car that was stopped or traveling 12 miles per hour or slower.[376]

In 2015, cybersecurity experts Charlie Miller and Chris Valasek made headlines by remotely hacking into a Jeep Cherokee and steering it into a ditch.[377] They have found AVs are much more difficult to hack into.[378] Since their Jeep hacking event, the industry has become much more in-tune to cybersecurity risks.[379] AV sensors, computer systems, and on-board mapping can enable the ADS to detect if something is amiss.[380] Attackers can't trick an AV by blinding its LiDAR system since it should just stop if it doesn't have the necessary data.[381] The biggest defense mechanism for HAVs is to limit the attack surface by removing everything unnecessary for the vehicle's operation. Past car hacks involved reprogramming some vehicular component, but trusted execution can check if any component has been changed and then keep the car from even starting if so.[382] Miller and Valasek suggest that security can be improved by requiring component makers to use secure Transmission Control Protocol (TCP) connections rather than existing User Datagram Protocol (UDP) connections. UDP delivers data faster by not checking for errors. TCP delivers an ordered and error-checked stream of data over a network by having the recipient verify to the sender that the packet was received, so that no data is lost or corrupted in transit. However, this slows data connection and increases latency.

These examples show the cybersecurity limitations of vehicles on the road today. Researchers have identified several potential entry points where present-day vehicles could be hacked. The on-board diagnostics port (OBD-II) is mandated to be included in all vehicles and used for emissions testing and diagnostic assessments.[383] It has direct access to all in-vehicle communications networks, including safety critical systems, such as brakes and steering, but can only be reached through direct, physical access—which limits its usefulness as an attack vector.[384] Built-in Bluetooth, short-range cellular and long-range wireless connections, including the telematics unit, can all potentially be accessed remotely and used to take control of safety critical systems.[385] Another concern arises from the controller area network (CAN), which controls many in-vehicle communications systems for

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[372] *Vehicle Cybersecurity.*
[373] James Gelinas, "Hacker Accesses GPS and Kills Car Engines," *Komando*, April 27, 2019, www.komando.com/security-privacy/hacker-accesses-gps-and-kills-car-engines/563934/ (accessed December 11, 2019).
[374] Gelinas, "Hacker Accesses GPS and Kills Car Engines."
[375] Gelinas, "Hacker Accesses GPS and Kills Car Engines."
[376] Gelinas, "Hacker Accesses GPS and Kills Car Engines."
[377] Rubenking, "Self-Driving Cars are Surprisingly Secure."
[378] Rubenking, "Self-Driving Cars are Surprisingly Secure."
[379] Rubenking, "Self-Driving Cars are Surprisingly Secure."
[380] Rubenking, "Self-Driving Cars are Surprisingly Secure."
[381] Rubenking, "Self-Driving Cars are Surprisingly Secure."
[382] Rubenking, "Self-Driving Cars are Surprisingly Secure."
[383] *Vehicle Cybersecurity.*
[384] *Vehicle Cybersecurity.*
[385] *Vehicle Cybersecurity.*

most automobile models.[386] The CAN is a major security weakness because it isn't secured or restricted in any way and doesn't verify that messages traveling across it come from a trusted source.[387] Wireless telematics devices, also known as dongles, plug into the OBD-II port and transmit data to third parties such as insurance companies. These are a potential vulnerability that could enable an attacker to take control of safety-critical systems and turn what was a direct attack pathway into a remote one.[388]

A modern luxury vehicle has more than 100 million lines of code, compared to just 6.5 million in a Boeing 787 Dreamliner.[389] The longer the code, the greater risk there is for bugs, errors, and related vulnerabilities.[390] The amount of code contained in future CVs and HAVs will be far greater. Regardless, most potential attacks require sophisticated hacking capabilities and specialized knowledge.[391] For example, it is very difficult to create authentic looking messages that a vehicle's communications network will both accept and act on.[392] Beyond safety impacts, cyberattacks could have other implications, such as privacy intrusions where personal information like credit card numbers or emails are transmitted.[393]

The National Institute of Standards and Technology's (NIST) *Cybersecurity Framework's* systematic approach to develop a layered cybersecurity protection for vehicles around five functions:[394]

1. Identify – through a risk-based prioritization.
2. Protect – safety-critical vehicle control systems and personally identifiable information.
3. Detect – in a timely manner.
4. Respond – rapidly to potential vehicle cybersecurity risks.
5. Recover – design-in methods and measures to facilitate rapid incident recovery when they happen and institutionalize methods for accelerated adoption of lessons learned across the industry through effective information sharing, including participation in the global Information Sharing and Analysis Center (ISAC).

Cybersecurity is still relatively new to the automotive industry. Some key practices for mitigating vulnerabilities include:[395]

- Risk assessments – inform and prioritize cybersecurity protections by assessing threats and vulnerabilities to electronic systems and personally identifiable information.
  - What are the functions?
  - What are the implications if they are exploited?
  - What are the potential safety hazards that could be exposed by these vulnerabilities?
  - What is the safety risk to society and the value risk to the organization?
  - What can be done to minimize exposure to the potential loss or damage?
  - What design decisions could be made with respect to the risk assessment process?
  - Who and what are the threats and vulnerabilities?

[386] *Vehicle Cybersecurity*.
[387] *Vehicle Cybersecurity*.
[388] *Vehicle Cybersecurity*.
[389] *Vehicle Cybersecurity*.
[390] *Vehicle Cybersecurity*.
[391] *Vehicle Cybersecurity*.
[392] *Vehicle Cybersecurity*.
[393] *Vehicle Cybersecurity*.
[394] National Highway Traffic Safety Administration, *Cybersecurity Best Practices for Modern Vehicles* (Washington, DC: U.S. Department of Transportation, 2016, Report No. DOT HS 812 333).
[395] *Vehicle Cybersecurity*; and National Highway Traffic Safety Administration, *Cybersecurity Best Practices for Modern Vehicles*.

- Inventory all vehicles and equipment that has some form of connectivity to each other or to other services.
- Incorporate security-by-design principles – build in cybersecurity protections beginning with initial design phases.
  - Create domain separation for in-vehicle networks – locate safety critical systems and non-safety systems on separate in-vehicle networks and minimize communications between these domains to the greatest extent possible.
  - Implement a layered approach to security – to reduce the probability of a successful cyberattack, and create multiple hurdles for cyberattackers in the case of a cyberbreach.
    - Protect integrity of electronic core unit (ECU)—which executes core vehicle functions including driving, convenience, and entertainment—both hardware and software.
    - Hardware security module to ensure the communications it facilitates can be trusted.
    - Microkernal – a very small portion of software securely designed to ensure a single ECU with multiple functionalities can send trusted messages to other ECUs.
  - Protect the integrity of critical messages transmitted through in-vehicle networks and secure external interfaces that facilitate communications with external networks and devices (such as the telematics unit).
    - Gateway – a device that interconnects and enables communication between two or more networks, including multiple internal vehicle networks and internal and external networks.
    - Firewall – controls and limits communication between two or more networks, including multiple internal vehicle networks and internal and external networks. Firewalls can sit on gateways and block any messages not on a predetermined approved list.
    - Control communication to back-end servers – employ widely accepted encryption methods in any IP-based communications between the vehicle and external services. These connections should block invalid certificates.
  - Limit the proliferation of network ports, protocols, and services – the use of network servers on vehicle ECUs should be limited to essential functions only and services over these ports should be protected to prevent unauthorized access. Any software listening on an internet protocol (IP) port offers a potential attack vector.
  - Message authentication and encryption – coding techniques that verify the legitimacy of message senders and receivers. These techniques can be used to secure communications among higher-bandwidth in-vehicle networks, such as Ethernet, or between the vehicle and the auto manufacturer's back-end server.
- Limit developer/debugging access in production devices – software developers have considerable access to electronic control units (ECUs) through open debugging ports or the serial console. Access should be restricted if there is no operational reason for it in deployed units.
- Control keys – any key or password that can provide unauthorized, or elevated access to computing programs should be protected from disclosure. Any key obtained from one vehicle's platform should not grant access to other vehicles.
- Control vehicle maintenance diagnostic access – diagnostic features should be limited to a specific operation and the intended purpose of the associated feature. Diagnostic operations should be designed to eliminate or mitigate potentially dangerous ramifications if they are abused or misused.
- Control access to firmware – firmware often determines an ECU's actions. Extracting firmware is often the first step to finding a vulnerability or conducting an end-to-end cyberattack.

- Limit ability to modify firmware – this would make it more challenging to install malware on vehicles. Firmware updates should employ signing techniques to prevent the installation of damaging software that did not originate from an authorized motor vehicle or equipment manufacturer.
- Intrusion detection and prevention system – software that monitors network messages and analyzes them for signs of possible incidents. Intrusion prevention systems also attempt to stop possible incidents when they are detected, ideally before the target is reached.
- Log events – an immutable event log, sufficient to reveal the nature of a cybersecurity attack or breach, should be maintained and periodically scrutinized by qualified personnel to track cyberattack trends.
- Control wireless interfaces – it may be necessary to exert fine-grained control over a vehicle's connection to a cellular wireless network. The automotive industry should plan for and design-in features that could allow for changes in network routing rules to be quickly propagated and applied to one, a subset, or all vehicles.
- Conduct:
  - Penetration testing – where skilled assessors and evaluators simulate real world cyberattacks and try to identify ways to circumvent and defeat cybersecurity protections.
  - Code reviews – where skilled assessors and evaluators systematically examine the software code to identify and fix any mistakes that may have been overlooked in the initial development phase.
  - Documentation of all actions to fix detected cybersecurity vulnerabilities.
- Develop over-the-air (OTA) update capabilities – establish capabilities to securely update software and firmware remotely over the life of the vehicle in order to respond to vulnerabilities as they are identified.

The Center for Internet Security's (CIS) *Critical Security Controls for Effective Cyber Defense* further recommends developing implementation road maps, effectively and systematically executing cybersecurity plans, integrating controls into vehicle systems and business operations, and reporting and monitoring progress through iterative cycles.[396]

Most of these practices cannot be simply added onto existing vehicle designs.[397] Rather, everything must be incorporated at the beginning of the production process, which takes roughly five years to complete. This lag can give cyberattackers time to understand and breach protections and makes it difficult for automakers to be protected against the latest known threats.[398] Other challenges include the lack of transparency, communication, and collaboration around vehicle cybersecurity by all the various players.[399] Low automotive industry profit margins mean even small cybersecurity modifications can potentially be cost prohibitive.[400] Also, there are no metrics to measure cybersecurity effectiveness.[401] Testing every line of code in a vehicle's software system would take months, and is not feasible or practical to do.[402]

Safety critical systems on CVs and AVs could be easier to reach through remote cyberattacks because their systems are closely connected to and rely on external connections.[403] CVs, in

[396] National Highway Traffic Safety Administration, *Cybersecurity Best Practices for Modern Vehicles.*
[397] *Vehicle Cybersecurity.*
[398] *Vehicle Cybersecurity.*
[399] *Vehicle Cybersecurity.*
[400] *Vehicle Cybersecurity.*
[401] *Vehicle Cybersecurity.*
[402] *Vehicle Cybersecurity.*
[403] *Vehicle Cybersecurity.*

particular, could give cyberattackers new vulnerabilities to exploit through the large wireless networks used to facilitate the technology, including capability to remotely take control of multiple vehicles simultaneously.[404] A fundamental challenge for HAV cybersecurity is to create a system that is both very fast, as required by on-board decision- making systems, and secure.[405] A millisecond delay to authenticate and verify messages within a collision avoidance system could be the difference between walking away from a crash or being seriously injured, or killed, in one.[406] As vehicle speeds increase, the systems processing 'visual' data from the travel environment will have a harder time keeping up with authentication and verification requests.[407] The private sector has a strong incentive to resolve and keep current from a cyber perspective, and may not want to rely on state and local governments keeping connected services up to date.[408] CVs and HAVs will also need to be able to resist cyberattacks from new technologies, such as from a quantum computer.[409]

One answer to these challenges was the formation of the global ISAC for the auto industry in 2015.[410] This and other automotive industry partnerships can benefit manufacturers by reducing the costs of developing and testing software as well as increasing the quality of the product.[411] There is a severe shortage of automotive cybersecurity specialists. The current automotive workers, technical individuals, the future workforce, and non-technical individuals can all be enriched through cybersecurity education.[412] Colleges and universities should develop curriculums that foster skill sets across a range of security applications, including vehicle cybersecurity, and work with the NHTSA, manufacturers, suppliers, and other stakeholders on these efforts.[413] There is, unfortunately, no guarantee that implementing all of these recommendations will ensure cybersecurity, which must be seen as an ever-evolving threat that requires vigilance to protect against.

Automatic Software Updates

OTA updates are critical to cybersecurity response so that auto manufacturers can respond to incidents if and when they occur.[414] Any software upgrades or updates or changes to a state or federal law could automatically be uploaded OTA to the ADS software.[415] For example, Tesla has routinely rolled out new features to its software. In June 2017, an update to Model S and Model X vehicles produced after December 2016 added several safety features: full-speed automatic emergency braking at all speeds, smoother Autopilot steering, perpendicular parking, and adjustable display brightness based on the light conditions the vehicle is operating in.[416] Mercedes and NVIDIA are partnering to develop a perpetually updatable computer platform that can add and adjust automated driving functions over time using OTA updates.[417] Each update, however, could introduce

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[404] *Vehicle Cybersecurity.*
[405] Robert Dingess, e-mail dated August 12, 2020.
[406] Robert Dingess, e-mail dated August 12, 2020.
[407] Robert Dingess, e-mail dated August 12, 2020.
[408] Robert Dingess, e-mail dated August 12, 2020.
[409] *Ensuring American Leadership in Automated Vehicle Technologies: Automated Vehicles 4.0* (Washington, DC: National Science and Technology Council and United States Department of Transportation, January 2020) www.transportation.gov/sites/dot.gov/files/docs/policy-initiatives/automated-vehicles/360956/ensuringamericanleadershipav4.pdf.
[410] *Vehicle Cybersecurity.*
[411] *Vehicle Cybersecurity.*
[412] National Highway Traffic Safety Administration, *Cybersecurity Best Practices for Modern Vehicles.*
[413] National Highway Traffic Safety Administration, *Cybersecurity Best Practices for Modern Vehicles*.
[414] National Highway Traffic Safety Administration, *Cybersecurity Best Practices for Modern Vehicles*.
[415] Harari, *21 Lessons for the 21st Century.*
[416] Brian Wong, "Tesla Rolls out Autopilot Update," *Cars.com*, June 13, 2017, www.cars.com/articles/tesla-rolls-out-autopilot-update-1420695726988/ (accessed November 1, 2019).
[417] Binder, "The Future of Transportation: Impact of COVID-19 on Mobility."

new risks of bugs or other problems with the code. Automatic software updates also assume the ADS isn't self-programming through AI at the vehicle level.

Other Technical Challenges

Other technical challenges beyond cybersecurity remain for HAV development, such as cooling and powering computers in EVs.[418] Construction, severe weather, and glare can temporarily blind HAV sensors or interrupt its road maps.[419] Complex electronic systems are prone to failure, and even something as simple as a false sensor, distorted signal, or software failure can lead to disastrous outcomes.[420] HAVs require computing powers that are a scale above what they are now, but at the same time will need to use much less power.[421] On-board computing systems use thousands of watts and sensors need to be low-cost, while also being vibration resistant and able to last for 10 or 20 years without failing.[422] Equipment needs to be able to operate in the Alaska winter and the Death Valley summer, without losing functionality due to salt, rust, and dust from the road.[423]

HAVs will need maps loaded into the vehicle's on-board computers that detail every square foot of a road's area, which must then be carefully digitized with computing technology and human review to ensure that everything is included.[424] It will be difficult to ensure that any change—traffic signals, signs, lane markings, crosswalks, construction—in the road's right-of-way is kept current in this map.[425] This process is far too involved to map all four million miles of roads in the United States.[426]

Sensors

Since each sensor technology has its own potential faults and vulnerabilities, satisfying all ADS needs requires a combination of sensors.[427] This adds cost and complexity.[428] The array of sensors currently used on AVs can't deal with all road and weather conditions.[429] Sensors have less perception than humans, who can identify and respond to objects much further away than cameras, LiDAR, and radar.[430] The need to filter sensor data adds lag time to ADS decision making.[431] New sensor-signal processing and data-fusion algorithms need to be able to discriminate between benign and hazardous objects with near zero false negatives—where hazardous objects are not identified—and few false positives—where benign objects are misidentified causing incorrect responses such as swerving or braking.[432]

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418 Ackerman, "Toyota's Gill Pratt on Self-Driving Cars and the Reality of Full Autonomy."
419 Bits and Atoms, *Taming the Autonomous Vehicle: A Primer for Cities*.
420 Litman, *Autonomous Vehicle Implementation Predictions*.
421 Ackerman, "Toyota's Gill Pratt on Self-Driving Cars and the Reality of Full Autonomy."
422 Ackerman, "Toyota's Gill Pratt on Self-Driving Cars and the Reality of Full Autonomy."
423 Ackerman, "Toyota's Gill Pratt on Self-Driving Cars and the Reality of Full Autonomy."
424 Lee Gomes, "Driving in Circles: The Autonomous Google Car May Never Actually Happen," *Slate*, October 21, 2014, www.slate.com/articles/technology/technology/2014/10/google_self_driving_car_it_may_never_actually_happen.2.html (accessed October 22, 2014).
425 Gomes, "Driving in Circles: The Autonomous Google Car May Never Actually Happen."
426 Gomes, "Driving in Circles: The Autonomous Google Car May Never Actually Happen."
427 Schladover, "The Truth About Self-Driving Cars."
428 Schladover, "The Truth About Self-Driving Cars."
429 David Cardinal, "The Future of Sensors for Self-Driving Cars: All Roads, All Conditions," *ExtremeTech*, February 4, 2020, www.extremetech.com/computing/305691-the-future-of-sensors-for-self-driving-cars-all-roads-all-conditions (accessed February 13, 2020).
430 David Cardinal, "The Future of Sensors for Self-Driving Cars: All Roads, All Conditions."
431 Jay Ramey, "Here's Why Our Gleaming Self-Driving Future Has Been Delayed Indefinitely."
432 Schladover, "The Truth About Self-Driving Cars."

There are hundreds of sensors used in today's AVs, which cost more than $100,000 in total, though these costs are coming down.[433] Velodyne offers a variety of LiDAR options, including the Velobit, which is expected to cost just $100 once it is available.[434] LiDAR performance is being improved by adding intelligence and processing power.[435]

There are presently more than 50 million front-facing cameras in ADAS systems.[436] Visible-light imaging sensors, which are used for lane-keeping and parking sensors, are the most common sensors found on today's vehicles.[437] Visible light imaging systems don't work when facing into the sun and have a difficult time when light levels suddenly change, such as when entering or exiting tunnels.[438] Adaption time needs to be sped up while limiting overshoot before exposure settles on a new value.[439] Dxomark has built custom hardware that will be able to sense LEDs that flicker at various frequencies and enable automakers and suppliers to measure light for proposed camera designs.[440]

Traditional cameras have a difficult time sensing distance and working in bad light, such as: deep shade, back light, or at night.[441] Thermal cameras avoid these problems by directly sensing longer-wave radiation emanating from anything giving off heat.[442] These cameras are challenged by all types of glass, from opaque to infrared automotive.[443]

Radar is used in all adaptive cruise control systems and blind spot monitors.[444] Cruise uses more than 20 of them, in addition to 5 LiDAR and 16 cameras.[445] Radar developers are looking to improve object classification and vehicle localization functionality.[446] Neither radar nor LiDAR can read speed limit, stop, and other roadway signs, including those warning for oncoming trains at at-grade crossings.[447] Systems that don't have an audible sensor can't 'hear' an oncoming train.[448]

Sensor architecture will need to be completely overhauled to achieve Level 4 or Level 5 automation.[449] The entire car will need to be surrounded with low-cost, high-performance antennas, cameras, and other sensors connected to a central processing unit by optical fiber.[450]

6. Regulating AVs

Bryant Walker Smith's *Automated Vehicles are Probably Legal in the United States* gets right to the point that there is little in current codes to stop the deployment of HAVs. However, there are many relevant state vehicle codes and provisions, as well as local government regulations that may need to be clarified.

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[433] David Cardinal, "The Future of Sensors for Self-Driving Cars: All Roads, All Conditions."
[434] David Cardinal, "The Future of Sensors for Self-Driving Cars: All Roads, All Conditions."
[435] David Cardinal, "The Future of Sensors for Self-Driving Cars: All Roads, All Conditions."
[436] David Cardinal, "The Future of Sensors for Self-Driving Cars: All Roads, All Conditions."
[437] David Cardinal, "The Future of Sensors for Self-Driving Cars: All Roads, All Conditions."
[438] David Cardinal, "The Future of Sensors for Self-Driving Cars: All Roads, All Conditions."
[439] David Cardinal, "The Future of Sensors for Self-Driving Cars: All Roads, All Conditions."
[440] David Cardinal, "The Future of Sensors for Self-Driving Cars: All Roads, All Conditions."
[441] David Cardinal, "The Future of Sensors for Self-Driving Cars: All Roads, All Conditions."
[442] David Cardinal, "The Future of Sensors for Self-Driving Cars: All Roads, All Conditions."
[443] David Cardinal, "The Future of Sensors for Self-Driving Cars: All Roads, All Conditions."
[444] David Cardinal, "The Future of Sensors for Self-Driving Cars: All Roads, All Conditions."
[445] David Cardinal, "The Future of Sensors for Self-Driving Cars: All Roads, All Conditions."
[446] David Cardinal, "The Future of Sensors for Self-Driving Cars: All Roads, All Conditions."
[447] Eliot, "Why Railroad Crossings are a Grave Danger for Self-Driving Cars."
[448] Eliot, "Why Railroad Crossings are a Grave Danger for Self-Driving Cars."
[449] David Cardinal, "The Future of Sensors for Self-Driving Cars: All Roads, All Conditions."
[450] David Cardinal, "The Future of Sensors for Self-Driving Cars: All Roads, All Conditions."

This doesn't mean that HAVs can simply be rolled out on the nation's roads. This lesson was recently learned by Transdev, which was using a slow-moving automated shuttle to transport school kids in Florida as part of a temporary testing and demonstration permit.[451] The NHTSA quickly shut down the operation noting that it violated its permitted authorization.

The NHTSA is charged with setting Federal Motor Vehicle Safety Standards, which set minimum requirements that manufacturers must self-certify that vehicles and equipment conform to. The NHTSA rates new vehicle safety and crashworthiness through a five-star rating program, can recall vehicles or equipment deemed to pose an unreasonable motor safety risk (this authority will extend to AVs), leads investigations into defects and crashes, and researches safety trends and countermeasures.

Regulating HAVs presents both an opportunity and a challenge. The opportunity comes from using the regulatory process as a driver for safer and more equitable innovation. The Porter Hypothesis states "[s]trict environmental regulations do not inevitably hinder competitive advantage against foreign rivals; indeed, they often enhance it. Tough standards trigger innovation and upgrading." Similar safety and equity regulations could further enhance, rather than hinder, innovation.

However, a challenge to such thinking is that setting standards so high that only the best can attain them could force HAV developers with poor records to stop trials.[452] This could reduce competition and increase the economy-of-scale and network effect advantages of the Digital Revolution.[453] These advantages are based on data and how the computers that drive HAVs improve with experience.[454] The more data they have, the better they become at predicting what road objects are and reacting accordingly.[455] While each vehicle can feed into its network software, some systems will be safer than others.[456] The safer and more reliable companies will attract more funding and customers, enabling them to collect greater amounts of data.[457] Governments may have to decide if the safest operators should be required to share their technology or be given exclusive rights to use the roads?[458] Should preventable deaths from cars running on inferior code be accepted?[459] Scaling up will also benefit sharing and maintenance.[460] Shared mobility services should cost less than personal vehicles, which sit idle most of the time.[461] Sharing services become more useful as their customer-base expands: the more users there are in an area, the more economical it is to operate vehicles in it, and the more likely a rider is to find an option nearby.[462] Centralized facilities are likely to be more productive then distributed repair shops, and shared fleets are less likely to have the asymmetrical information disadvantages that individuals have relative to mechanics.[463]

Most state vehicle codes are currently silent on the subject of automation and up until now there have been concerns that enacting state-level AV legislation too soon could hinder testing and

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[451] Zac Palmer, NHTSA Shuts Down 'Unlawful' Autonomous School Bus Transporting Kids in Florida," *Autoblog*, October 22, 2018, www.autoblog.com/2018/10/22/nhtsa-shuts-down-unlawful-autonomous-school-bus/ (accessed December 2, 2019).
[452] "The Market for Driverless Cars Will Head Towards Monopoly," *The Economist*, June 7, 2018, www.economist.com/finance-and-economics/2018/06/09/the-market-for-driverless-cars-will-head-towards-monopoly (accessed June 14, 2018).
[453] "The Market for Driverless Cars Will Head Towards Monopoly."
[454] "The Market for Driverless Cars Will Head Towards Monopoly."
[455] "The Market for Driverless Cars Will Head Towards Monopoly."
[456] "The Market for Driverless Cars Will Head Towards Monopoly."
[457] "The Market for Driverless Cars Will Head Towards Monopoly."
[458] "The Market for Driverless Cars Will Head Towards Monopoly."
[459] "The Market for Driverless Cars Will Head Towards Monopoly."
[460] "The Market for Driverless Cars Will Head Towards Monopoly."
[461] "The Market for Driverless Cars Will Head Towards Monopoly."
[462] "The Market for Driverless Cars Will Head Towards Monopoly."
[463] "The Market for Driverless Cars Will Head Towards Monopoly."

deployment. [464] A particular concern is that if every state creates its own unique requirements it will be impossible for HAV manufacturers to comply with them all. Constantly changing technologies give additional challenges in determining what policy actions and infrastructure investments to take, and when.[465] However, there are starting to be calls for federal legislation that copies the aviation's safety management system, which ensures airplanes, control towers, and airport management all work together so that planes don't crash into each other.[466]

Legislation will need to sort out liability as to who is responsible when an HAV is involved in a crash. It may also be needed to determine which public body or non-profit will test the safety and certify before HAV operations commence. State insurance underwriting rules will need to clarify how underwriters should determine risk without actuarial data. International laws and legal systems will need to be consistent across national boundaries so manufacturers don't have to uniquely program for each country. Regulations around operating without a licensed driver for software-driven Level 5 (and possibly Level 4) HAVs will need to be updated.

Distracted driving, operating under the influence, and open alcohol container laws may need to be modified for HAV operators and occupants.[467] Pennsylvania state law currently requires a vehicle to have both a steering wheel and a brake pedal, potentially limiting HAV manufacturers that plan to build vehicles without them. New Jersey state law defines an operator as a person in control of a vehicle, this definition will need to be changed in order to enable ADS operations.[468] Title 16 of the New Jersey Code refers to presence of 'operators' and 'drivers' in specific actions and interactions of both passenger and commercial vehicles, which will also need to be revised for ADS operations.[469] Automated heavy trucks currently have to follow the same hours of service restrictions as human-driven trucks.

The *New Jersey Autonomous Vehicle Task Force Final Report* reviewed existing state-level AV legislation, finding that there is wide variation amongst the states. Several states require completing an application in advance of roadway testing, excess liability coverage between $2 and $10 million, some prohibit local governments from passing any sort of AV legislation, and a handful require a law enforcement interaction plan. One state—North Carolina—requires specific titling and registration for HAVs and another—Nevada—requires a specific license plate for HAVs.

Current Federal Motor Vehicle Safety Standards, which are set by the NHTSA, are likely to need some modifications to allow for the incorporation of automated technologies into vehicle design.[470] Policymakers may need to consider how much wiggle room to give an ADS to selectively break traffic laws in certain circumstances. For instance, when there is an obstruction in the road and an HAV would need to cross a double yellow line in order to continue.[471]

Updating codes and regulations will require carefully balancing state and federal regulatory roles and responsibilities. Industry lobbyists are unlikely to write transparent HAV legislation that maintains a safety-first mentality, and prioritizes the needs of minority and low-income populations.

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[464] *Automated Vehicles: Comprehensive Plan Could Help DOT Address Challenges* (Washington, DC: Government Accountability Office, 2017) www.gao.gov/assets/690/688676.pdf.
[465] *Automated Vehicles: Comprehensive Plan Could Help DOT Address Challenges*.
[466] Baker, "Infrastructure is Next Big Thing in AV Investment."
[467] U.S. Department of Transportation, *Preparing for the Future of Transportation: Automated Vehicles 3.0*.
[468] Carnegie and Aimen, *New Jersey Autonomous Vehicle Task Force, Final Report.*
[469] Carnegie and Aimen, *New Jersey Autonomous Vehicle Task Force, Final Report.*
[470] *Automated Vehicles: Comprehensive Plan Could Help DOT Address Challenges*.
[471] Smith, *How Governments Can Promote Automated Driving*.

Succeeding in this endeavor will require considerable public education and outreach, which is inclusive of a broad range of perspectives and socioeconomic backgrounds.

Roadway AV Testing

AV developers have been testing vehicles on roadways around the country for a number of years. Even so, we remain in the early phase of AV on-road testing, and there is limited understanding of the safety risks.[472] The 2018 death of Elaine Herzberg, who was crossing a road when she was fatally struck by a Level 2.5 AV, raises serious questions about the safety of on-road testing. While most expect CVs and HAVs to drastically reduce crashes in the long-run relative to current levels, it remains unclear what additional regulations are needed both for the on-road testing being conducted today and for widespread deployment.[473] Automakers and testing companies are generally considered liable for crashes and damages, and there are some provisions that govern the on-road testing in its current phase.[474] There is currently very little literature about HAV on-road testing insurance requirements, so analyzing the current testing liability environment can provide a start for future liability rules when HAVs are more widely adopted.[475]

A comparative analysis of on-road testing programs in the U.S., Germany, and Australia by Dasom Lee and David J. Hess, identified three main safety issues for on-road testing—safety driver presence, safety management, and data and reporting—and liability.[476] The best practices that emerge from their research include:[477]

- On-road testing of vehicles should have at least one human safety driver who is ready to take control to maximize safety until HAV on-road testing advances further.
- If a government decides to allow testing with a remote monitor, then it should create a separate permit with additional requirements.
- Safety drivers and remote monitors should be able to easily deactivate the system at any time.
- A training program for safety drivers and remote monitors can improve safety and help to avoid accidents caused by safety driver failure, which appears to be a contributing cause in the 2018 crash that killed Elaine Herzberg in Tempe, Arizona.
- A full safety management plan could help to ensure that safety plans are implemented and can help to ensure that testing companies have thought through the safety issues.
- Recording trials in real time can help to ensure that safety plans are implemented and provide information that can be used to enhance vehicle safety.
- Substantial fines or penalties for non-compliance can incentivize best practices from testing companies, and associated investigations can provide useful, detailed information on accidents and disengagements.
- Testing companies should be required to file disengagement reports that are standardized across manufacturers. Annual public metrics that address possible improvements beyond disengagement reporting can provide additional information to regulators, the public, and consumer safety organizations can be used to enhance safety design.

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[472] Dasom Lee and David J. Hess, "Regulations for On-Road Testing of Connected and Automated Vehicles: Assessing the Potential for Global Safety Harmonization," *Transportation Research*, March 23, 2020, www.sciencedirect.com/science/article/pii/S0965856419308006 (accessed August 19, 2020).
[473] Lee and Hess, "Regulations for On-Road Testing of Connected and Automated Vehicles."
[474] Lee and Hess, "Regulations for On-Road Testing of Connected and Automated Vehicles."
[475] Lee and Hess, "Regulations for On-Road Testing of Connected and Automated Vehicles."
[476] Lee and Hess, "Regulations for On-Road Testing of Connected and Automated Vehicles."
[477] Lee and Hess, "Regulations for On-Road Testing of Connected and Automated Vehicles."

- Testing permits should require considerable insurance coverage.
- Requiring a black box for safety inspections can help to improve knowledge and determine liability when crashes occur.

The City of Pittsburgh has identified a set of principles for public AV testing, known as the Pittsburgh principles:

- Instituting transparent lines of communication between the City and partners testing autonomous vehicles, and annual reports on the implementation of AV policies
- Promoting automated driving systems that encourage high vehicle occupancy with lower or no emissions, and lower cost and equitable transportation options
- Engaging industry leaders and community stakeholders to collaboratively facilitate the further development and deployment of self-driving technology.

In advance of testing or operations, infrastructure owner operators (IOOs) need to know what conditions HAVs can safely operate in, and how they will impact roadway infrastructure and surrounding communities.[478] There are particular safety concerns with HAVs and at-grade rail crossings. The Federal Railroad Administration (FRA) conducted a literature review and scenarios to identify operations and system requirements for safe negotiations at roadway and rail intersections.[479] U.S. DOT and the FRA are partnering with the Association of American Railroads to develop a closed loop safety system to facilitate HAV movements at at-grade rail crossings.[480]

The Final Report from New Jersey's Autonomous Vehicle Task Force recommends that states with best practices in AV testing could be given reciprocal testing authority in the Garden State.

Driver's Licenses

Driver's license requirements will need to be adjusted in response to higher-level AV and CV functionality. Driver tests for HAV operations may be able to be simplified. Driver's licenses may need to have different classes, with one version authorizing the use of lower level AVs and one for Level 4 and 5 HAVs.[481]

- CV driver training may add instruction on V-2-V and V-2-I warnings and appropriate response.
- Level 3 HAVs testing and license requirements may need to verify an individual's ability to monitor the road and take over control of the vehicle when conditions warrant.
- Level 4 HAVs operating within their ODD and Level 5 HAVs may not need individual licensing, and training may focus on the basic rules governing the use of self-driving vehicles. Instead, the ADS itself may need to pass a driver's license test in order to demonstrate a minimal set of skills and safe driving judgements in an artificial setting.

However, driver's license training and testing for the operation of human-driven vehicles may need to be updated around how to share the road with HAVs. Employment at drivers' license agencies could be impacted.[482]

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[478] U.S. Department of Transportation, *Preparing for the Future of Transportation: Automated Vehicles 3.0.*
[479] U.S. Department of Transportation, *Preparing for the Future of Transportation: Automated Vehicles 3.0.*
[480] U.S. Department of Transportation, *Preparing for the Future of Transportation: Automated Vehicles 3.0.*
[481] Zmud et al., *Advancing Automated and Connected Vehicles.*
[482] Zmud et al., *Advancing Automated and Connected Vehicles.*

Insurance Liability

Who pays for insurance and who is liable for crashes may change. Issues that need to be worked out include who pays for the liability coverage for an ADS system: the vehicle manufacturer, subcomponent manufacturer, the vehicle owner and operator, the vehicle manufacturer, or the infrastructure owner operator (IOO)? Which one of these parties will shoulder the blame when there is a crash?[483] As HAVs are deployed, new types of insurance will be needed, such as product liability for automakers and comprehensive insurance for fleet owners.[484] Insurance liability questions will abound in virtually any deployment scenario. Future liability analyses will have to consider the different risk levels associated with human and ADS drivers. This may lead to two different insurance measures, and potentially higher rates for humans if they are less safe than ADSs. Given the uncertainty in how an HAV system will operate, at least initially, it will be very difficult to clearly define all liabilities. During the transition to HAVs, insurance will need to be able to determine risk without actuarial data.[485] ADS data from a vehicle involved in a crash may be very useful for safety investigators and insurance adjusters, but it's not clear that service providers will willingly make it available.[486] State laws and policies may obscure or distort the cost of either conventional or automated driving, particularly by limiting what automotive liability insurance writers can and cannot do when setting rates.[487] Governments can help to rationalize the cost of insurance by ensuring insurance companies have access to the data needed for setting rates.

When a Level 2.5 Uber AV hit and killed a pedestrian in Tempe, Arizona in March 2018, the company was absolved of all criminal liability, while the safety driver is facing vehicular manslaughter charges.[488] Elish research has identified a 'moral crumple zone,' where humans who have only limited control of a highly automated system are still blamed when these systems fail; and then become a liability magnet that assumes all legal and moral responsibility in incidents, regardless of how little or unintentionally they are involved in it.[489] This highlights the disconcerting way in which AI—and related AV—systems and their liability is seen: human operators often have little influence over the design of the technologies they interact with, yet often pay the highest cost when the technology fails.[490] Regulators need to find more nuanced ways to fairly distribute liability, and will have to consider regulating sociotechnical systems, especially whether or not the system's design works within its operating context and if it sets up human operators for success or failure.[491] At stake is how human value and potential is able to develop within human-machine teams.[492]

Various studies have estimated the cost of a traffic fatality is between $1.5 and $10 million. In comparison, U.S. motorists are required to carry an average of just $30,000 in liability insurance.[493] AV developers are required to carry $5 million crash liability policies, and TNC drivers have higher liability coverage requirements than non-commercial drivers. Requiring motorists to carry more insurance could make the cost of driving more apparent; give more resources to support those

[483] Schladover, "Progress Toward Automated Driving."
[484] Lee and Hess, "Regulations for On-Road Testing of Connected and Automated Vehicles."
[485] Schladover, "Progress Toward Automated Driving."
[486] Hedlund, PhD, *Preparing for Automated Vehicles: Traffic Safety Issues for States*.
[487] Smith, *How Governments Can Promote Automated Driving*.
[488] Karen Hao, "When Algorithms Mess Up, the Nearest Human Gets the Blame," *Technology Review*, May 28, 2019, www.technologyreview.com/s/613578/ai-algorithms-liability-human-blame/ (accessed June 3, 2019).
[489] Hao, "When Algorithms Mess Up, the Nearest Human Gets the Blame."
[490] Hao, "When Algorithms Mess Up, the Nearest Human Gets the Blame."
[491] Hao, "When Algorithms Mess Up, the Nearest Human Gets the Blame."
[492] Hao, "When Algorithms Mess Up, the Nearest Human Gets the Blame."
[493] Zmud et al., *Advancing Automated and Connected Vehicles*.

seriously injured or the families of those killed in crashes; eliminate what is essentially a public subsidy to unsafe vehicles and drivers, and increase the incentive to purchase and operate safer automobiles.[494] Increased coverage requirements could raise prices and increase the number of uninsured drivers on the road.[495] This could call for more enforcement, though there are possible technological solutions such as requiring every vehicle to have a transponder that transmits real-time proof of insurance.[496] However, these solutions would likely be unpopular with drivers and could create potential equity issues. Higher insurance minimums could push many, particularly low-income individuals, out of the insurance market. Failure to raise minimums, however, means society will continue to shift the costs of deaths and injuries from those who cause them to the victims and their families.

Zmud et al., have suggested one potential liability solution is to implement no-fault insurance, which is already the law in 12 states. A no-fault approach lets crash victims claim damages from their own insurer after a crash, rather than seeking them from another driver. States with these laws all have an injury threshold where sufficiently serious injuries, in terms of financial costs, lift the no-fault restrictions and the plaintiff can sue whomever they deem liable.[497] This would largely keep the existing system that requires drivers to bear the financial responsibility for crashes without having to make difficult determinations of responsibility between drivers, automobile manufacturers, and other parties.[498] It would keep manufacturers from facing increased liability costs, which could slow the introduction of HAV technology.[499] The case for no-fault insurance depends on how important it is to clarify liability and reduce manufacturer liability risk.[500] However, no-fault insurance programs have higher liability coverage costs and could reduce HAV and CV incentives by decreasing purchaser benefits if the crashes they avoid are those where the operator would have been at fault.[501] No-fault programs can also reduce safety incentives for manufacturers who have reduced legal risk because operators recover their damages from insurers.[502] Both insurers and consumer groups have mixed opinions on no fault insurance; while trial lawyers have generally been opposed to no-fault programs and would likely be a barrier to enactment.[503]

The Need for Federal Government Leadership

An overarching and perhaps even unilateral federal policy governing HAV adoption may be a prerequisite to widespread deployment. The federal government currently lacks a visionary transportation policy. If regulations are left up to each state, metro area, or municipality, there will inevitably be huge differences in the rules and standards governing HAVs. At the very least, that will stunt the growth of the industry; it could also mean that HAVs simply only go certain places and not others. For instance, without interoperability across boundaries, passengers could have to transfer to a different HAV every time they cross a state line. Achieving this degree of leadership will require bipartisanship to overcome the high levels of political polarization that currently exist in the country.

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[494] Zmud et al., *Advancing Automated and Connected Vehicles.*
[495] Zmud et al., *Advancing Automated and Connected Vehicles.*
[496] Zmud et al., *Advancing Automated and Connected Vehicles.*
[497] Zmud et al., *Advancing Automated and Connected Vehicles.*
[498] Zmud et al., *Advancing Automated and Connected Vehicles.*
[499] Zmud et al., *Advancing Automated and Connected Vehicles.*
[500] Zmud et al., *Advancing Automated and Connected Vehicles.*
[501] Zmud et al., *Advancing Automated and Connected Vehicles.*
[502] Zmud et al., *Advancing Automated and Connected Vehicles.*
[503] Zmud et al., *Advancing Automated and Connected Vehicles.*

Overcoming Externalities in the Existing Transportation Network

Externalities are unforeseen or unintended effects that result from a process or activity. Positive externalities are beneficial to parties who are affected by but did not participate in the process or activity. Negative externalities have detrimental consequences to individuals who did not undertake in the process or activity. Five major examples of negative externalities in the existing transportation system include congestion, air and noise pollution, insurance liability, traffic law enforcement, and inefficient land use:[504]

- Congestion – underpriced roads mean each vehicle entering a roadway operating at or above its capacity causes more delay to each driver using the facility.
- Air and noise pollution – could be reduced by new technologies, but are not currently priced in the existing system.
- Insurance liability – underpriced insurance liability serves as a subsidy for driving, and could slow the transition to safer automated driving. While raising insurance premiums could push some drivers out of the insurance market, particularly low-income individuals, failure to do so means the costs of deaths and injuries are shifted from those who cause them to the victims and their families.
- Traffic law enforcement – human drivers regularly travel above the speed limit and go through yellow and red lights, while CVs and HAVs are likely to be bound by all the rules of the road. This will potentially slow these vehicles down relative to human driven ones. Automated enforcement could help to both level the playing field and improve safety.
- Inefficient land use – facilitating vehicle movement takes considerable space and has negative environmental, economic, and health externalities. Motorized vehicles have transformed the design of our communities in ways that inhibits social interaction, entrenches class boundaries, and harms local economies by reducing walking, biking, and transit.[505] HAVs may reduce the need for parking, particularly if they are shared. To encourage shared HAV fleets, communities can relax parking requirements in existing zoning codes and begin to identify reuse opportunities for existing parking facilities, such as pick-up and drop-off zones, transfer stations between modes, EV charging stations, wider sidewalks, green infrastructure, protected bike lanes, street furniture, or bus-only lanes.

If HAVs and CVs improve safety and convenience, while lowering transportation costs, they could worsen these externalities.[506] However, society could benefit if HAVs reduce land used for parking, enabling denser development in existing communities. Overcoming these externalities will be critical to successfully deploying HAVs.

7. COVID-19 and Black Lives Matter Protests Effects on HAV Development

Current events are causing unprecedented societal transformation. The Coronavirus Disease 2019 (COVID-19) is a public health crisis unlike anything the modern world has seen: a deadly, highly-infectious disease, to which few, if any, people are immune to. The Black Lives Matter protests have brought serious attention to the racial disparities that affect people of color in a variety of ways, and how ingrained racism, policy, and unfair police treatment go back to before the founding of the nation. These issues are front and center in the national dialogue, and could shape HAV deployment.

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[504] Smith, *How Governments Can Promote Automated Driving*.

[505] Ben Walsh, "Self-driving Cars Are Still Cars—Which Means They Won't Improve Your Commute," *The New Republic*, May 29, 2014, www.newrepublic.com/article/117943/googles-self-driving-cars-miss-problem-mobility-america (accessed August 6, 2015).

[506] Zmud et al., *Advancing Automated and Connected Vehicles*.

COVID-19

The COVID-19 virus is primarily transmitted person-to-person through respiratory droplets that form through breathing, talking, sneezing, or coughing.[507] The pandemic has had a heavy human toll, with well-documented, disproportionate impacts to Black, Latinx, and older adult populations. While older individuals have elevated risks due to compromised immune systems, the legacy of racism, exclusion, and environmental factors—urban heat islands, air and water pollution—along with economic, health, and social disparities in BIPOC communities are all being laid bare by COVID-19.

The virus has spread to a point where containing it is quite unlikely. Resolving the crisis increasingly looks like it will require either a vaccine, achieving herd immunity—which can be obtained through either a vaccine or enough people recovering from the virus and being protected against reinfection—or if the virus mutates to be less harmful. Assuming one can be found, the fastest vaccine ever developed, for the mumps, took four years—though current reliable estimates put a potential vaccine being ready by the end of 2020. A vaccine may not be a silver bullet. Even if its overall effectiveness is only 90 percent and just 60 percent of the population gets it, then there will still be a lot of vulnerable people requiring some degree of social distancing measures to remain in place.[508] There have also been concerns about how long immunity will last, which is hard to know given how short the virus has been with us.[509] Relying on herd immunity is risky because it's not clear that recovered COVID-19 patients have long lasting protection against reinfection.[510] Even if recovered individuals do have long lasting immunity, roughly 70 percent of the population would need to have survived the virus in order to achieve herd immunity.[511] Around 200 million individuals in the U.S. alone would need to recover to achieve herd immunity, which could overload hospital systems and cause millions of deaths and leave many more with chronic long-term disabilities.[512] A new COVID strain in Denmark, which was passed back to humans from minks, has not responded to antibodies from the more dominant strain.[513] Mutations such as this could also impact the effectiveness of potential vaccines.[514]

The disease has a wide range of health effects, with about 80 percent of those who test positive remaining asymptomatic or having only mild symptoms, while a small percent of infected individuals get sick enough to require hospitalization.[515] A very small percent of COVID-19 patients quickly worsen and die within days, usually from respiratory weakness and multi-organ failure.[516] 'Long haulers' is the term being given to patients who suffer from long lasting, often debilitating symptoms—shortness of breath, extreme fatigue, intermittent fevers, cough, difficulty concentrating,

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[507] "COVID-19 Employer Information for Bus Transit," *Centers for Disease Control*, Updated August 5, 2020, www.cdc.gov/coronavirus/2019-ncov/community/organizations/bus-transit-operator.html (accessed August 28, 2020).
[508] Allison Aubrey, "A COVID-19 Vaccine May Be Only 50% Effective. Is That Good Enough?" *National Public Radio*, September 12, 2020, www.npr.org/sections/health-shots/2020/09/12/911987987/a-covid-19-vaccine-may-be-only-50-effective-is-that-good-enough (accessed October 11, 2020).
[509] Apoorva Mandavilli, "Immunity to the Coronavirus May Last Years, New Data Hint," *New York Times,* November 17, 2020, www.nytimes.com/2020/11/17/health/coronavirus-immunity.html (accessed November 18, 2020).
[510] "Herd Immunity and COVID-19 (Coronavirus): What You need to Know," *The Mayo Clinic*, undated, www.mayoclinic.org/diseases-conditions/coronavirus/in-depth/herd-immunity-and-coronavirus/art-20486808 (accessed October 8, 2020).
[511] "Herd Immunity and COVID-19 (Coronavirus): What You need to Know," *The Mayo Clinic.*
[512] "Herd Immunity and COVID-19 (Coronavirus): What You need to Know," *The Mayo Clinic.*
[513] Matt Miller, "How a Coronavirus Mutation in Minks Could Wreak Havoc on Vaccine Development," *Slate*, November 6, 2020, www.slate.com/technology/2020/11/coronavirus-mutation-minks-denmark.html (accessed November 7, 2020).
[514] Miller, "How a Coronavirus Mutation in Minks Could Wreak Havoc on Vaccine Development."
[515] Joshua Cohen, "Report Suggests Some 'Mildly Symptomatic' COVID-19 Patients Endure Serious Long-Term Effects," *Forbes*, June 13, 2020, www.forbes.com/sites/joshuacohen/2020/06/13/report-suggests-some-mildly-symptomatic-covid-19-patients-endure-serious-long-term-effects/ (accessed July 11, 2020).
[516] Zoe Cormier, "How COVID-19 Can Damage the Brain," *BBC Future*, June 22, 2020, www.bbc.com/future/article/20200622-the-long-term-effects-of-covid-19-infection (accessed July 20, 2020).

brain fog, chest pressure, headaches, heart palpitations, and others—raising concerns that the virus may cause long-term disabilities, even for patients with only mild cases.[517] These effects could have severe impacts to both individual health and well-being, as well as the workforce if a sizable number of workers struggle with even simple cognitive and physical tasks.

As this report is going to publication, at least two Phase 3 vaccine trials are reporting promising interim, preliminary results. A partnership between Pfizer and BioNTech reported more than 90 percent effectiveness and a second trial by Moderna has reported nearly 95 percent effectiveness. A non-peer reviewed study has shown that people who have recovered from COVID-19 still have strong immune memory T and B cells more than eight months later.[518] This suggests immunity against the virus could last for years. In further good news, a separate study has found that survivors of SARS, which was caused by another coronavirus, still have immunity to it more than 17 years later.[519]

Fears have been raised that the pandemic could cause a major economic depression of up to 10 years.[520] There are estimates that up to 42 percent of the millions of jobs lost in the immediate aftermath of the shutdown may never come back.[521] Other forecasts suggest that up to 75 percent of small businesses, restaurants, and shops may permanently close their doors, which will be costly for both their former employees and the communities they were located in.[522] As small companies struggle to adapt, the pandemic could further entrench the dominance of a handful of digital superstar companies, which are able to attract the best talent, buy the most valuable patents and startups, and make the most advantageous deals.[523] High household savings levels, as consumers have been social distancing and less able to spend money, and a fast rising stock market provide a counternarrative to forthcoming recession, and instead indicate an economy primed for takeoff.[524] Either way, the entire post-pandemic economy is likely to look very different from what existed before the virus struck. For one, working from home will likely rise significantly compared to pre-pandemic levels. Major companies, such as Google, Twitter, and Nationwide Insurance, have publicly announced plans to allow large portions of their workforce to continue working from home post-pandemic. The growth of e-commerce during the pandemic is unlikely to reverse once it is over.

COVID-19 has shown how efficiently urban areas can reinvent themselves in order to adapt to change, particularly in terms of closing roads to vehicles to increase recreation area in dense neighborhoods, and taking of parking spaces to expand outdoor dining areas for restaurants. These changes haven't been welcomed by everyone, particularly essential workers whose need to get to work or deliver goods were made harder. This resistance to change could preview what could happen when and if HAVs are deployed and urban space is reapportioned around them—particularly if these changes are seen as more greatly benefitting wealthier and whiter populations.

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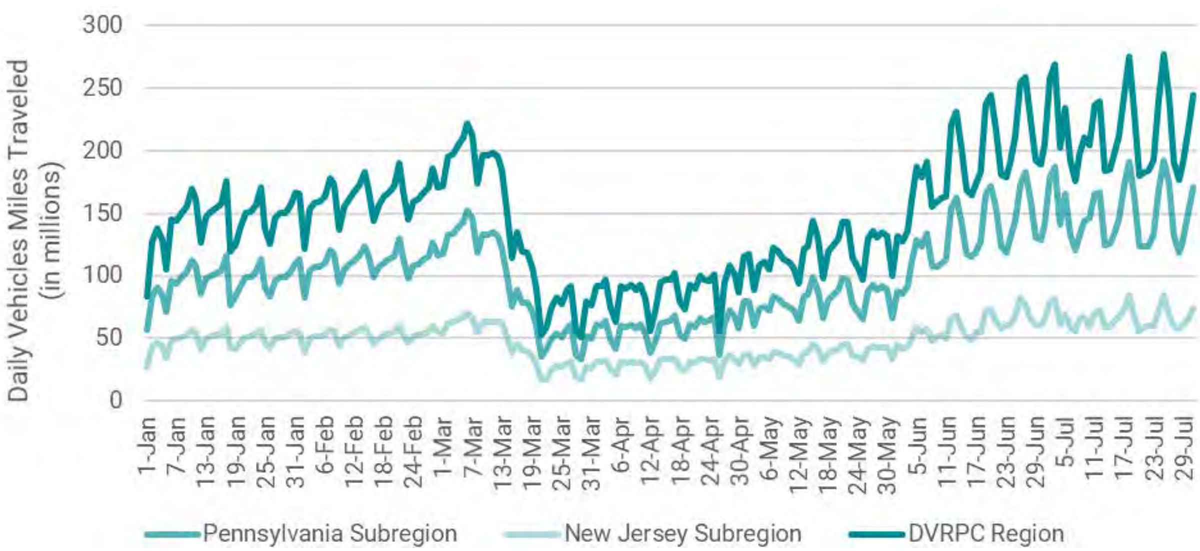
[517] Cohen, "Report Suggests Some 'Mildly Symptomatic' COVID-19 Patients Endure Serious Long-Term Effects."
[518] Mandavilli, "Immunity to the Coronavirus May Last Years, New Data Hint."
[519] Mandavilli, "Immunity to the Coronavirus May Last Years, New Data Hint."
[520] Nouriel Roubini, "Ten Reasons Why a 'Great Depression' for the 2020s is Inevitable," *The Guardian*, April 29, 2020, www.theguardian.com/business/2020/apr/29/ten-reasons-why-greater-depression-for-the-2020s-is-inevitable-covid (accessed May 23, 2020).
[521] Jose Maria Barrero, Nick Bloom, and Steven J. Davis, *COVID-19 Is Also a Reallocation Shock* (Chicago, IL: Becker Friedman Institute for Economics at the University of Chicago, Working Paper No. 2020-59, June 2020) www.bfi.uchicago.edu/wp-content/uploads/BFI_WP_202059.pdf/.
[522] Lloyd Alter, "The Coronavirus and the Future of Main Street," *Treehugger*, April 20, 2020, www.treehugger.com/urban-design/coronavirus-and-future-main-street.html (accessed May 25, 2020).
[523] Steve LeVine, "Our Economy Was Just Blasted Years into the Future," *Medium Marker*, May 26, 2020, www.marker.medium.com/our-economy-was-just-blasted-years-into-the-future-a591fbba2298 (accessed May 28, 2020).
[524] Derek Thompson, "What Will Happen to Cities in 2021?" *The Atlantic*, December 9, 2020, www.theatlantic.com/ideas/archive/2020/12/the-2021-post-pandemic-prediction-palooza/617332/ (accessed December 21, 2020).

The pandemic has radically altered the world of transportation.

- Shelter at home orders vastly reduced demand for transportation throughout the spring of 2020.
- Original equipment manufacturers (OEMS) initially halted production of new vehicles and new vehicle components.[525] Ford lost more than $2 billion from April to June 2020, though carmakers had a better quarter from July through September as the pandemic stimulated car purchases.
- On-road vehicle AV testing was delayed. Testing conducted during the shutdown could be unusable given this period's irregular travel patterns, and even testing done pre-pandemic could be less valuable if the 'new normal' changes significantly.[526]
- There have been severe drops in transit ridership, and shared mobility services. As a result, transportation networking companies are pivoting from moving passengers to home deliveries.[527] Uber laid off 3,500 workers. Car rental company Hertz filed for bankruptcy.
- Sales of personal mobility devices, such as bikes and scooters, have risen at historic rates.
- New York City went two months without a traffic fatality at the height of its lockdown in the spring of 2020.[528] However, KSI has been well above average in the months since, as reduced congestion has enabled faster travel speeds.
- Our sudden change in so many behaviors is breaking AI programs that manage inventories, detect fraud, conduct marketing, and perform other tasks, with some programs stopping working altogether and others are requiring manual corrections.[529]

Figure C-2. Greater Philadelphia VMT, January to July 2020



Source: Streetlight, 2020.

As lockdowns began to be lifted in the summer of 2020, regional VMT rebounded faster, while transit ridership has been slower to recover. July 2020 regional VMT was above pre-pandemic travel,

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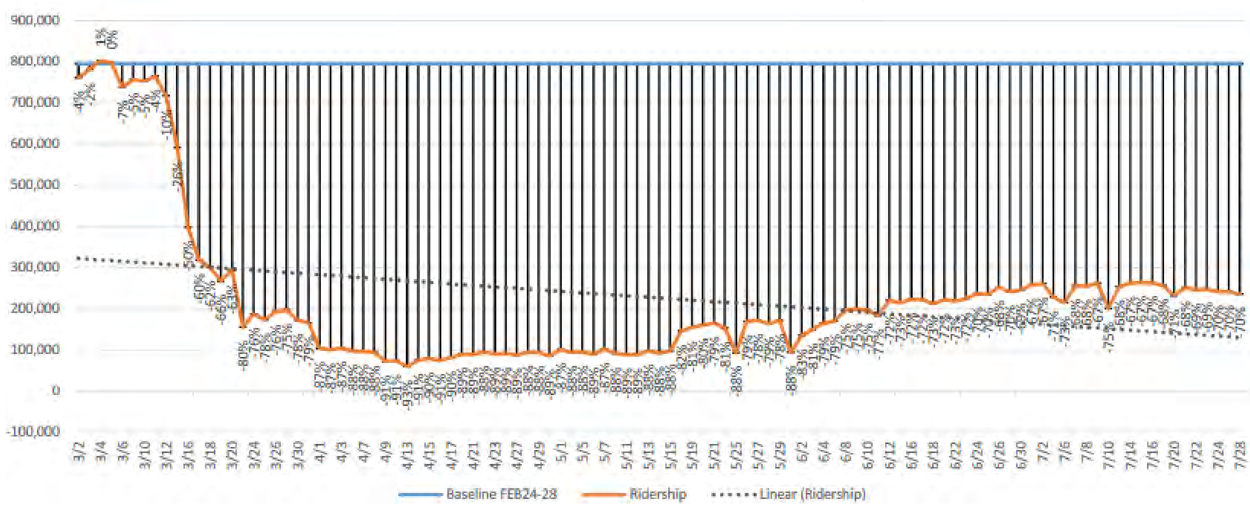
525 Binder, "The Future of Transportation: Impact of COVID-19 on Mobility."
526 "COVID-19 AVs & Shared Mobility Implications."
527 Binder, "The Future of Transportation: Impact of COVID-19 on Mobility."
528 Farhad Manjoo, "I've Seen a Future Without Cars, and It's Amazing," *New York Times*, July 9, 2020, www.nytimes.com/2020/07/09/opinion/sunday/ban-cars-manhattan-cities.html (accessed July 16, 2020).
529 Will Douglas Heaven, "Our Weird Behavior During the Pandemic is Messing With AI Models," *MIT Technology Review*, May 11, 2020, www.technologyreview.com/2020/05/11/1001563/covid-pandemic-broken-ai-machine-learning-amazon-retail-fraud-humans-in-the-loop/ (accessed May 19, 2020).

though there are seasonality factors at play. Typically, winter VMT are well below annual average, and summer VMT are well above annual average travel. The latest forecast is that PennDOT will lose approximately $600 million in revenue in 2020, which has come down substantially from an early forecast that PennDOT would lose around one billion dollars in revenue due to decreased driving.[530]

SEPTA's ridership decline peaked at 7 percent of its February 24 to 28 baseline, but had only recovered to about 30 percent of the baseline by the end of July. This ridership loss is costing SEPTA one million dollars per day in lost fare revenues, which will create a huge hole in the agency's operating budget going forward. PATCO's ridership is even lower, at about 21 percent of pre-pandemic levels. In a reverse from pre-pandemic, both transit and roads have seen higher use demand on weekends than during weekdays. While people have avoided transit out of fear of catching the virus in tightly confined quarters, subway systems are constantly cooling and filtering air within the vehicle which helps to limit viral particles from building up.[531] On average, ventilation units on both ends of a subway car fully turn over the air in the vehicle with air outside the vehicle every three minutes and 20 seconds.[532]

Figure C-3. SEPTA March to July 2020 Consolidated Transit Weekday Ridership



Baseline ridership 794,559 established from weekdays 2/24/20 to 2/28/20.
Based on SEPTA Key and Farebox legacy data and excludes free interchange counts.
April 1st began free rear door boarding with fare collection waived for Bus, Trolley, and NHSL service.
April 9th began widespread route and station closures with service remaining on a Saturday schedule.
May 18th began front door boarding and the return to farce collection, however capacity limits by vehicle type remain in effect.
June 1st SEPTA suspended all service starting at noon.
June 5th the Greater Philadelphia region moved into the yellow phase, lifting the stay-at-home order with fewer restrictions.
Daily ridership will change slightly due to the delay in farebox data collection.
Source: SEPTA.

Regional trail use has been much higher than previous years, as people have been seeking ways to escape their in-home confinement, get exercise, and spend time in nature.

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530 Rachel Yonkunas, "PennDOT Estimating Nearly $1 Billion in Revenue Losses Due to COVID-19 Shutdowns," *MSN*, May 29, 2020, www.msn.com/en-us/news/us/penndot-estimating-nearly-1-billion-in-revenue-losses-due-to-covid-19-shutdowns/ar-BB14JyzC (accessed September 1, 2020).
531 Mika Gröndahl, Christina Goldbaum, and Jeremy White, "What Happens to Viral Particles on the Subway," *The New York Times*, August 10, 2020, www.nytimes.com/interactive/2020/08/10/nyregion/nyc-subway-coronavirus.html (accessed August 28, 2020).
532 Gröndahl, Goldbaum, and White, "What Happens to Viral Particles on the Subway."

The future of transportation beyond COVID-19 is hard to predict. Many analysts speculate that there will be a long-term transition away from transit and shared mobility and toward personal vehicles. The pandemic may accelerate some forms of automation, such as personal delivery devices and middle-mile delivery vans and trucks, while severely slowing the development of others, such as automated shuttles and personal vehicles. Demand for contactless transactions in transportation and other fields is raising interest in touchless, biometric, and facial recognition technologies that would normally raise strong privacy concerns.[533] AV developers may struggle to stay in business in the event of a major economic slowdown or even a depression. Even the big automakers and tech companies could go into survival mode, curtailing AV testing and development programs.

If working from home becomes more routine as a result of COVID-19 than it was pre-pandemic, then there could be long-term declines in demand for transportation infrastructure in the peak period. This suggests a need to revisit the importance of projects designed to deal with peak hour road congestion and transit overcrowding.

Black Lives Matter Protests

Following the deaths of Breanna Taylor, Ahmaud Arbery, George Floyd, and far too many other Black and Brown people at the hands of the police, the U.S. erupted into protests demanding racial and social justice in the spring and summer of 2020. Ending police brutality has been a major focus of Black Lives Matter (BLM) protestors. Transportation is not innocent in the systematic racism that has held back Black, Indigenous, and People of Color (BIPOC). Historically, Interstates and highways were sited so they cut off Black neighborhoods from the wider community; transit systems were segregated in the South up through the 1950s, minorities continue to feel unwelcome in public space, taxis have been well documented in avoiding picking up and dropping off in BIPOC neighborhoods, and a lack of community engagement when planning transportation projects in low-income and underprivileged communities. It is clear that the transportation sector has a long way to go to make up for past transgressions and current shortcomings if it is going to equitably serve everyone.

A handful of opinion articles, such those by prominent planners Destiny Thomas and Amina Yasin and biking advocate Tamika Butler, give some indication to how BLM proponents think that urbanists and transportation professionals can become better allies. Butler notes that "[b]icycling cannot solve systemic racism in the United States. But systemic racism can't be fixed without tackling it within bicycling."[534] Thomas asks that transportation infrastructure agencies stop focusing on white comfort while ignoring the burdens of Black and Brown lives that have been lost in the streets.[535] She further notes that "[p]rivate vehicles will be the primary mode of transportation until Black people are no longer being hunted down by vigilantes, white supremacists, and rogue police."[536]

Yasin is concerned that planners are too focused on fighting cars, while ignoring human rights and silencing protestors who point out that streets aren't really for everyone.[537] While urbanists are

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[533] Steve LeVine, "Our Economy Was Just Blasted Years into the Future."
[534] Tamika Butler, "Why We Must Talk About Race When We Talk About Bikes," *Bicycling*, June 9, 2020, www.bicycling.com/culture/a32783551/cycling-talk-fight-racism/ (accessed June 16, 2020).
[535] Destiny Thomas, "Safe Streets Are Not Safe for Black Lives," *Bloomberg CityLab*, June 8, 2020, www.bloomberg.com/news/articles/2020-06-08/-safe-streets-are-not-safe-for-black-lives (accessed August 8, 2020).
[536] Thomas, "Safe Streets Are Not Safe for Black Lives."
[537] Amina Yasin, "Whose Streets? Black Streets," *TheTyee.ca*, June 18, 2020, www.thetyee.ca/Analysis/2020/06/18/Whose-Streets-Black-Streets/ (accessed August 20, 2020).

advocating for cities that are for everyone and open streets for people of all ages, abilities, and backgrounds; they often ignore the fact that Black people are being harassed and killed in public spaces while they are running, biking, walking, playing, bird watching, barbecuing, simply existing in public space, or driving their cars.[538] Ibram X. Kendi's *How to be an Antiracist* notes that cities were built on stolen land by stolen people, so there is "no such thing as a non-racist idea." In other words, the built environment was constructed on a foundation of racism, slavery, and stolen land.[539] Yasin calls for planners to acknowledge and respond to underprivileged communities' call for life-saving help by answering the calls for justice, redress, and reparations.[540] Kendi further recommends that we understand how "every institution in every community in every nation is producing or sustaining either racial inequity or equity."

Butler and Thomas recommend that urbanists should not rush to redesign cities around longstanding agendas—such as open streets—as a result of the pandemic. They and other protesters are concerned that any changes made before racism is stamped out could reinforce existing racist social structures. Ending racism requires giving voice to disadvantaged Black, Latinx, and other disadvantaged communities, where residents are more likely to be essential workers and at risk from COVID-19.[541] BLM advocates urge undertaking difficult dialogue about the causes of community erasure, structural racism, environmental justice, and unequal wealth distribution.[542] Even then, conversations about radical changes to transportation infrastructure should only occur after infrastructure basics in BIPOC communities have been accommodated in order to mitigate from the disparities caused by racist legacies—appropriate drainage, floodplain planning, cooling down pavement heat indexes, upgrading underground utilities, reducing toxic industries, accessible curbs and crossings, adequate shelter and shade, and dignified support for curbside residents.[543] Transformative transportation projects must be developed through a collective decision-making process centered on the experience of those living in a disadvantaged position in society.[544]

HAVs could help end the racial profiling that often occurs for those who are pulled over for 'driving while Black,' but this outcome won't be assured without first eliminating systemic racism. The intersection of racial inequality and HAV deployment is a topic that needs to be further explored.

II. Second-Degree Deployment Outcome Uncertainties

The following uncertainties are likely to emerge as a result of HAV deployment. The impacts of these uncertainties are generally analyzed around Level 4 HAV deployment. Though it is likely farther off, Level 5 deployment is likely to have dramatic, near unknowable effects. In *Technopoly: The Surrender of Culture to Technology,* Neil Postman wrote that technological change is neither additive nor subtractive, it is ecological in that it changes everything. For example, introducing the printing press to Europe doesn't simply mean there is Europe plus the printing press, rather there was an entirely new environment.[545] Likewise, a world filled with Level 5 HAVs will be transformed in ways that are

538 Yasin, "Whose Streets? Black Streets."
539 Yasin, "Whose Streets? Black Streets."
540 Yasin, "Whose Streets? Black Streets."
541 Alissa Walker, "Coronavirus Is not Fuel for Urbanist Fantasies," *Curbed*, May 20, 2020, www.curbed.com/2020/5/20/21263319/coronavirus-future-city-urban-covid-19 (accessed June 1, 2020).
542 Walker, "Coronavirus Is not Fuel for Urbanist Fantasies."
543 Thomas, "Safe Streets Are Not Safe for Black Lives."
544 Thomas, "Safe Streets Are Not Safe for Black Lives."
545 Neil Postman, *Technopoly: The Surrender of Culture to Technology* (New York, NY: Vintage Books, 1992).

completely unimaginable in the present—much like how cars have transformed our societies and communities over the last 120 years.

1. Automation's Impact on the Economy

Dr. Richard Mudge, Dr. David Montgomery, Erica Groshen, John Paul MacDuffie, Susan Helper, and Charles Carson in *America's Workforce and the Self-Driving Future* estimate that AVs will generate $800 billion in annual economic and social benefits by 2050—and a cumulative $6.3 trillion in these benefits up to that time. These include increased productivity and efficiency, more industrious commute times, increased energy efficiency, less dependency on cartel-based foreign energy sources, improved environmental conditions, expanded labor markets, and better access to retail.[546] Low-income individuals and persons with disabilities, in particular, could gain better access to opportunity and save billions of dollars from missed healthcare appointments.[547] As a result, Mudge et al. warn that any delay in deploying AVs could vastly reduce public welfare—though they don't specify the SAE AV level they are anticipating in their model.[548]

Any number of industries could undergo radical changes as a result of increased efficiencies yielded by automation technologies. Automated tractors and farm equipment could allow farmers to deploy multiple planting or harvesting vehicles and remotely monitor field operations.[549] Sensor and software advances will enable equipment to operate in more complex environments and make precise operational decisions, such as applying herbicides only when weeds are detected.[550] Ports are also beginning to incorporate automation technologies and dynamic scheduling in an effort to increase productivity and safety at container terminals. Automated cranes and guided vehicles are being used to efficiently move containers from ships to stacks and from stacks to rail wagons or truck chassis. It is estimated that port automation could decrease operating expenses by 25 to 55 percent and increase productivity by 10 to 30 percent.[551] AI-enabled diagnostics, telemedicine, and other innovations could allow patients to be cared for in a HAV that comes to them, decentralizing healthcare and even allowing hospitals to become smaller and more specialized.[552]

Automated trucks can potentially safely haul freight over long distances, decreasing transport times and gaining new supply chain efficiencies and cost savings—and let long-distance drivers stay closer to home.[553] Most of the improved efficiency and cost savings ensue from eliminating the driver and faster travel times because work breaks are no longer required. These efficiencies and cost savings could cause a mode shift of certain goods from rail to truck, adding more vehicles to the roads.

In addition, there are many efforts and pilots underway to automate the last mile of freight delivery. Sidewalk robots deliver food and packages. Some notable companies working in this field include Starship Technologies and Kiwibot. Delivery vehicles that utilize the sidewalk bring their own set of challenges (safety for sidewalk users, sidewalk space and congestion, dedicated/appropriate

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[546] Richard Mudge, PhD, David Montgomery, PhD, Erica Groshen, John Paul MacDuffie, Susan Helper, and Charles Carson, *America's Workforce and the Self-Driving Future* (Washington, DC: Securing America's Energy Future, June 2018) https://avworkforce.secureenergy.org/wp-content/uploads/2018/06/SAFE_AV_Policy_Brief.pdf.
[547] Ensuring American Leadership in Automated Vehicle Technologies: Automated Vehicles 4.0.
[548] Mudge, PhD, et al., America's Workforce and the Self-Driving Future.
[549] *Ensuring American Leadership in Automated Vehicle Technologies: Automated Vehicles 4.0.*
[550] *Ensuring American Leadership in Automated Vehicle Technologies: Automated Vehicles 4.0.*
[551] Fox Chu, Sven Gailus, Lisa Liu, and Liumin Ni, "The Future of Automated Ports," *McKinsey*, December 2018, www.mckinsey.com/industries/travel-transport-and-logistics/our-insights/the-future-of-automated-ports (accessed February 18, 2020).
[552] Bits and Atoms, *Taming the Autonomous Vehicle: A Primer for Cities*.
[553] Chu, et al., "The Future of Automated Ports."

loading and drop-off space). Automated road delivery vehicles are being tested by Nuro for groceries and Udelv, which has partnered with Walmart. Amazon Prime Air is a drone delivery service.

The Digital Revolution

While HAVs will clearly have a major impact if and when they are deployed, they are just one part of a much larger driving force that is reshaping regions, societies, and economies: The Digital Revolution. The Digital Revolution is based on a set of interrelated technologies: ubiquitous computing; mobile and broadband Internet access; the proliferation of digital devices; the declining cost and rising capacity of data storage; and sensors that gather data, process it, and turn it into actionable intelligence.[554] It has been upending nearly every industry in an ongoing process that:

- Connects more and more things to the Internet.
- Creates new options (fragmentation).
- Drastically increases data collection and availability.
- Reduces transaction costs.
- Allows actions to be completed remotely.
- Decreases the effects of economies-of-scale, while facilitating greater customization and personalization.
- Flattens both the effects and cost of distance.
- Empowers user-driven networks.
- Enables real-time communications.
- Replaces low-digital skill jobs with high-digital skill ones.

Longer term, Jeremy Rifkin has forecast that various technologies associated with the Digital Revolution—the IoT, digital fabrication and 3D printing, robotics, and AI—will fully automate all work tasks, create abundance, and allow everyone to live a life of luxury with little need to work. Underpinning his analysis is the theory that when technology combined with an open source ethos becomes so efficient that the net marginal cost of production will approach zero, at which point capitalism becomes untenable since it is virtually impossible to turn a profit.[555] In contrast, Yuval Noah Harari forecasts a dystopian future where AI advances past humans to claim the highest point on the hierarchy of creation. As we lose the ability to understand or control AI systems, we may shift from creators and innovators, to chips, then data, and eventually disappear into the vast stream of the planet's data collection systems.[556] Neither of these futures are determined, but they raise the critical need for dialogue around the type of world we want to build for ourselves and how we can use technology to support that vision.

Job Impacts

General-purpose technologies (GPTs) have long and persistent impacts in the productivity of many unrelated industries, that generally lead to a complete reorganization of the entire economy.[557] Past GPTs have included the steam engine, the combination of automobiles and the Interstate Highway System, and information technology and the Internet. Since nearly every aspect of the economy relies on transportation for both goods and services, increased productivity in this sector has more

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[554] Dubravac, Ph.D. *Digital Destiny*.
[555] Jeremy Rifkin, *The Zero Marginal Cost Society* (New York, NY: Palgrave Macmillan, 2014).
[556] Harari, *Homo Deus*.
[557] Scott Andes and Mark Muro. "Robots Are Infiltrating the Growth Statistics," *Brookings Institute*, April 27, 2015. www.brookings.edu/blogs/the-avenue/posts/2015/04/27-robots-growth-statistics-andes-muro (accessed April 29, 2015).

potential to add benefits to the rest of the economy than almost any other industry.[558] Both HAVs and AI are potential GPTs emerging from the Digital Revolution. It is impossible to separate these technologies since HAVs are a particular application of AI.[559] The history of GPTs offers some lessons for potential HAV and AI deployment outcomes:[560]

- Benefits can be significantly underestimated. For example, a 1995 *Newsweek* article called 'Why the Web Won't Be Nirvana" dismissed the Internet's potential, saying "[some say] stores will become obsolete. So how come my local mall does more business in an afternoon than the entire Internet handles in a month?"
- We cannot fully anticipate the extent of the impact. Standard models have underestimated both the expanse and scope of their network-scale shifts. In the early days of the Internet, it would not have been easy to predict the rise of Amazon, Netflix, Facebook, and Google, as none existed at the time. Nor could analysts have anticipated how Interstates combined with the deregulation of trucking would lead to 'big box' retailing and distribution models. HAVs will likely lead to new opportunities and business models that provide considerable public benefit.
- Barriers to adoption diminish over time. For example, the relative cost of computer equipment declined by about 75 percent between 1994 and 2014.

Temporary challenges are likely to emerge during this economic transition when employers need more skilled workers than are readily available, and some workers have skills with less demand in the marketplace.[561] If HAVs broaden job access, this can expand opportunity for job seekers who may otherwise have a difficult time finding a position suited to their skills.[562] Employers will benefit from access to a broader pool of skilled workers, which can help drive economic growth.[563] Upward economic mobility depends on broad and equitable access to affordable mobility.[564] HAV expansion of job access in low income communities can create new opportunities as well.[565]

The declining cost of distance may dramatically change the model for investment and export-led growth.[566] In a change from the current global economy, local producers will gain the advantage over global producers due to greater knowledge of local demand and ability to customize products to fill it.[567] Countries and regions that generate strong domestic demand—based on a large pool of middle-class consumers—will then have an economic advantage in a world of increased local production.[568] Though, expanding the middle class may prove challenging as a result of other changes being wrought by the Digital Revolution.

There has been a widespread media message that the combination of automation and AI could cause massive job disappearance. More nuanced academic and professional analyses warn that the combination of HAVs, automation, and robotics could have major impacts on labor demand. Joseph

[558] Mudge, PhD, et al., *America's Workforce and the Self-Driving Future*.
[559] Mudge, PhD, et al., *America's Workforce and the Self-Driving Future.*
[560] Mudge, PhD, et al., *America's Workforce and the Self-Driving Future*.
[561] Mudge, PhD, et al., *America's Workforce and the Self-Driving Future*.
[562] Mudge, PhD, et al., *America's Workforce and the Self-Driving Future.*
[563] Mudge, PhD, et al., *America's Workforce and the Self-Driving Future*.
[564] Mudge, PhD, et al., *America's Workforce and the Self-Driving Future*.
[565] Mudge, PhD, et al., *America's Workforce and the Self-Driving Future*.
[566] Karen Harris, Andrew Schweden, and Austin Kimson, "Spatial Economics: The Declining Cost of Distance," *Bain & Company,* February 10, 2016, www.bain.com/publications/articles/spatial-economics-the-declining-cost-of-distance.aspx (accessed March 20, 2018).
[567] Harris et al., "Spatial Economics: The Declining Cost of Distance."
[568] Harris et al., "Spatial Economics: The Declining Cost of Distance."

Kane and Adie Tomer identified 9.5 million U.S. workers across 329 different occupations, more than 1 out of every 20, whose jobs are at risk as transportation automates and digitizes in 2017.[569]

- 3.9 million were employed in seven driving occupations: school bus drivers, transit bus drivers, drivers/sales workers, heavy and tractor-trailer truck drivers, delivery services drivers, taxi drivers, and ambulance drivers.
- 3.8 million workers whose job is to design, build, and maintain vehicles, including those employed in motor vehicle and parts manufacturing, automotive repair shops, and wholesale and retail operations, assemblers, salespersons, and other mechanics.
- 1.8 million workers are employed in: construction and highway maintenance, shipping clerks, logistics, and surveyors.

Additionally, computing and telecommunications jobs that are doing the research and development behind these transportation innovations, will potentially be endangered as the technology matures.[570] Every state will feel the impacts differently, depending on how many there are and what their affected workers doing; Kane and Tomer estate that somewhere between 6.3 percent and 7.5 percent of workers will be impacted in Pennsylvania and New Jersey.[571]

But while HAVs, automation and AI may change work tasks, there may be little actual reason to believe that they will displace human workers any time soon. For one, the higher levels of AI, that may cause substantial job impacts, seem to be far off. Even once they are here, these technologies will likely continue to work as they have long done by creating new jobs and shifting skill and task requirements for existing ones. It is hard to envision AI having the capability to do many of the tasks required of a plumber, electrician, HVAC technician, or many other common jobs.

Even amongst one of the fields most considered at risk, truck driving jobs may only be minimally impacted—at least through Level 4 automation. Steve Viscelli's *Driverless? Autonomous Trucks and the Future of the American Trucker* considers automation's likely impact on U.S. trucking jobs. The analysis considers firm size and specialization, they include all trucks that drive lots of miles, a large chunk of which are specialized carriers unlikely to automate. The report separates trucking jobs into different long distance and local classifications for full truckload drivers, including dry and refrigerated trucks, and estimates there are about 2.1 million in total jobs, of which the heavy truck total includes:

- 1.8 million are employees; including around 83,000 less than truckload (LTL) and parcel truck drivers, and 877,800 local delivery drivers, who are generally employees.
- About 300,000 are owner-operators, including roughly 75,000 port drivers, who tend to be contract labor and are not considered employees.

It ultimately estimates that 294,000 out of 2.1 million total trucking jobs could be lost due to Level 4 automation (number of jobs at risk in each category are in parenthesis).

- Full truckload drivers (211,000 driver jobs at risk) move goods from factories to distribution centers and then onto retail stores, often for just a single customer. Drivers rarely perform loading or unloading or special care for cargo work. Drivers often work for large, for-hire firms, which tend to misclassify workers as independent contractors due to low unionization rates. Pay

[569] Joseph Kane and Adie Tomer, "How Big Could the AV Industry be? 9.5 Million Workers and Counting," *Brookings*, November 15, 2018, www.brookings.edu/blog/the-avenue/2018/11/15/how-big-could-the-av-industry-be-9-5-million-workers-and-counting/ (accessed November 20, 2018).
[570] Kane and Tomer, "How Big Could the AV Industry be? 9.5 Million Workers and Counting."
[571] Kane and Tomer, "How Big Could the AV Industry be? 9.5 Million Workers and Counting."

is generally low, as it sets the competitive standard within this segment. These jobs tend to be high turnover due to low pay and strenuous working conditions.

- LTL (all 51,000 driver jobs at risk) and parcel (all 32,000 driver jobs at risk) truck drivers combine freight at terminals for different customers. Freight is initially taken to a facility near the destination, and then drivers take it for delivery. These workers tend to have the highest wages in the industry, thanks to higher unionization rates. As a result, many LTL and parcel drivers have made a career out of this work, and are older on average than all truck drivers and all workers. Long-distance drivers rarely do much more than the driving task, making these jobs ripe for automation.
- Local driving jobs (jobs not seen as at risk), including light-duty pickup and delivery truck drivers. These drivers deliver express packages, flowers, and other wide-ranging products. They are lower paid than long-distance drivers. Though, it's not clear that this analysis accounts for risks from personal delivery devices.
- Port drivers (jobs not seen as at risk) work long hours for low wages. If they are contractors, they may not even earn the minimum wage.

The report's key finding is that without policy intervention, Level 4 truck automation may eliminate high- and mid-wage trucking jobs, while creating more low-quality ones.[572] Automated trucks may be able to handle long-distance highway driving in the near-term, but it may be decades before Level 5 trucks are able to navigate busy local roads.[573] Workers will still be needed for local driving, and to perform tasks such as coupling trailers, fueling, inspections, paperwork, interactions with customers, and loading and unloading.[574] The most likely scenario for automation is that it displaces about 83,000 LTL and parcel jobs and about 211,000 full truckload jobs, which include some of the best paid jobs that are generally unionized and can be made into a career.[575] The individuals currently holding these jobs tend to be older than the average worker.[576]

In the near-term, Level 2 and 3 automation may split trucking into self-driving highway operations and human driving on non-limited access facilities.[577] This would increase the digitization of freight matching, and put downward pressure on driver earnings.[578] More e-commerce and lower shipping costs, thanks in part to automation, could create many new jobs in the future, such as:[579]

1. Moving loads to and from autonomous truck ports (ATPs), which are freight transfer stations located near major highway exit ramps.
2. Shuttling goods from large, centralized warehouses located in urban hinterlands to smaller local depots to enable quick last-mile delivery (similar to the approach being used by Amazon).
3. Delivering packages and goods to customers.

Without policy intervention, these new jobs are more likely to be contract-based and low paying, with worse working conditions than the jobs that will be lost.[580] ATP drivers are likely to have similar working conditions to what ports drivers currently endure: low pay, long periods of unpaid waiting, and misclassification as independent contractors. Port drivers can put in 16-hour days and still lose

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[572] Steve Viscelli, *Driverless? Autonomous Trucks and the Future of the American Trucker* (Berkeley, CA: Center for Labor Research and Education, University of California, Berkeley, and Working Partnerships USA, September 2018) www.driverlessreport.org.
[573] Viscelli, *Driverless? Autonomous Trucks and the Future of the American Trucker*.
[574] Viscelli, *Driverless? Autonomous Trucks and the Future of the American Trucker*.
[575] Viscelli, *Driverless? Autonomous Trucks and the Future of the American Trucker.*
[576] Viscelli, *Driverless? Autonomous Trucks and the Future of the American Trucker.*
[577] Viscelli, *Driverless? Autonomous Trucks and the Future of the American Trucker*.
[578] Viscelli, *Driverless? Autonomous Trucks and the Future of the American Trucker.*
[579] Viscelli, *Driverless? Autonomous Trucks and the Future of the American Trucker*.
[580] Viscelli, *Driverless? Autonomous Trucks and the Future of the American Trucker*.

money after paying off truck loans, company charges, and other fees. If local drivers can only afford older and more inefficient trucks, then surrounding neighborhoods will suffer from more air pollution and resulting health concerns, such as asthma. Delivery drivers are currently paid less than half what many long-distance drivers earn. Retailers seem especially likely to subcontract or adopt the Amazon Flex model of independent contractor drivers—who receive no benefits, must provide their own vehicle, and have no right to organize for higher wages or improved working conditions.

Mudge et al. anticipate similar results in their modeling of AVs in the broader economy. They project that the first effects on employment from HAVs won't start to be felt until the early 2030s. While HAVs are likely to create new jobs that take the place of those they eliminate, there will be a delay where they increase national unemployment rate by between 0.06 and 0.13 percent at the peak sometime from 2045 to 2050, before returning back to full employment in the early 2050s.

Robotics and automation stealing jobs make for attention-grabbing headlines. However, Brookings research has found that, while 5 million manufacturing jobs were lost in the U.S. between 2000 and 2015, with automation often getting the blame for this, though other countries have utilized more robots yet lost fewer jobs.[581] Instead, the Institute's researchers concluded that technology continues to develop new jobs by creating new industries, while bolstering firm competitiveness, and growing wages by reducing prices—which increases purchasing power.[582] HAVs will enable the creation of entirely new products and services, and will allow businesses to restructure and reorganize in ways that increase productivity.[583] Positive indirect impacts on employment seem likely due to dramatically decreased transportation costs for consumers and businesses alike.[584]

McKinsey's *Jobs Lost, Jobs Gained* report focuses on broader employment impacts from robotics and automation, and sounds a more disconcerting alarm for the need to rapidly transition workforce skills. This report estimates that up to 30 percent of work hours could be automated by 2030.[585] A much higher percent of work hours are automatable for jobs that require less education (between 44 percent and 55 percent), than those with a bachelor's degree and higher (22 percent).[586] Rapid automation presents two risks to employment: if these technologies are adopted too fast, they could increase the rate of worker displacement; and if many sectors simultaneously automate, the percent of affected workers could increase.[587] The activities that are most susceptible to automation are routine tasks such as operating machinery, fast food preparation, collecting and analyzing data, mortgage origination, paralegal work, accounting, and back-office transaction processing.[588]

Advanced economies are likely to see declines in routine jobs that are easier to automate: office support occupations (record clerks, office assistants, finance and accounting), some customer interaction jobs (hotel and travel workers, cashiers, food service workers), assembly line workers, dishwashers, food preparation workers, drivers, agricultural and other equipment operators.[589]

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[581] Scott Andes, "'Job Stealing' Robots are an Economic Distraction," *Brookings*, October 12, 2016, www.brookings.edu/blog/metropolitan-revolution/2016/10/12/job-stealing-robots-are-an-economic-distraction/ (accessed November 4, 2017).
[582] Andes, "'Job Stealing' Robots are an Economic Distraction."
[583] Bits and Atoms, *Taming the Autonomous Vehicle: A Primer for Cities*.
[584] Bits and Atoms, *Taming the Autonomous Vehicle: A Primer for Cities*.
[585] *Jobs Lost, Jobs Gained: Workforce Transitions in a Time of Automation* (San Francisco: McKinsey Global Institute, December 2017) www.mckinsey.com/global-themes/future-of-organizations-and-work/what-the-future-of-work-will-mean-for-jobs-skills-and-wages.
[586] *Jobs Lost, Jobs Gained: Workforce Transitions in a Time of Automation*.
[587] *Jobs Lost, Jobs Gained: Workforce Transitions in a Time of Automation*.
[588] *Jobs Lost, Jobs Gained: Workforce Transitions in a Time of Automation*.
[589] *Jobs Lost, Jobs Gained: Workforce Transitions in a Time of Automation*.

These changes in areas of occupational demand could require between 16 and 54 million U.S. workers (up to 32 percent) to shift occupations mid-career.[590]

Automation can raise labor productivity, enabling firms that adopt this technology to generate more and better-quality outputs with the same or fewer inputs (materials, energy, labor).[591] Automation will also increase economic investment, creating short-term GDP growth.[592] Automation is likely to have less of an effect on non-routine and low paying jobs that involve managing and developing people, applying expertise, communicating and social interaction, gardening, plumbing, and child and elder care.[593] These activities require: social and emotional skills and interaction and advanced cognitive capabilities, such as higher-level logical reasoning, creativity, and the application of expertise that the machines are currently less capable of performing.[594] Examples of the types of jobs that may be harder to automate include:[595]

- Health care providers, such as doctors, nurses, physicians' assistants, pharmacists, childcare workers.
- Professionals, such as engineers, accountants, and analysts.
- IT specialists and technicians.
- Managers and executives.
- Educators.
- Creatives, such artists, performers, and entertainers who will be in demand with rising incomes increasing leisure and recreation.
- Non-routine manual and service workers, such as home health aides and gardeners.
- Builders and related professions will grow if there is increased investment in buildings and infrastructure.

McKinsey's research has found that about 0.5 percent of jobs in any given year did not previously exist.[596] This suggests about 8 to 9 percent of jobs in 2030 will be in new occupations that do not currently exist.[597] Most of these new jobs in the U.S. and other advanced economies will be in high-wage occupations.[598]

In an example of how technology can create new jobs, Harari reports that the U.S. military needs 30 people to help fly each one of their 'pilotless' drones.[599] Analyzing the data collected in each drone flight requires 80 more people.[600] The military recently lacked enough trained workers for these tasks, creating an ironic situation where it didn't have enough personnel to fly its unmanned aircraft. So, while drones cause human pilots to lose out, they create new opportunities in maintenance, remote control, data analysis, and cybersecurity.[601] Each of these new jobs, however, requires a high degree of expertise.[602]

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590 *Jobs Lost, Jobs Gained: Workforce Transitions in a Time of Automation*.
591 *Jobs Lost, Jobs Gained: Workforce Transitions in a Time of Automation*.
592 *Jobs Lost, Jobs Gained: Workforce Transitions in a Time of Automation*.
593 *Jobs Lost, Jobs Gained: Workforce Transitions in a Time of Automation.*
594 *Jobs Lost, Jobs Gained: Workforce Transitions in a Time of Automation.*
595 *Jobs Lost, Jobs Gained: Workforce Transitions in a Time of Automation*.
596 *Jobs Lost, Jobs Gained: Workforce Transitions in a Time of Automation*.
597 *Jobs Lost, Jobs Gained: Workforce Transitions in a Time of Automation*.
598 *Jobs Lost, Jobs Gained: Workforce Transitions in a Time of Automation.*
599 Harari, *21 Lessons for the 21st Century.*
600 Harari, *21 Lessons for the 21st Century.*
601 Harari, *21 Lessons for the 21st Century.*
602 Harari, *21 Lessons for the 21st Century.*

There are few precedents for such a rapid turnover of workforce skills.[603] Labor market frictions, such as gender stereotypes and job-worker geographic mismatches, could further impede this transition.[604] Some early estimates of the types of jobs that HAVs may create include hardware and software engineers, customer service call representatives, cleaning and car repair services, and high definition map makers.[605] A recent look at available jobs at Waymo included positions for vehicle inspection and repair technicians, fleet managers to handle vehicle logistics, remote assistants to guide AVs through difficult situations, and customer service representatives.[606] Low-wage jobs will mostly decline, though some will increase, such as nursing and teaching assistants.[607] This suggests income polarization could increase in the future.[608]

Policymakers need to consider the labor market implications at the same time they are developing regulations for HAVs.[609] Decision makers will play a critical role in developing HAV policies and recommendations, but will have do so without a full accounting of HAVs potential positive and negative aspects. Pursuing rapid HAV deployment, while redirecting some of the benefits to mitigate costs to workers, will likely provide the most societal benefits. Mudge et al. offer the following principles to guide any policy formulation:

- Develop comprehensive solutions – HAVs are just one of many potential causes of job displacement. Other technologies and long-term economic policies must also be considered. What works in one place may not work in another, as no single approach will cover every base and a combination of policies may be needed to address the full scope of change.
- Use a broad range of policies – modeling suggests that effects may reach a variety of regions, demographic groups, and workers at different points in their careers.
- Strengthen existing workforce development institutions – there are presently more than 2,000 American Job Centers. Additionally, the Department of Labor offers unemployment insurance that could be expanded to support individuals as they seek reemployment—though a wider range of services could be provided.
- Solutions need to be evidence-based – policies and programs must constantly be evaluated for impact and efficacy. Government should expand data collection efforts, conduct further research, and engage the private sector as a key piece of the solution.
- Identify areas for additional study – some potential examples: industry-level analyses to determine other jobs that could be impacted by HAVs, industries and occupations where unemployed drivers can find new jobs, duration of unemployment, changes in wages, productivity enhancements from reduced driving time, and monitor labor market impacts from alternative transportation options due to HAVs.

Workforce development programs can mitigate disruption and speed the evolution of worker skills that contribute to economic growth and employment levels.[610] The future HAV workforce could

[603] *Jobs Lost, Jobs Gained: Workforce Transitions in a Time of Automation*.
[604] *Jobs Lost, Jobs Gained: Workforce Transitions in a Time of Automation*.
[605] Timothy B. Lee, "Self-driving Cars Will Destroy a Lot of Jobs—They'll Also Create Lot," *Ars Technica*, www.arstechnica.com/tech-policy/2018/08/self-driving-cars-will-destroy-a-lot-of-jobs-theyll-also-create-a-lot/ (accessed November 21, 2018).
[606] Lee, "Self-driving Cars Will Destroy a Lot of Jobs."
[607] *Jobs Lost, Jobs Gained: Workforce Transitions in a Time of Automation.*
[608] *Jobs Lost, Jobs Gained: Workforce Transitions in a Time of Automation*.
[609] Joseph Kane and Adi Tomer, "Equipping Today's AV Workforce with Skills to Succeed Tomorrow," *Brookings*, February 1, 2019, www.brookings.edu/blog/the-avenue/2019/01/31/equipping-todays-av-workforce-with-skills-to-succeed-tomorrow/ (accessed February 5, 2019).
[610] Mudge, PhD, et al., *America's Workforce and the Self-Driving Future.*

benefit from state coordination on occupational licensing and certification programs in order to expand geographic mobility.[611]

Reduced Transportation Costs and More Productive Use of Time

Urban areas are testaments to spatial economics as they reduce the need to travel long distances minimizing the cost of moving raw materials, labor, and goods.[612] The combination of robotics, 3-D printing, delivery drones, logistics innovations, HAVs, and low Earth-orbit (LEO) satellites may drastically shift the cost of distance, enabling manufacturers to produce competitively in small batches at the local level, and employees to work remotely from anywhere.[613]

MaaS integrates end-to-end trip planning, booking, e-ticketing, and payment across all public and private transportation modes. It can encourage more vehicle sharing and reduce the need for vehicle ownership, a significant portion of transportation costs. Whether shared or not, HAVs can potentially reduce costs as a result of fewer crashes, lower insurance costs, less congestion, and decreased operating costs with a shift to electric powertrains. New types of vehicles and lighter weight vehicles could also reduce costs, though these may require achieving Level 5 fully automated operations. Rather than driving, HAV passengers can put their time to other, more productive uses ranging from relaxing to entertainment to socializing to working as they are being transported.

The software and development costs for HAVs are going to be considerable and manufacturers are going to look for a return on investment. HAVs may also require new types of subscription services, such as navigation and security services. For example, navigation services, such as OnStar and TomTom, currently cost between $200 and $600 per year.[614] Shared HAVs may provide new business opportunities and at the same time increase consumer costs for:[615]

- Routine maintenance and cleaning.
- Dispatching and fleet management.
- Business administration and insurance.
- Physical security and cybersecurity.
- Empty vehicle miles to pick up and drop off passengers.
- Detailed digital road mapping.

Rise of Digital Monopolies and Surveillance Capitalism

While networks being created by the Digital Revolution are largely *distributed*—a noncentralized communications system where participants share resources and jointly manage and process information—they are also capturing user data and using it to *recentralize* economic power.[616] While there is currently fierce competition in the race to bring the first HAV to the market, network effects suggest that this race will be short lived and just a handful of players will eventually dominate the industry.[617] Transportation has a history of monopolies in the form of powerful 19th and early 20th century railroads and transit providers. As economies of scale and network effects form they

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[611] Kane and Tomer, "Equipping Today's AV Workforce with Skills to Succeed Tomorrow."
[612] Harris et al., "Spatial Economics: The Declining Cost of Distance."
[613] Harris et al., "Spatial Economics: The Declining Cost of Distance."
[614] Litman, *Autonomous Vehicle Implementation Predictions*.
[615] Litman, *Autonomous Vehicle Implementation Predictions*.
[616] Tom Wheeler, "How We Connect: Network Revolutions from Gutenberg to Google," *The Brookings Cafeteria Podcast*, February 22, 2019, www.brookings.edu/podcast-episode/how-we-connect-network-revolutions-from-gutenberg-to-google/ (accessed March 6, 2019).
[617] "The Market for Driverless Cars Will Head Towards Monopoly," *The Economist*.

increase advantages around data, sharing and maintenance costs.[618] ADSs improve with experience, and the more data they have the better they become at predicting what road objects are and reacting accordingly.[619] Cars used in shared mobility services should cost less than personally-owned vehicles, which sit idle the vast majority of time.[620] Centralized maintenance facilities should have productivity advantages over distributed repair shops, and shared fleets are less likely to have the asymmetrical informational disadvantage that individuals have relative to mechanics.[621] Sharing services become more useful as their customer-base expands in multisided platforms where the more users there are in an area, the more economical it is to operate vehicles in it, and the more likely a rider is to find an option nearby.[622]

Some commentators have raised concerns about how shared mobility companies could work to build 'walled gardens'—which are closed platforms that limit the information or options made available to users.[623] Movement in this direction is already playing out as TNCs acquire or partner with bike sharing, car sharing, scooter sharing, and trip planning and ticketing services.[624] TNCs aren't expected to integrate with each other or with open MaaS apps anytime soon because they want to own the customer experience and the data it generates.[625] While these investments make sense from the company's perspective by providing a hedge against a new mode eating into their core ride hailing business, they don't necessarily benefit the public—especially if they end up cutting into transit service.[626] Even if transit is integrated into a TNC app—as Lyft has done—there is no guarantee that the company won't try and nudge consumers away from transit and onto its service or that it won't expect a commission in return for each transit trip generated, potentially eating away at transit operating budgets.[627]

Shoshana Zuboff's *The Age of Surveillance Capitalism* suggests something even more pernicious is going on with the current iteration of the digital economy. Surveillance capitalists capture and use personal data to better understand each individual's motives, needs, preferences, desires, moods, personality, disposition, and honesty in order to profit from it. As a result, power accumulates within surveillance capitalist firms, while human experience is dispossessed through unilateral and pervasive programs that capture personal data, and then sell it to benefit surveillance capitalists at everyone else's expense.[628] The result is asymmetrical knowledge, where surveillance capitalists know everything about us, while they leave everyone else in the dark about them and their activities.[629]

Zuboff considers surveillance capitalism to be both anti-free markets and anti-democracy. Adam Smith's theory of the invisible hand was developed long before modern transportation, communications, and computing systems.[630] Today, the complex market system is no longer

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618 "The Market for Driverless Cars Will Head Towards Monopoly," *The Economist*.
619 "The Market for Driverless Cars Will Head Towards Monopoly," *The Economist*.
620 "The Market for Driverless Cars Will Head Towards Monopoly," *The Economist*.
621 "The Market for Driverless Cars Will Head Towards Monopoly," *The Economist*.
622 "The Market for Driverless Cars Will Head Towards Monopoly," *The Economist*.
623 David Zipper, "Why Uber and Lyft Want to Create Walled Gardens—and Why it's Bad for Urban Mobility," *Fast Company*, November 2, 2018, www.fastcompany.com/90261748/why-uber-and-lyft-want-to-create-walled-gardens-and-why-its-bad-for-urban-mobility (accessed November 5, 2018).
624 Zipper, "Why Uber and Lyft Want to Create Walled Gardens."
625 Zipper, "Why Uber and Lyft Want to Create Walled Gardens."
626 Zipper, "Why Uber and Lyft Want to Create Walled Gardens."
627 Zipper, "Why Uber and Lyft Want to Create Walled Gardens."
628 Zuboff, *The Age of Surveillance Capitalism*.
629 Zuboff, *The Age of Surveillance Capitalism.*
630 Zuboff, *The Age of Surveillance Capitalism.*

unknowable, and surveillance firms can use data capture, behavior modification, and prediction to reduce uncertainty and better guarantee outcomes.[631] At the same time, surveillance capitalists are replacing many of society's gatekeepers, such as journalists and publishers, allowing misinformation campaigns to move from out of the shadows and into the mainstream.[632] From their vantage point on top of the information chain, surveillance capitalists can determine value by clicks, purchases, and dwell time, regardless of moral content or outcomes.[633] Rather than asking people what they want, in a messy democratic process, surveillance capitalists can use people's data to determine individual preferences for them.[634]

Much of this personal data has been based on activity in the digital world, through web searches, social media, and other online activity. The next step in surveillance capitalism is to move from the virtual world into the real one where individuals are tracked on the road and in their community, in their bloodstream, and throughout their homes.[635] Smartphones, smart homes, smart cities, and vehicle telematics are some of the ways in which surveillance capitalism is expanding into the physical realm. HAVs could potentially be a powerful tool for surveillance capitalism. They may ultimately profit the most from vehicle automation by capturing the value of time an individual spends in the vehicle. One such example may be an HAV containing a store that comes and picks someone up and takes them to work while they shop.[636] Another example would be an advertising company offering free rides in exchange for watching screens that can't be turned off or muted.[637]

The current form of surveillance capitalism is just one of many possible digital economies. In the long-run, we are all better off being full market participants, as earners and customers, rather than partial participants manipulated through digital networks.[638] There are higher energy, more intense digital economy peaks out there, ones that are ideally more empowering to individuals.[639]

Government Adaptation to Change

Governments generally work to maintain a familiar and comfortable status quo while often seeing imagined changes—which are different and untested—as threatening.[640] Overcoming systemic inertia and resistance is difficult, and there is no single pathway that leads to successful governmental innovations.[641] Reform sometimes comes as a response to an impending crisis, while other times it is the result of short-lived opportunities to tackle long-standing problems.[642] When innovation does happen, it is usually either acute—happening over a short period, with leadership from individuals closely tied to decision makers—or incubated—where innovation develops slowly, needing many years to gain traction, and as a result is often slowed down by partisan feuding.[643]

The First Industrial Revolution, starting in the 1760s, was fueled by steam power and mechanical production, which helped form both capitalism and democracy, and led to the growth of cities and

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[631] Zuboff, *The Age of Surveillance Capitalism.*
[632] Zuboff, *The Age of Surveillance Capitalism.*
[633] Zuboff, *The Age of Surveillance Capitalism.*
[634] Greenfield, *Radical Technologies.*
[635] Zuboff, *The Age of Surveillance Capitalism.*
[636] "Autonomous Vehicles: Separating the Hype from Reality."
[637] Roberts, "Here's the Real Nightmare Scenario for Self-Driving Cars."
[638] Jaron Lanier, *Who Owns the Future* (New York, NY: Simon & Schuster, 2013).
[639] Lanier, *Who Owns the Future*.
[640] William A. Galston and Elizabeth McElvein, "Institutional Innovation: How It Happens and Why It Matters," *Brookings*, April 22, 2015, www.brookings.edu/research/papers/2015/04/22-institutional-innovation-galston-mcelvein (accessed April 24, 2015).
[641] Galston and McElvein, "Institutional Innovation: How It Happens and Why It Matters."
[642] Galston and McElvein, "Institutional Innovation: How It Happens and Why It Matters."
[643] Galston and McElvein, "Institutional Innovation: How It Happens and Why It Matters."

factory towns, and canals and railroads. Governments responded to these changes by creating urban water and sanitation systems, urban park networks, and public health departments. The Second Industrial Revolution, starting in the 1870s, was fueled by electricity and lighting, and led to mass production and new communications technologies such as the telegraph and the radio. It also led to mass migration into large cities full of rising skyscrapers—thanks to the invention of mechanical cranes and elevators. These cities also expanded outward along new trolley and subway lines and later through cars, buses, and trucks. Governments rose to meet challenges created by the of the second Industrial Revolution, by regulating work week lengths, eliminating child labor, setting up universal education, zoning, food and drug inspections, anti-trust legislation, women's suffrage, and the construction of new roads and infrastructure.

The rapid technological change being brought about by the Digital Revolution is transforming the functions of our societies and economies.[644] While these technologies bring many benefits, they also raise concerns and have left many groups feeling vulnerable, anxious, and angry.[645] Our political and regulatory systems were developed to respond to the challenges brought about by the Industrial Revolution, and are not prepared to respond to a world of accelerated disruption and misinformation from the Digital Revolution. The recent rapid pace of innovation has left many governments without a clear path for transparently incorporating technology into urban areas.

We are at a historical juncture, where we need to rethink the entire political economy.[646] The leadership needed to bring about change requires relentless effort and dedication.[647] Not having the foresight to adapt to change leads to expensive crises, which are paid for by future generations.[648] Governments will need to work together and with the private sector and the nonprofits in new ways—but at the same time, governments must continue to look out for the public good and can't just accept the private market's claims about new technologies. Governments will need to determine if existing policies may inadvertently set up roadblocks to purchasing technologies needed to support HAV deployment; and will need to ensure the parameters around the types of proposals they can accept and offer contracts that do not prohibit them for working with the technology companies that offer HAV technology support.[649] If the U.S. and the region cannot find ways to fund infrastructure maintenance and technological modernization needs, productivity will decline relative to international competitors and infrastructure failures will become more common.[650]

2. More Mobility with Less Congestion

Pulling off the seemingly impossible feat of more travel and reduced congestion requires ensuring availability of a variety of shared transportation modes; a combination of closer vehicle spacing and narrower travel lanes to increase space efficiency. Shared mobility could further reduce the need for parking and its costs, freeing up land for a variety of higher and better uses and enabling denser development patterns. However, none of these are givens, and the rebound effect has long shown that more efficient use of a resource tends to increase its overall consumption.[651]

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[644] Kaushik Basu, "Why is Democracy Faltering," *Brookings*, October 29, 2018, www.brookings.edu/opinions/why-is-democracy-faltering/ (accessed November 20, 2018).
[645] Basu, "Why is Democracy Faltering."
[646] Harari, *21 Lessons for the 21st Century.*
[647] Galston and McElvein, "Institutional Innovation: How It Happens and Why It Matters."
[648] Galston and McElvein, "Institutional Innovation: How It Happens and Why It Matters."
[649] *Autonomous Vehicles: A Policy Preparation Guide.*
[650] Galston and McElvein, "Institutional Innovation: How It Happens and Why It Matters."
[651] Basu, "Why is Democracy Faltering."

HAVs will likely be programmed to follow all rules of the road and be defensive drivers, which means travel speeds could decrease and reduce current road throughput capacities. HAVs may also block traffic if and when they stop and wait for instructions whenever they encounter unsafe conditions.[652] Experts, such as Schladover, warn that HAVs are unlikely to result in significant safety, congestion, and road capacity expansion benefits until they are operating in their own facilities and are not mixed with human-driven vehicles.[653]

An explosion in VMT could overwhelm the system's ability to handle increased traffic flows. This could lead to widespread gridlock and encourage more sprawling development patterns, potentially reversing the current millennial generation's trend of shunning driving. The impacts from increased travel and resulting congestion may not be felt evenly across the region. Urban areas may feel a bigger increase in congestion if HAV trips replace bike, transit, and pedestrian trips.[654] HAVs could compete with and undermine existing transit services, eventually decimating its operations and potentially worsening safety, since transit currently has a better safety record than even the most optimistic forecasts from HAV developers.[655]

Shared Mobility, Including Walking, Biking, and Transit

If HAVs serve as the death knell for transit, the region could have less space efficient transportation—which reduces mobility and worsens gridlock. In addition, HAVs could decrease walking and biking simply due to their ease of use. However, greater safety from HAVs could encourage more biking due to less perceived risk—though this assumes HAVs prove to be safer around bicyclists and pedestrians than human drivers. If HAVs increase people's willingness to travel, they may spend more time in a vehicle. Some walking, biking, and transit trips, which currently require more physical activity, may be replaced by auto trips. Health impacts from being more sedentary include increased risk of heart disease, strokes, diabetes, and other diseases caused by a lack of physical activity.

Rebound Effect

HAVs can expand mobility options for those who are too young, too old, or otherwise unable to drive. This could reduce chauffeuring burdens for family members and friends, and increase access to education and employment, all of which can increase economic productivity.[656] HAVs could help to reduce congestion through increased vehicle sharing, shorter headway spacing requirements between vehicles, smoother traffic flow, shorter signal lag times, fewer crashes, and more efficient real-time routing. One early estimate suggested that a 90 percent HAV fleet could increase road capacity by up to 80 percent.[657] However, there are several factors why HAVs could actually worsen congestion. There is a 'rebound effect' that occurs whenever driving is made easier or less expensive, which increases peak period motorized travel through a variety of ways:

- Spatial: some drivers change their routes to use the improved facility during peak hours.
- Time: some drivers begin to use the facility during the peak period, rather than another time.
- Mode: some transit, bicyclist, and pedestrian commuters start driving.

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[652] Fagnant and Kockelman, *Preparing a Nation for Autonomous Vehicles: Opportunities, Barriers and Policy Recommendations*.
[653] Schladover, "Progress Toward Automated Driving."
[654] Moavenzadeh and Lang, *Reshaping Urban Mobility with Autonomous Vehicles: Lessons from the City of Boston.*
[655] Sam Schwartz, "No One at the Wheel," Presentation to DVRPC Futures Group, June 19, 2019.
[656] Litman, *Autonomous Vehicle Implementation Predictions*.
[657] Fagnant and Kockelman, *Preparing a Nation for Autonomous Vehicles: Opportunities, Barriers and Policy Recommendations*.

- Frequency: some people start to drive more often.
- Locational decisions: households and businesses make different decisions on where they choose to live or conduct their operations.

The rebound effect occurs as a result of lower operating costs that make driving less expensive and thereby increase vehicular travel; cause people to shift away from transit, walking, and biking to HAVs; create new zero-occupant trips; expand mobility for non-drivers; and lead to more spread out development patterns. In *The Fundamental Law of Road Congestion*, Duranton and Turner found a near one-for-one increase in VMT for each additional road lane mile and that more or less provision of roads had no impact on a region's congestion levels.[658] In general, new efficiencies make the rebound effect possible.

Transportation Network Company Services as a Precursor to HAVs

Transportation network company (TNC) operations around the world potentially give an early insight into what an automated future may look like. TNC rider surveys have suggested that the vast majority of these trips would have otherwise been made by more sustainable modes—walking, biking, and transit—if TNCs weren't an option, and very few TNC rides replace driving trips.[659] In early 2017, Bruce Schaller published *Unsustainable,* which was one of the first in-depth analyses of TNC data in New York City. Schaller found that Uber, Lyft, and other TNCs are replacing taxi and transit trips, while increasing congestion by disrupting the system's equilibrium. They were serving 500,000 passengers a day in fall 2016, and had tripled their ridership over the previous 18 months.[660] Between 2013 and 2016, TNCs generated 31 million vehicle trips. These services created more than ten times as much additional travel as they reduced over this period as they replaced 56 million miles of personal travel, but generated 600 million additional VMT that wouldn't have otherwise occurred.

In 2016, TNCs traveled 1.19 billion miles in NYC, increasing the city's total VMT by seven percent. Shared mobility services, such as ridesplitting, have not reduced VMT, and impacts on motorized travel depends on what mode the passenger is shifting from. TNCs serve as both a push and pull factor away from bus ridership, by offering new cost competitive services and adding congestion to roadways that slows down transit service. Schaller suggests that TNCs necessitate the need to apply congestion pricing to roads, and make transit more competitive through bus only lanes, signal prioritization, preboarding fare payments, and other ways to speed up service.

Schaller's report has generated considerable debate. Robin Chase has noted that personal vehicles are still used for 86 percent of all trips. While not exactly disagreeing with Schaller, Chase argues shared mobility services are still new, and governments would best focus on making cities more attractive for walking, biking, and shared mobility in order to help people move away from auto ownership and single-occupant vehicle (SOV) trips. Failing to do this portends a transportation future with HAVs that is more auto reliant and congested, with less equity and environmental sustainability.[661]

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[658] Gilles Duranton and Matthew A. Turner, *The Fundamental Law of Road Congestion: Evidence from US Cities* (Cambridge, MA: National Bureau of Economic Research, Working Paper 15376, September 2009) www.nber.org/papers/w15376.pdf.

[659] Lisa Rayle, Susan Shaheen, Nelson Chan, Danielle Dai, and Robert Cervero, *App-based, On-Demand Ride Services: Comparing Taxi and Ridesourcing Trips and User Characteristics in San Francisco* (Berkeley, CA: University of California Transportation Center, 2014) www.uctc.net/research/papers/UCTC-FR-2014-08.pdf.

[660] Bruce Schaller, *Unsustainable: The Growth of App-Based Ride Services and Traffic, Travel and the Future of New York City* (Brooklyn, NY: Schaller Associates, February 27, 2017) www.schallerconsult.com/rideservices/unsustainable.pdf.

[661] Robin Chase, "If Your Car is Stuck in Traffic, it's not Uber and Lyft's Fault," *CityLab*, July 27, 2018, www.citylab.com/transportation/2018/07/dont-blame-ride-hailing-for-traffic-congestion/566222/ (accessed August 1, 2018).

Testing Road Pricing with TNCs

TNCs burst onto the global scene by offering convenient rides in real time, while experimenting with dynamic pricing in ways that has never been done before. Various municipalities around the world are now further testing how to apply taxes on TNC operations in ways that further local goals. Transportation-based TNC fees have tried to address goals that: offset the negative impacts arising from increased urban congestion; fund investments in transportation infrastructure and transit; level the playing field between TNC and taxi services; fund TNC regulation and other community needs.[662] To their credit, TNCs have been supportive of various road pricing approaches, particularly those that can reduce congestion—so long as they are on equal footing with all other vehicles and don't single out their services.

Philadelphia has a 1.4 percent tax on TNC fares, two-thirds of revenue generated goes to the Philadelphia School District, and the other one-third goes to the Philadelphia Parking Authority (PPA) to cover TNC regulatory expenses. The PPA has had a hard time auditing TNC accounts, since they are privileged information and not publicly available even under a right-to-know request. The authority has no way of knowing whether the payment requirements are being met. As a result, the authority has proposed shifting to a flat 50 cents per passenger payment system, which could more easily be audited.

Table C-1. Local Taxes on TNC Operations Used to Support Transportation Goals

City	TNC Tax	How Is it Used?
Fortaleza, Brazil	2% of fare, reduced to 1% if company pays for mitigation measures to reduce road use, such as bus or bike-only lanes and sidewalks.	Mitigation measures for road use.
Mexico City, Mexico	1.5% of fare.	Fund for taxis, transportation.
New York, NY	8.875% of fare, surcharges of $2.75 per trip ($0.75 for pooled rides) in lower and midtown Manhattan.	Split between state and city general funds, while surcharge revenue goes to Metropolitan Transportation Authority.
Portland, OR	$0.50 per trip.	100% to Bureau of Transportation.
Sao Paulo, Brazil	$0.04/mile, discounts for shared rides.	Dedicated to fulfilling the goals of the city's urban mobility plan.
Seattle, WA	$0.24 per trip.	$0.14 to Department of Finance and Administrative Services; $0.10 to Wheelchair Accessible Services Fund.
Washington, DC	6% of fare.	17% dedicated to the Department of For-Hire Vehicles, 83% to Washington Metropolitan Area Transit Authority.

Source: Adapted from World Resources Institute, date from shared mobility repository of WRI Ross Center for Sustainable Cities and Eno Center for Transportation.

[662] So Jung Kim and Robert Puentes, "Eno Brief: Taxing New Mobility Services: What's Right? What's Next?" *Eno Center for Transportation*, July 23, 2018, www.enotrans.org/eno-resources/eno-brief-taxing-new-mobility-services-whats-right-whats-next/ (accessed July 26, 2020).

Road Pricing

Duranton and Turner conclude that dynamically pricing the use of roadway facilities to manage demand is the only way to reduce congestion. As more and more vehicles move away from the ICE and to alternate fuel sources, the gas tax will increasingly become obsolete. More public dialogue is needed to develop consensus on a preferred replacement. Some road pricing options include:

congestion pricing, mileage-based user fees, various forms of taxation, requiring HAV developers to invest in infrastructure to support their technology, direct funding from the trucking industry and e-commerce merchants, charging for the use of valuable curb space, and tax incentives to help get new technology deployed sooner. Some key considerations for any new transportation tax or fee, as identified by the Economy League of Greater Philadelphia:

- Ease of Implementation—Is there an existing mechanism for collection of this revenue source?
- Revenue Yield and Adequacy—How much would the source generate, and will it be sufficient?
- Stability and Sustainability—Will the source be stable and not fluctuate unpredictably?
- Fairness and Equity—Are costs of the revenue balanced with the benefits? Will the revenue distribute across jurisdictions? Will it unfairly burden low-income or minority communities?
- Economic Efficiency—How will the source impact economic behavior? How will it impact regional land development patterns? How much revenue will be lost due to administration costs?

New taxes could be implemented incrementally, perhaps coinciding with different levels of AV availability. Pricing can even be structured to further internalize pollution costs, such as by charging higher prices for heavier and/or older vehicles, or to decrease with higher vehicle occupancy. This can then encourage a shift toward newer and more fuel-efficient vehicles and less zero-occupant vehicle (ZOV) and SOV travel. Though higher road pricing for low-income individuals, who may be less able to afford new vehicles, may raise equity concerns.[663]

3. Energy Use and Greenhouse Gas Emissions

Severe weather events and changes to our climate due to global warming pose threats to both the environment and the economy. Global warming is widely recognized as the result of rising levels of GHGs trapping heat in the atmosphere and threatening the life-supporting balance of the global ecosystem. GHGs are predominantly formed by the burning of fossil fuels. The transportation system is currently the second largest source of GHG emissions in both the region and the U.S. as a whole.

In Greater Philadelphia, climate change is expected to increase precipitation and cause more frequent and intense storms—though with fewer precipitation events. Sea-level rise combined with increased total precipitation may lead to more coastal and nuisance flooding. Rising temperatures, with more variability, are likely to mean more days with temperatures greater than 90° F. More freeze-thaw cycles in the winter will harm transportation infrastructure and cause other damages. As impacts may be greater in other parts of the world, the region could see an increase in climate refugees—though the region is not immune to climate risks either, as shown by the impacts of hurricanes Irene and Sandy. A variety of new health concerns could emerge, such as increasing heat-related deaths and tropical diseases becoming more prevalent.

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[663] Zmud et al., *Advancing Automated and Connected Vehicles.*

Clean energy technologies have promise in responding to climate change. A revolution in energy production and distribution is possible when combined with increased consumer willingness to be off the grid; reduced cost of solar, wind, and other forms of renewable energy; improved battery storage technologies; and microgrids. HAVs can help to further reduce energy use and GHG emissions by supporting the move toward electric powertrains, along with vehicle sharing. They can also reduce air and noise pollution through right-sized vehicles and eco-driving techniques. However, more travel and larger vehicles could increase emissions. Pennsylvania state law currently requires energy production and distribution to be conducted by separate entities, which limits the potential for microgrids.

Jevons Paradox, which is related to the rebound effect, states that when technological progress enables more efficient use of a resource, its total consumption rises due to increasing demand. Despite energy efficiency gains in appliances, vehicle fuel economy, and lighting, total energy consumption and carbon emissions continue to rise year after year. Vehicle fuel efficiency has been offset by increased horsepower, curb weight, and travel—while annual VMT has doubled since 1980.[664] The environment is unlikely to benefit when fuel efficiency saves drivers money, because the savings are often spent on other goods or services that involve more energy consumption.[665] This shows how efficiency, which requires little individual sacrifice, counterintuitively worsens the problems we are trying to solve.[666] Carbon taxes and cap-and-trade require individual sacrifice, which makes them less politically palatable, but can drive total consumption down or promote a shift to less carbon intensive, renewable energy sources.[667] The central question for climate change is whether humanity can collectively eliminate human-induced GHG emissions, particularly by quickly developing clean energy and setting market-based signals to further reduce total carbon-based energy consumption, and designing urban areas and systems that require less energy input. Depending on their deployment, HAVs can either help or hinder this desperately needed progress.

Electric Vehicles

The degree to which EVs reduce GHG emissions depends on the source of the fuel used to generate the electricity that powers their batteries. Transportation can decarbonize with a move to EVs and as the electricity mix on the grid includes more zero-carbon sources such as nuclear, solar, wind, and hydropower. While many analysts expect the complex and energy intensive demands of HAV computing systems to require electric vehicle powertrains, others note that the high non-traction electrical load required by these vehicle's systems may mean internal combustion engines (ICEs) are more reliably able to meet electricity demands.

Beyond reducing CO_2, EVs can also reduce emissions of fine particulate matter ($PM_{2.5}$).[668] $PM_{2.5}$ is composed of small particles of dust, metals, toxins, and liquids. When breathed deep into the lungs, it can cause wheezing, coughing, breathing difficulty, or aggravate asthma or bronchitis. $PM_{2.5}$ also poses a health risk for individuals with heart conditions. The smallest particles may enter the bloodstream, changing blood chemistry. This can make the heart work harder to get oxygen to the body. Long-term exposure to $PM_{2.5}$ has been linked to decreased lung function and shortened life

[664] David Owen, "The Efficiency Dilemma," *The New Yorker*, December 13, 2010, www.newyorker.com/magazine/2010/12/20/the-efficiency-dilemma (accessed August 1, 2020).
[665] Owen, "The Efficiency Dilemma."
[666] Owen, "The Efficiency Dilemma."
[667] Owen, "The Efficiency Dilemma."
[668] McKerracher et al., *An Integrated Perspective on the Future of Mobility.*

expectancy. Increased $PM_{2.5}$ emissions raise the likelihood that at-risk groups will develop problems or have them worsen.

While EVs are currently more expensive than traditional ICE vehicles, McKinsey estimates they will be cost competitive by the mid-2020s.[669] As of 2019, the Kia Soul and the Chevy Bolt are two EVs selling on the market below the median price of a new car.[670] As battery technology advances, EV ownership costs could decrease considerably. Already, EVs are generally cheaper to operate due to lower fuel costs, although these costs are offset by the expense of purchasing and installing residential charging infrastructure. Tesla's maintenance costs are about $0.06 per mile, in line with an average ICE vehicle.

Thirteen countries and 20 cities around the world are beginning to phase out ICEs through legislation. Norway will do so by 2025; Denmark, Iceland, Ireland, the Netherlands, Slovenia, and Sweden by 2030; France and the United Kingdom by 2040; Costa Rica by 2050; and China has announced a ban but has not yet set a date. India aims to phase out the ICE by 2030. Several auto manufacturers may also pursue ICE prohibitions. Generally, these regulations will restrict sales or registration of new vehicles, while allowing existing vehicles to remain in service.

If EV uptake moves faster than upgrades to the electrical grid, they could put additional pressure on aging infrastructure and demand for more energy could cause less efficient and rarely used fossil fuel power plants to be put back into service. A move to electric vehicles will undoubtedly be less environmentally damaging than continuing with vehicles powered by the ICE. However, there is some question as to whether the environment can afford the stresses caused by the billions of cars forecast to be built between now and 2050 in order to maintain the current personal ownership model. Globally, between 57 and 97 million cars were built annually from 2000 to 2019.[671] While EVs are much more efficient in operating, their manufacture is energy intensive. Replacing the world's 2 billion ICE vehicles with EVs would use between 20 and 25 percent of the annual U.S. energy consumption.[672] In addition, meeting the material needs to replace all the world's ICE cars with EVs would require increasing extraction and production of neodymium and dysprosium by 70 percent, more than doubling copper output, and 3.5 times more cobalt.[673] The UK Committee on Climate Change has published a report suggesting that there is not enough cobalt, lithium, or copper to do this.[674] Cobalt is primarily produced in the Democratic Republic of the Congo, and is seen as a conflict metal—even if it isn't officially listed as one by the U.S. Government.[675] Powering these EVs with renewable wind or solar energy would require the production of more copper, dysprosium, high-purity silicon, indium, tellurium, and gallium.[676] Economists generally assume substitute resources will become available to deal with any shortages. In addition, powering vehicles with electricity rather

[669] McKerracher et al., *An Integrated Perspective on the Future of Mobility*.
[670] Michael J. Coren, "Electric Cars Are Changing the Cost of Driving," *Quartz*, November 8, 2019, www.qz.com/1737145/the-economics-of-driving-seven-teslas-for-2-5-million-miles/ (accessed November 13, 2019).
[671] I. Wagner, "Estimated Worldwide Automobile Production from 2000 to 2019," *Statista*, April 1, 2020, www.statista.com/statistics/262747/worldwide-automobile-production-since-2000/ (accessed August 11, 2020).
[672] Lloyd Alter, "Why Electric Cars Won't Save Us: There are not Enough Resources to Build Them," *Treehugger*, June 10, 2019, www.treehugger.com/cars/why-electric-cars-wont-save-us-there-are-not-enough-resources-build-them.html (accessed June 18, 2019).
[673] Alter, "Why Electric Cars Won't Save Us."
[674] Alter, "Why Electric Cars Won't Save Us."
[675] Todd C. Frankel, "The Cobalt Pipeline," *The Washington Post*, September 30, 2016, www.washingtonpost.com/graphics/business/batteries/congo-cobalt-mining-for-lithium-ion-battery/ (accessed December 3, 2019).
[676] Alter, "Why Electric Cars Won't Save Us."

than ICEs does not address any of the transportation challenges not related to vehicle tailpipe emissions—road building, parking, sprawl, and crashes with pedestrians, cyclists, and other vehicles.

Gas taxes are the primary way in which the region and nation pay for transportation infrastructure construction and maintenance. Increasing fuel efficiency, along with new types of fuel, will further reduce the flat-rate gas tax revenues that fund most transportation projects, making it even more difficult to maintain the system in the future. Increased use of alternative-fuel vehicles will necessitate finding a new mechanism to raise revenue for transportation infrastructure. Also, there are currently about 125,000 gas stations in the U.S.—which will be potential future redevelopment opportunities—though they will likely require some degree of environmental remediation. [677]

4. Maintaining Urban Vitality and Open Space

The factors that have influenced land development in the U.S. can be seen as the result of both market forces and public policy decisions.[678] If HAVs and CVs increase safety and convenience of vehicle travel, while lowering travel costs, and increasing the willingness to travel farther, then there will be major implications in the location decisions made by people and businesses. However, if HAV technology is incorporated into transit and shared vehicles, then vehicle ownership could decline in favor of transit and shared HAVs, and could result in growth focused in existing urban areas.[679] By reducing the demand for parking, these facilities could be opportunities for redevelopment and potentially denser development can be built with more space efficient transportation allowing more people to be moved within the existing transportation right-of-way.

A primary function of urban areas is to connect individuals with work opportunity within labor markets. The larger the labor market, the more opportunity workers have and the better that firms are able to find workers to meet specific needs. HAVs can benefit workers by expanding job accessibility and labor sheds. However, if large numbers of people relocate as a result of shifting labor market dynamics, then equity concerns will arise as those with the greatest wealth will tend to have the first choice in where to locate, while the least well off may be at risk of being shut out from their neighborhood of choice.

Level 5 HAVs could promote a new round of megasprawl based on an increased willingness to travel, potentially harming rural areas and the environment, while cities lose vitality at the same time.[680] If housing demand and other development shifts to more exurban and rural areas, these places could become less affordable to low-income individuals living there now, and development could encroach on critical wetlands, wildlife habitat, and agricultural lands. If development shifts to more suburban and rural areas, shared-HAV fleets may have a harder time catching on due to the longer amount of time needed to summon a vehicle, which will increase during peak periods.[681] It's also worth noting that there are large areas of existing suburban development in both Greater Philadelphia and around the U.S. that probably won't change development patterns significantly when HAVs begin to roll out—but implications for these areas have not been well studied when considering HAV deployment implications.

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[677] Patrick J. Kiger, "Designing for the Driverless Age," *Urban Land*, July 23, 2018, https://www.urbanland.uli.org/planning-design/designing-driverless-age/ (accessed August 8, 2018).
[678] Zmud et al., *Advancing Automated and Connected Vehicles.*
[679] Zmud et al., *Advancing Automated and Connected Vehicles.*
[680] Zmud et al., *Advancing Automated and Connected Vehicles.*
[681] Litman, *Autonomous Vehicle Implementation Predictions*.

The Digital Revolution and Land Use

Research by Enrico Moretti, Edward Glaeser, Richard Florida, and many others, has found that the knowledge-based digital economy is highly agglomerative. Larger, well-educated regions tend to become more productive as a result of clustering due to knowledge sharing and the concentration of industries, firms, suppliers, and skilled labor. Industries benefit from access to ideas and larger labor pools, while workers benefit from higher wages and more opportunity. Large areas also benefit from having more buyers and sellers, making it easier to match supply and demand.[682]

The Digital Age's agglomeration economies have built winners and losers at the regional level.[683] Innovation hubs have formed in the San Francisco and the Silicon Valley, Seattle, Austin, New York City, and Boston regions due to their combination of highly educated workforces and innovative companies. Many other regions, often former industrial powerhouses, have struggled in the Digital Age because they don't have the workforce skills needed to attract fast growing industries. At the same time, globalization has hastened their decline as U.S. manufacturers have struggled to compete with China in the production of consumer goods.[684] Those that haven't yet clearly been made into either a winner or a loser—such as Greater Philadelphia—may eventually either go one way or the other. This winner-take-all economy is creating deep, structural inequalities between regions.[685]

A looming question is whether these agglomeration effects will disperse more evenly around the country as the Digital Revolution evolves. This force is spinning off entirely new industries even as it undermines older, long-standing ones. Moretti notes that industries have life cycles:[686]

1. When they are new, they contain many widely dispersed small producers.
2. They cluster together during their formative years, as they hit their innovative stride, to take advantage of agglomerations.
3. As they mature and become less innovative, they tend to decentralize again and seek out low wage and low-cost locations for production.

This process of clustering and then decentralizing has been well documented for industries as diverse as flour milling, iron founding, cigarette production, and automobile manufacturing.[687] The combination of maturing digital industries and technologies, such as HAVs, could reverse the current agglomeration effect and lead to either a dispersed or decentralized development pattern.

5. Achieving Equitable Access

There are multiple definitions of equity that can be applied to different scales (geographic areas, groups, or individuals) and areas (markets, access to opportunity, equal outcomes). The definition of equity that this report will use is the just and fair inclusion in a society where everyone can participate, prosper, and reach their full potential. Given such a definition, the use of HAVs in transportation will not be equitable if the benefits of and access to this technology are based on ability to pay or operational skill level to use rather than transportation needs of persons, populations, and geographies, or a comparable travel accessibility through other modes.

[682] Enrico Moretti, *The New Geography of Jobs* (Boston: Mariner Books, 2013).
[683] Moretti, *The New Geography of Jobs*.
[684] Moretti, *The New Geography of Jobs*.
[685] Moretti, *The New Geography of Jobs*.
[686] Moretti, *The New Geography of Jobs*.
[687] Moretti, *The New Geography of Jobs*.

Initial technology adopters tend to be those who are both technologically adept and have the means to afford it. If successful, the technology then diffuses to a wider portion of the population. But it often reaches those with the lowest incomes last, especially without government intervention. Thus, there is always a persistent gap in access to the latest technology between the most and least well off. If AVs and HAVs are both safer and more expensive; those with greater wealth and income levels may have more access to them. So, even though AVs could help to level the playing field for access to safe and low-cost transportation, those most in need may have less access to them.

For HAVs to positively impact social equity, the transportation network and the technology will need to be managed as a public good in an inclusive fashion.[688] This means getting pricing right, managing parking and the public right-of-way, and ensuring that transit uses of HAV technology become more convenient and service-oriented. If HAV technology focuses on those who can pay, an unfair situation may arise where everyone else is left with declining service, particularly if transit is disrupted. Achieving equitable access and looking out for the public good will require groups to work closely together in ways that they haven't ever done before.

While individuals with disabilities are widely expected to benefit from improved access to transportation and delivery of needed goods, food, and medicine, many may still experience access issues and conflicts in the built environment. Some individuals will still need help entering and exiting vehicles, depending on their disability. In other instances, the technology could limit the ability of persons with disabilities to get around if access isn't designed with everyone's needs in mind. For example, disability-rights advocate Emily Ackerman had her path back to a sidewalk ramp blocked by a delivery robot while crossing a busy avenue on the University of Pittsburgh campus.[689] Ackerman was able to hop the curb using her power wheelchair, however this comes with a painful jolt and risks getting stuck on the curb.[690] After tweeting about her experience, the robot's manufacturer, Starship Technologies, pulled all devices out of testing and invited Ackerman for a discussion on how to better design for individuals with disabilities.[691]

Additionally, reports have indicated that AVs have not been adequately programmed to detect people of color.[692] This disconcerting issue must be resolved quickly, even in advance of further on-road testing. Both of these examples show equity shortcomings in AV development. The Silicon Valley technology mantra is to move fast and break things, but there needs to be more consideration about how technology may negatively impact individuals and communities. Technology companies should work to ensure that the teams designing and testing AVs and other technologies have wide-ranging diversity and perspective.

Since operations collect data in real-time, ADSs could potentially use individual characteristics—such as age, gender, or race—into consideration when they need to act in unavoidable crash situations.[693] Germany passed legislation in 2017 that prevents HAVs from identifying people on the street by their characteristics.[694]

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[688] "Autonomous Vehicles: Separating the Hype from Reality."
[689] Emily Ackerman, "My Fight with a Sidewalk Robot," *CityLab*, November 19, 2019, www.citylab.com/perspective/2019/11/autonomous-technology-ai-robot-delivery-disability-rights/602209/ (accessed November 30, 2019).
[690] Ackerman, "My Fight with a Sidewalk Robot."
[691] Ackerman, "My Fight with a Sidewalk Robot."
[692] Teale, "Study: AVs May Struggle to Detect Pedestrians with Dark Skin."
[693] Christina Leuker and Wouter Van Den Bos, "We Need to Save Ignorance from AI," *Nautilus*, June 14, 2018, www.nautil.us/issue/61/coordinates/we-need-to-save-ignorance-from-ai (accessed June 21, 2018).
[694] Leuker and Van Den Bos, "We Need to Save Ignorance from AI."

The cost to use shared HAVs may vary based on supply and demand, since it would be inefficient to size fleets to meet peak-hour demand.[695] This means the calculus of each trip that an individual takes could vary based on the available supply and demand for each mode and create price surges, leading to affordability and equity issues.[696] Increased congestion could lead to more regulation that has unintended equity consequences that widen the economic divide within the public right-of-way. For example, charging congestion prices in urban centers may worsen income inequality. In addition, existing TNC services continue to seek ways of hailing and paying for ridehailing services without requiring access to a smartphone. This issue is likely to still be a concern with shared AV fleets. To better address shared mobility equity issues society may need to:

- Provide subsidies based on need.
- Ensure shared mobility providers serve low-income areas.
- Develop prepaid or digital banking options.
- Provide alternative on-demand ride-hailing methods: concierge, corner store, phone call, kiosk, text message, or others.

6. Redesigning the Transportation Network

HAVs are seen as a way to reset and fix a transportation system that seems to be fundamentally broken. But simply plopping down HAVs on the existing transportation network could be a recipe for disaster, one that could increase auto dependence, disrupt walking, biking, and transit, and lead to global gridlock. Rather, HAVs present an opportunity to redesign transportation around a vision for a shared, integrated multimodal network. HAVs can fill gaps in a transportation network that puts biking and walking at the top of the hierarchy, followed by transit, then shared motorized mobility, with privately-owned motorized vehicles at the bottom (see Figure C-4). Freight and goods movement vehicles would fit into this scheme based largely on whether they have an occupant (SOV) or not (ZOV). HAVs may need to be prioritized over human-driven cars if society wants to receive many of the potential benefits from vehicle automation. Technology can be used to provide more travel information through integrated apps that can identify intermodal options, book and navigate trips across modes, and use real-time info to optimize travel.[697] On the back end, technology can help to better manage traffic flow with real-time data collected from vehicles and infrastructure for active traffic management, and dynamic routing and pricing.[698]

With more options for getting around, need for car ownership and parking can be reduced. On-street parking and parking facilities can be repurposed as pick-up and drop-off zones, transfer stations between modes (mobility hubs), electric vehicle charging stations, wider sidewalks, pedestrian plazas, protected bike lanes, street furniture, green infrastructure (trees, parklets, rain gardens, daylit streams), bus- or shared-mobility-only lanes, or returning land to the private market.

Shared mobility can potentially help solve the first-mile and last-mile access to transit problem that has long been one of the biggest challenges to increasing ridership. Automated shuttles, on-demand vehicles, and other new modes could be used as feeders into an optimized, high-capacity transit network. Transit capacity can be improved through bus-only lanes, signal prioritization, pre-boarding fare payment and other transit first strategies. HAV technology can be applied to bus rapid transit

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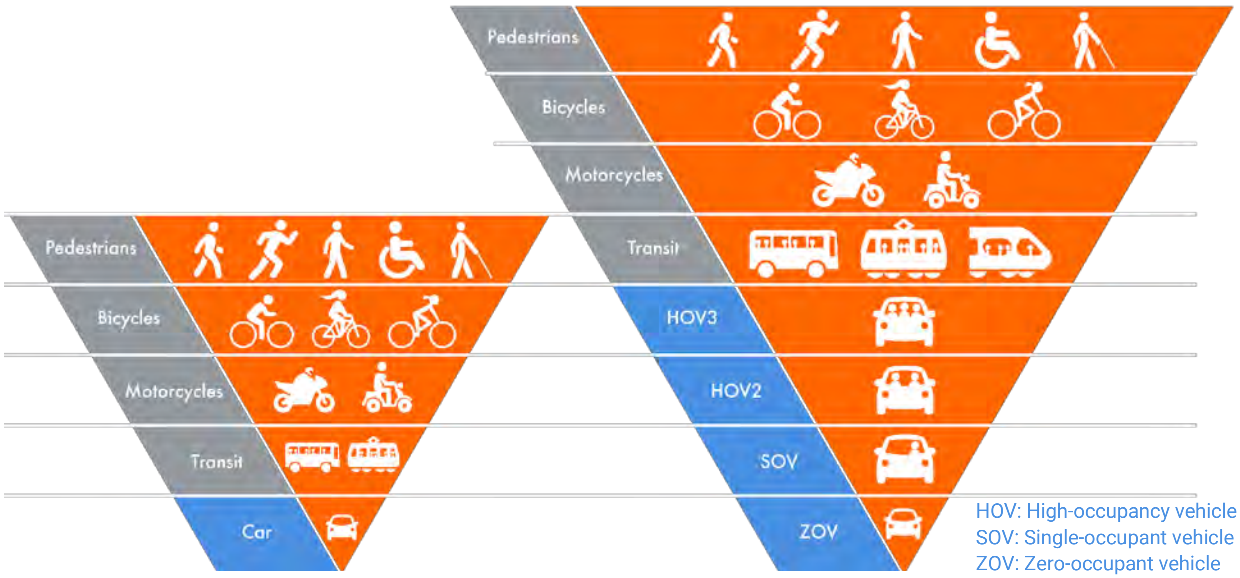
[695] Joe Cortright, "The Price of Autonomous Cars: Why it Matters," *Strong Towns Blog,* October 4, 2016, www.strongtowns.org/journal/2016/10/3/the-price-of-autonomous-cars-why-it-matters (accessed October 12, 2016).
[696] Cortright, "The Price of Autonomous Cars: Why it Matters."
[697] Moavenzadeh and Lang, *Reshaping Urban Mobility with Autonomous Vehicles: Lessons from the City of Boston.*
[698] Moavenzadeh and Lang, *Reshaping Urban Mobility with Autonomous Vehicles: Lessons from the City of Boston.*

with dedicated lanes.[699] Since drivers can account for more than 50 percent of transit operating expenses, automation could lower these costs and enable increased service frequency with the savings. However, it's not clear that a group of strangers will feel safe sharing space inside a smaller moving vehicle without someone in charge of keeping order. The role of the bus driver may, instead, shift to a concierge, who maintains control, provides wayfinding guidance, and gives other types of assistance as needed, which could perhaps limit the opportunity for operating cost savings.

Figure C-4. Example of Multimodal Transportation Hierarchy, Without and With HAVs



Source: Carma.

Precision docking can allow buses to have rail-like accuracy, within one centimeter, letting a wheelchair roll on and off without needing a ramp.[700] HAVs are often touted as an opportunity to improve mobility for persons with disabilities. However, these individuals may need help in order to enter and exit vehicles. As a result, paratransit drivers may be replaced by more skilled medical technicians who can also perform triage and preventative care.[701]

There may be other opportunities to transform infrastructure once HAVs become commonplace. For example, AVs can more consistently drive in the center of a lane, so current lane widths could be reduced. A road with three 12-foot lanes today could be turned into a road with four 9-foot lanes on a facility that is restricted to HAV use only. Some analysts have even suggested that AVs could get by in as little as 8-foot lanes.[702] Roads that are narrowed could either have more lanes in the same right-of-way or give space back to different transportation modes or other uses. However, these narrowed lanes may need to be limited to active driving HAVs. Even still, there would be risks if they need to partially depart from their lane to avoid objects and could hit a car in the adjacent lane.

There are huge, potentially insurmountable challenges for the compatibility of HAVs and different operating environments: highways, arterials, rural roads, suburban roads, and the urban grid. These

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[699] "Autonomous Vehicles: Separating the Hype from Reality."
[700] Schladover, "Progress Toward Automated Driving."
[701] Bits and Atoms, *Taming the Autonomous Vehicle: A Primer for Cities.*
[702] Ryan Snyder, "Street Design Implications of Autonomous Vehicles," *Congress of New Urbanism*, March 12, 2018, www.cnu.org/publicsquare/2018/03/12/street-design-implications-autonomous-vehicles (accessed December 31, 2018).

environments are often strenuous for human drivers. If HAVs can't navigate pedestrian-rich areas, such as Center City, Philadelphia, then their deployment may be quite difficult.

While the vision is compelling, there is no easy and clear roadmap to get from the existing system to an envisioned shared mobility network. It is difficult to design both for today's requirements and prepare for tomorrow's needs.[703] The way forward is full of uncertainty, from when HAVs will be available to how they will be used, to how they will overcome all kinds of externalities in the existing system, and even as the new network is being built the old must still be maintained. Any change that favors new technologies, especially if they are expensive, may have major equity concerns. In addition to thinking about what new types of infrastructure will be needed, figuring out what to do with old infrastructure that is no longer needed—gas stations for example—will be another challenge; though gas stations could potentially be repurposed as EV-charging or battery-swapping stations.

Mobility-as-a-Service

Shared mobility is a key way in which HAVs could reduce transportation costs and make mobility more sustainable. Vehicle ownership can be reduced if shared mobility services are available, higher level automation is achieved, and/or the technology increases vehicle costs. MaaS combines multiple transportation modes with monthly subscriptions or other payment plans, and operates as an integrated network with transit as its backbone. Companies either provide multimodal transportation services or partner with existing operators.

MaaS could change the current transportation model from vehicle ownership to individual rides and monthly subscriptions as the major cost of mobility. Each trip is made using the best available mode through real-time travel information, using an app that simplifies payment across service providers. The app is open to all verified reliable transportation providers, operated by a public or non-service provider entity so that it doesn't manipulate results to favor any particular entity or mode. It enables individuals to customize their travel preferences around environmental friendliness, cost, speed, comfort, and ability to do other things such as read, watch videos, socialize, rest, or work. Level 4 HAVs may be used as shared mobility robotaxis within defined ODDs and automated shuttles could be either hailed on demand or operate fixed route service within MaaS services, if they are able to operate without a safety driver. Level 5 HAVs that can go anywhere and everywhere without the need for a safety driver could greatly strengthen the potential for MaaS, but Level 5 automation is also the point where consumers may be most interested in owning their own HAV.

By making travel easier for everyone, MaaS services risk steering people to more motorized vehicle use, regardless of income, disability, or location.[704] It could make mobility easier for the tech-savvy and for urban residents, and harder for those who are already excluded and marginalized.[705] It could be a great, readily scalable concept, or it could be something that isn't really needed or wanted.[706] Vehicle ownership rates may also remain high if new types of smaller, lighter weight vehicles bring down costs or COVID-19 fears reduce the desirability of shared mobility.

British consulting firm Urban Transport Group has published a report highlighting three key issues for the viability of MaaS services: their underlying economics will determine how impartial, stable, extensive, and competitive they are; the resolution of data ownership, sharing, and resourcing; and

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[703] Snyder, "Street Design Implications of Autonomous Vehicles."
[704] "British Firm Examines Future Potential of 'Mobility-as-a-Service,'" *AASHTO Journal,* September 6, 2019, www.aashtojournal.org/2019/09/06/british-firm-examines-future-potential-of-mobility-as-a-service/ (accessed September 9, 2019).
[705] "British Firm Examines Future Potential of 'Mobility-as-a-Service."
[706] "British Firm Examines Future Potential of 'Mobility-as-a-Service."

how deeply engrained environmental, social, and health goals are built into MaaS systems—including whether they can reduce congestion in urban areas while also contributing to more inclusive, environmentally sustainable, and healthy communities. [707]

Governance of MaaS systems will impact its effectiveness as a program. Different potential models depend on who takes the lead role—a local government, the private market, or a transit agency. Without a focus on the public good, MaaS programs may not serve everyone, could disrupt transit service, or worsen congestion and/or safety. Private-market MaaS services could end up operating as 'walled gardens' that limit access to subscribers (see also 'Rise of Digital Monopolies and Surveillance Capitalism' section in this Appendix). Most MaaS services envision trip options, routing, and payment to be handled through an app. There are different models for setting this up, such as both the publicly facing front end and back-end database being created by either the public sector or the private market.[708] Another approach is to have a publicly developed back-end that different private market providers can interface with for the front end.[709]

Simply creating a MaaS app on its own won't convince people to get out of their cars. A supportive MaaS policy framework must also include carrots and sticks such as: building more protected bike lanes and dedicated micromobility parking; closing major thoroughfares to cars, as New York and San Francisco have done; removing transit policies that prevent riders from bringing bikes on board trains and subways and allowing micromobility parking at transit stations; and slowly increasing the price of residential parking permits.[710] The American Public Transportation Association recently toured four European cities that are among the world's most advanced in developing MaaS, and came back with nine similar key takeaways:[711]

1. Connect the vision with strategy, and back both with political will. Articulate the local challenges being addressed before implementing MaaS. Supportive policies for parking, congestion pricing, land use, and traffic management will all be critical to the success of MaaS programs.
2. Be ready: for the technical needs, to cooperate with other service providers, to set rules of engagement between partners (including for data governance), to increase transit system robustness, and to physically integrate modes. MaaS solutions will look different in every locale.
3. Develop data protocols for open mobility data, the use of application programming interfaces (APIs), and the protection of individual privacy. MaaS systems will generate massive amounts of data, and as a result MaaS companies are often really in the data business. Data can be used to right-size operations, allocate revenues, and in other ways.
4. Experiment and use pilots to foster innovation, with incentives for risk taking, failing fast, and learning from experience. A federal funding program modeled on the Smart Cities Challenge could be beneficial.
5. Measure what matters. Update performance indicators to gauge the success of integrated and shared mobility platforms. New metrics are needed to measure the system as a whole. Increasing transit ridership may not be a proper goal or intended outcome.
6. Find synergies in new partnerships, including with non-traditional partners such as tech companies, automakers, universities, and research institutions.

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[707] "British Firm Examines Future Potential of 'Mobility-as-a-Service."
[708] *Being Mobility-as-a-Service (MaaS) Ready* (Washington, DC: American Public Transportation Association, June 2019) www.apta.com/wp-content/uploads/MaaS_European_Study_Mission-Final-Report_10-2019.pdf.
[709] *Being Mobility-as-a-Service (MaaS) Ready*.
[710] Zipper, "There's No App for Getting People Out of Their Cars."
[711] *Being Mobility-as-a-Service (MaaS) Ready*.

7. Make procurement policies less restrictive. MaaS requires a network of public and private transportation operators, and building it requires going well beyond traditional practices. Services must be easy to understand, use, and pay for. The workforce needs training for the digital age.
8. Focus on public and policy education in order to respond to cultural resistance to transformational changes in car ownership and widespread ridehailing. The role of public transit and a shared mobility system in reducing congestion, more efficiently using land, improving air quality, and promoting economic development needs to be made clear.
9. Design for social equity and access for all. A better understanding is needed of how shared mobility and HAVs could worsen mobility inequality or cause congestion. Studies have found TNCs draw customers away from and undermine public transit and contribute to congestion. A policy framework consisting of curb management, pricing, and contractual relationships between TNCs and the public sector can ward off these threats.

McKinsey's *An Integrated Perspective on the Future of Mobility* identifies three different emerging MaaS models.[712]

1. **Clean and shared** — pedestrian and transit-oriented systems will use a large variety of shared vehicles to improve traffic flow and safety without full-fledged autonomy. These models are emerging in developing countries with poor infrastructure and low adherence to traffic laws.
2. **Private autonomy** — areas with a history of sprawling, auto-oriented development with long commutes are likely to embrace privately owned, electric AVs, which will lead safer, more enjoyable and convenient, and cleaner transportation, while reducing costs. Communities may dedicate road space specifically to AVs and implement demand-based congestion fees, with only small, complementary roles for ride-hailing and car sharing. Transit service would shift more to on-demand vans, though existing transit lines will likely remain in service. However, reduced in-vehicle time costs and operating costs, due to electrification, are likely to increase VMT in these places by up to 25 percent by 2030.
3. **Seamless mobility** — these systems combine automation, electrification, and sharing to deliver a clean, low-cost door-to-door model in a radical departure from the current model—though they require the will and ability to make timely and scaled investments in public infrastructure. Public transit will form the backbone of these transportation networks, supplemented by shared EVs, and smart software apps that coordinate multimodal transportation and MaaS, including the ability to compare travel options and pay for fares across modes. Cities may leverage specialized providers with smart routing and dispatch algorithms to fill first- and last-mile to transit access needs and create a centralized platform for them that also smooths traffic flow. Shared mobility vehicles may receive priority treatment, and lower cost transportation could drastically increase travel by 20 to 50 percent even though the total number of vehicles remains the same or slightly declines. New vehicle sales in seamless mobility areas could be 100 percent electric by 2025. By 2030, up to two-thirds of vehicles on the road may be electric—due to favorable economics for high VMT EVs—and up to 40 percent may be automated.

McKinsey then projects what kind of MaaS model different types of communities will most likely pursue based on population density:[713]

- Rural areas are not expected to adopt a MaaS model.

[712] McKerracher et al., *An Integrated Perspective on the Future of Mobility.*
[713] McKerracher et al., *An Integrated Perspective on the Future of Mobility.*

- Suburban areas are expected to adopt MaaS using the private autonomy approach.
- Dense urban areas are projected to adopt seamless mobility.

Returning Social Life to U.S. Streets

Cars are generally not what makes a city an interesting place, especially if the goal is to have faster traffic on local streets.[714] Prior to the emergence of the automobile, streets had two functions: they were vibrant, social places with a variety of uses and users in addition to providing space for people and goods to move about. The automobile shifted the focus away from social uses and toward utilitarian throughput. The traditional city compresses people and space together so that people can efficiently share buses, streetcars, sidewalks, or bike lanes—instead of driving.[715] This generates public health, emotional well-being, and environmental benefits.[716] The way we design and layout our cities is as important to transportation safety as the technology in our vehicles.[717]

Motorized vehicles were initially seen as a menace to urban vitality. Until the 1930s, drivers who killed pedestrians were charged with technical manslaughter and newspaper stories, editorials, and cartoons regularly drew attention to the dangers that vehicles posed to other street users.[718] Automobile companies aggressively lobbied to change the public's view of streets, cars, and traffic by teaching children they had to stop for traffic and telling drivers that streets were for cars.[719] Traffic statutes that restricted pedestrian use and gave cars primacy over the streets were adopted to overrule common law.[720] Jaywalking, which didn't exist prior to the 1920s, was written into law.[721] This shows the configuration of American streets and the laws that govern them are not the result of some natural process, rather they were brought about by powerful automobile companies and their supporters.[722] Major public works projects, such as urban renewal, then tried to reshape urban areas around the car, rather than building places for people as had historically been done.

The embrace of AVs is out of touch during a time when Americans are showing less interest in vehicles by driving less, purchasing fewer cars, waiting longer to get their drivers' licenses and moving back into urban centers.[723] But it is technology users who tend to be agents of change.[724] So HAVs risk once again moving away from the goal of building places for the needs and desires of people and instead building for the needs of technology—even if this is the preference of a minority of the population. For example, a master plan for Shenzhen, China creates an elevated road network for HAVs and pedestrians, while leaving the street level for human-driven vehicles.[725] Even though elevated infrastructure above the street has rarely, if ever, been associated with good urban design.

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[714] Alison Arieff, "Driving Sideways," *New York Times*, July 23, 2013, www.opinionator.blogs.nytimes.com/2013/07/23/driving-sideways/ (accessed August 11, 2015).
[715] Tanya Snyder, "Peter Norton: We Can Learn from the Movement to Enshrine Car Dependence," *Streetsblog USA*, October 17, 2014, usa.streetsblog.org/2014/10/17/peter-norton-we-can-learn-from-the-movement-to-enshrine-car-dependence/ (accessed August 9, 2018).
[716] Snyder, "Peter Norton: We Can Learn from the Movement to Enshrine Car Dependence."
[717] Smith, "David Ward on Self-Driving Cars: 'Don't Put the Autonomous Cart Before the Horse."
[718] Sarah Goodyear, "The Invention of Jaywalking," *CityLab*, April 24, 2012, www.theatlanticcities.com/commute/2012/04/invention-jaywalking/1837/ (accessed September 22, 2014).
[719] Goodyear, "The Invention of Jaywalking."
[720] Goodyear, "The Invention of Jaywalking."
[721] Goodyear, "The Invention of Jaywalking."
[722] Goodyear, "The Invention of Jaywalking."
[723] Goodyear, "The Invention of Jaywalking."
[724] Peter D. Norton, "Street Rivals: Jaywalking and the Invention of the Motor Age Street," *Technology and Culture*, volume 48, number 2, April 2007, pp. 331-359.
[725] Kiger, "Designing for the Driverless Age."

An old transit adage is *operations, before electronics, before concrete*. In other words, pursue the lowest cost upgrades to improve the system as it exists before building new infrastructure. A similar adage for general transportation could be *place before software before infrastructure*. In other words, build communities with less need for infrastructure, before making operational improvements and programming to improve existing infrastructure. Then, expand roads and transit only when absolutely necessary or in cases where there is an overwhelming economic development opportunity. Prioritizing walking, biking, and transit at the top of the transportation hierarchy will be key in developing a transportation network around people and redesigning the currently overbuilt network relative to our societal willingness to fund it. Level 5 HAVs can then fill gaps in this network and enable a return of the social function of the street. Alternatively, if HAVs increase reliance on motorized travel, the transportation function of streets will further erase their historic social nature.

Managing the Curb

Curb space is increasingly being stretched to its limits by competing uses: parking for personal vehicles, charging stations for EVs, deliveries, transit stops and infrastructure, taxi and TNC pick up and drop off, bike lanes, bike and scooter parking, green infrastructure, ADA accessibility improvements, and parklets. Inadequate allocation of space on the curb for deliveries and TNC drop-offs leads to illegal stopping, double-parking, and blocking through lanes and bike lanes, thereby increasing congestion and its externalities. Designated curbside pick-up and drop-off zones are needed to ensure safe vehicle and building egress as more trips become door-to-door and to support the shared mobility operations that are critical to re-envisioning transportation.

Managing the curb requires municipalities inventory available curb space, measure performance, and reallocate space for optimal use in order to improve accessibility for residents, visitors, and business patrons. Curb management techniques include regulations on use by time of day, time limits, geofencing to identify pick-up and drop-off areas and other allowable curb uses, increased enforcement, and pricing.

Blurring Lines Between Public and Private Transportation

The role of public transit may need to evolve with shared HAVs. The lines between privately-operated shared HAV fleets and publicly-operated transit fleets are going to significantly blur. Public services, from transit agencies to the U.S. Post Office, struggle with a contradictory structural problem: they are expected to be available to everyone and they should be run like a business in order to achieve high use at low cost.[726] Public services are often portrayed as being in decline when use goes down.[727] Declining use is bad to the extent that public services rely on fare revenues to fund their operations—but revenue generation isn't the primary reason why we value public services.[728] Transit agencies are required to make service available across broad areas that private services, such as TNCs, don't have to follow.[729] This combined with compliance requirements for federal funding means that transit isn't competing on a level playing field with TNCs.[730]

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[726] Jarrett Walker, "Public Transit and the Postal Service Have the Same Problem," *Bloomberg CityLab*, August 31, 2020, www.bloomberg.com/news/articles/2020-08-31/how-public-transit-is-like-the-postal-service (accessed September 21, 2020).
[727] Walker, "Public Transit and the Postal Service Have the Same Problem."
[728] Walker, "Public Transit and the Postal Service Have the Same Problem."
[729] Walker, "Public Transit and the Postal Service Have the Same Problem."
[730] Walker, "Public Transit and the Postal Service Have the Same Problem."

The Postal Service isn't profitable because it is available everywhere and serves everyone.[731] If a transit agency was trying to maximize ridership it never would try to serve every household across a large region—because both services are more efficient in more densely developed areas.[732] However, transit is often criticized for its low use-based measures, even though this is not their only goal.[733] Determining if transit services are succeeding requires measuring them against the competing goals of availability—the goal for public services—and usage—the primary goal for private market providers.[734] Ridership goals can be measured directly by ridership, while availability can be measured by the percent of the population and jobs near transit, and then this can be compared with spending levels to determine if availability is being achieved in a cost-effective manner.[735]

To the extent that this technology will inevitably result in some degree of privatization of transportation systems, there are important questions about the public's ability to determine and choose its desired future for this technology. Will the public have any input into a privatized model? How equitable and inclusive will a private model be? These questions deserve a certain degree of emphasis because the questions are already upon us, and the answers we come up with now could have an impact on what is even available to us to choose from in 2030, 2040, 2050, and beyond.

Private-Market Infrastructure Development

In addition to expanded service delivery through MaaS applications, the private market is exploring transportation infrastructure development. The Boring Company, owned by Elon Musk, is building its first project in Las Vegas connecting the Strip with the city's convention center through two 14-foot tunnels that are just under one mile long at a cost of nearly $50 million.[736] The tunnels will allow cars to travel up to 50 miles per hour (mph).[737] The company has dubbed these projects 'Loop,' and early renderings planned for shared 16-passenger vehicles whisking along on skates at speeds of 155 mph—though these shared vehicles and the skate concept have since disappeared.[738] Musk has suggested that the loops will have continuously circulating vehicles for use by bicyclists and pedestrians.[739] Chicago and Washington, DC have also explored longer Loop tunneling projects—though DC's 35-mile tunnel project linking the District to Baltimore forecast a demand of just 2,000 vehicles per day.[740] While tolling is the likely funding plan for these projects, it is possible that they could have some creative financing within a broader MaaS framework.

Overreliance on Technology

As computers carry out more and more of our decision making, we risk being less able to make our own decisions in the future. Level 5 HAVs, in particular, would largely remove human checks. Simple, seamless interfaces and connections sweep away complexity, making it harder to repair automated systems when they do go down.[741] The automatic navigation systems in cars on the road today show how technology gives to people while at the same time taking things away from them. As

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[731] Walker, "Public Transit and the Postal Service Have the Same Problem."
[732] Walker, "Public Transit and the Postal Service Have the Same Problem."
[733] Walker, "Public Transit and the Postal Service Have the Same Problem."
[734] Walker, "Public Transit and the Postal Service Have the Same Problem."
[735] Walker, "Public Transit and the Postal Service Have the Same Problem."
[736] Alissa Walker, "Stop Calling Elon Musk's Boring Tunnel Public Transit," *Curbed*, January 8, 2020, www.curbed.com/2020/1/8/21046929/elon-musk-ces-vegas-boring-company (accessed September 21, 2020).
[737] Walker, "Stop Calling Elon Musk's Boring Tunnel Public Transit."
[738] Walker, "Stop Calling Elon Musk's Boring Tunnel Public Transit."
[739] Walker, "Stop Calling Elon Musk's Boring Tunnel Public Transit."
[740] Walker, "Stop Calling Elon Musk's Boring Tunnel Public Transit."
[741] Greenfield, *Radical Technologies*.

HAVs and other automated systems take over mundane tasks, they make things safer and lead to better outcomes.[742] When something goes wrong, however, even bigger mistakes can happen because the skills atrophy.[743] CVs that alert us to every potential road danger risk alert fatigue, where we become distracted just by dismissing all the warnings.[744]

A major goal is to make technology seamless so that its workings disappear from our view. If we then become increasingly dependent on this technology over time, future generations may not be able to fully understand how to fix or repair it when it breaks down—creating all kinds of systemic, and even potentially existential risks over the long run.

7. Data and Privacy

Governments at all levels can use data, including that generated by CVs and AVs, to improve decision making—which can be used for traffic control, public utilities monitoring, evaluating road safety, to enhance and build transit platforms, and identifying infrastructure needs to safely and efficiently deploy AVs—but only if it is shared.[745] It is unlikely that any party will willingly divulge proprietary data to each jurisdiction they operate, so all parties will need to find consensus on data security, transparency, and the good faith nature in which data is handled.[746] Data sharing could be centralized through anonymized raw data remittance between AV companies and state DOTs, with the DOTs then sharing high priority data with local governments.[747] Individual privacy must be protected as part of any and all data collection.

HAV logistics may mean that even more of our time is consciously programmed, structured, and optimized.[748] People have already lost much of their privacy through vehicle telematics. Today's cars continuously monitor everything from a driver's steering, acceleration, braking, fuel use, emissions, operating time, GPS locational data, detection of passengers, and even to when the windshield wipers are in use to know if it is raining.[749] GM has tracked which radio stations drivers listen to. This data is wirelessly transmitted to the manufacturer, without the consumer knowing how it is used. Beyond having no ability to control where the data is sent, most vehicle owners aren't even aware of it. A 2017 Auto Care Association survey found 72 percent of vehicle owners don't know what telematics are and still have a hard time comprehending them even with a full explanation.[750] Car companies may resell this data to insurance companies and advertisers.[751]

There are currently no federal laws or regulations about what automakers can collect or do with individual driving data.[752] Most vehicle manufacturers hide what they are collecting and sharing behind hard-to-decipher privacy policies. Many analysts think automakers currently keep only a fraction of the data each vehicle generates, and that they have struggled to figure out what to do

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[742] "Hands-Free, Mind-Free: What We Lose through Automation."
[743] "Hands-Free, Mind-Free: What We Lose through Automation."
[744] "Hands-Free, Mind-Free: What We Lose through Automation."
[745] *Autonomous Vehicles: A Policy Preparation Guide*.
[746] *Autonomous Vehicles: A Policy Preparation Guide*.
[747] *Autonomous Vehicles: A Policy Preparation Guide*.
[748] Hart, "Perpetual Motion Machines."
[749] Jeff Clabaugh, "What Your Car Knows About You—and Who it's Telling," *WTOP*, October 19, 2018, www.wtop.com/business-finance/2018/10/what-your-car-knows-about-you-and-who-it-is-telling/ (accessed November 25, 2019).
[750] Clabaugh, "What Your Car Knows About You—and Who it's Telling."
[751] Clabaugh, "What Your Car Knows About You—and Who it's Telling."
[752] Geoffrey A. Fowler, "What Does Your Car Know About You? We Hacked a Chevy to Find Out," *Washington Post*, December 17, 2019, www.washingtonpost.com/technology/2019/12/17/what-does-your-car-know-about-you-we-hacked-chevy-find-out/ (accessed December 23, 2019).

with all this data.[753] 5G networks will connect cars to the Internet with ultra-fast and high-capacity connections, giving opportunity to collect and transfer far more data.[754] Until automakers become more transparent, some individuals may be wary about using in-vehicle apps or signing up for additional data services.[755] If concerned about tracking, consumers should ask the dealer what connected services are associated with the vehicle and how to turn them off.[756]

Road safety audits identify crash and safety issues, evaluate risks, and brainstorm appropriate countermeasures through a dynamic and intensive short-term process conducted with local and subject-matter experts using crash data and a walking survey of the corridor. Road safety audits can be enhanced through additional information from cameras and other data generated by AVs and CVs. However, investigators will only have access to this data only if the federal government makes clarifications on its ownership and use.

CV-enabled transportation networks will generate copious amounts of data.[757] DOTs will need to identify what data collected by connected infrastructure will be made freely available, and whether some of it can—and should—be used to offset connected infrastructure development cost.[758] The key data uncertainty is the extent to which it will it be collected and aggregated—as well as how widely it will be shared, or restricted for privacy, security, or proprietary reasons. But there are many other uncertainties, some of which have yet to be widely discussed. For example, who is to blame when an algorithm makes a decision that leads to harmful outcomes due to bad data?[759]

[753] Fowler, "What Does Your Car Know About You? We Hacked a Chevy to Find Out."
[754] Fowler, "What Does Your Car Know About You? We Hacked a Chevy to Find Out."
[755] Fowler, "What Does Your Car Know About You? We Hacked a Chevy to Find Out."
[756] Fowler, "What Does Your Car Know About You? We Hacked a Chevy to Find Out."
[757] Baker, "Infrastructure is Next Big Thing in AV Investment."
[758] Baker, "Infrastructure is Next Big Thing in AV Investment."
[759] Greenfield, *Radical Technologies*.

Appendix D. Initial Vision, Goals, and Strategies for HAV Deployment in Greater Philadelphia

This initial vision, goals, and strategies were developed as part of this analysis and are presented here to show how they could be crafted to help guide HAV deployment. Ideally, a major public-private mobility partnership would undertake the visioning, goal development, and strategy formation process and then be empowered with the political will for implementation. Vision, goals, and strategies should additionally draw from and be consistent with those in DVRPC's Long-Range Plan.

Initial Vision and Goals

Since no entity in Greater Philadelphia has as of yet conducted a specific visioning exercise around automated vehicles, a good starting place would be for them to fit into the existing vision for transportation found in the *Connections 2045* Plan to create an integrated, multimodal transportation network. This initial vision is presented as a launching point for a Greater Philadelphia Advanced Mobility Partnership to refine and use to develop and prioritize implementation strategies for preparing the region for HAV deployment. While governments will need to look out for the public good, HAV developers and service providers also need to support the vision. The following initial vision is a combination of these goals:

- **Governments at all levels are prepared for HAV deployment well in advance of it happening.**
- **The public is well educated about interacting with HAVs and 'drivers' fully understand how to operate them.**
- **Technology is used to increase safety for all road users and to help obtain the Vision Zero goal of no transportation fatalities or serious injuries.**
- **HAVs support the growth in regional development Centers and denser land use patterns.**
- **HAVs are used for shared mobility and widely integrated with other modes—particularly transit—allowing users to find the best option to get around in ways that retain and expand access to mobility and opportunity, while the need for private vehicle ownership is reduced.**
- **Lower total energy use and greenhouse gas emissions.**
- **Serve all communities and people, regardless of race, ethnicity, gender, or sexual orientation, and not place undue burdens on low-income populations.**
- **Offer an equal opportunity to increase safety and expand access to jobs, education, services, and recreation.**
- **Improve mobility and reduce congestion, and lower the economic and environmental costs of getting around the region.**
- **Help return the historic social function of the street.**
- **Share data, while respecting the individual right to privacy.**

Table D-1 develops goals and performance measure metrics to track them for each portion of the vision.

Table D-1. HAV Vision and Associated Goals and Performance Measures

Vision	Goal	Performance Measure
Governments at all levels are prepared for HAV deployment well in advance of it happening.	Have governments at all levels prepared for deployment	Total and percent AVs by level in vehicle fleet
The public is well educated about interacting with HAVs and 'drivers' fully understand how to operate them.	Educate public and HAV operators	Transportation fatalities and serious injuries
HAV technology increases safety for all road users and helps to obtain the Vision Zero goal of no transportation fatalities or serious injuries.	Achieve Vision Zero	Transportation fatalities and serious injuries
Support the growth of regional development Centers with denser land use patterns and build agglomeration economies.	Support centers and energy-efficient economic growth	Total transportation GHGs, walking and biking commute modeshare
Help return the historic social function of the street.		
Reduce total energy use and greenhouse gas emissions.		
Be shared and widely integrated with other modes—particularly transit—allowing users to find the best option to get around in ways that retain and expand access to mobility and opportunity, while reducing the need for private vehicle ownership.	Build an integrated, multimodal mobility-as-a-service (MaaS) network	Vehicles per capita, percent of trips completed with two or more modes
Improve mobility and reduce congestion, and lower the economic and environmental costs of getting around the region.		
Serve all communities and people, regardless of race, ethnicity, gender, or sexual orientation, and not place undue burdens on low-income populations.	Serve everyone and increase access to opportunity	AV trip Rates by automation level and income level
Offer an equal opportunity to increase safety and expanded access to jobs, education, services, and recreation.		
Share data, while respecting the individual right to privacy.	Share data and respect the individual right to privacy	Units of data collected per capita

Source: DVRPC 2020.

The *Connections 2050* Plan update to Greater Philadelphia's long-range plan will offer an opportunity to further develop the vision and goals for HAV deployment.

Table D-2 compares the goals set in the vision for HAV deployment, compared to scenario-based outcomes. This is used to identify the gaps between potential future directions and the region's desired outcomes, and to help inform recommendations for guiding deployment.

Table D-2. HAV-Driven Progress on Vision by Scenario

Goals	Delayed Expectations	People Power	Technology in the Driver's Seat	Inclusive Tech
Have governments at all levels prepared for deployment	+/−	++	−	++
Educate public and HAV operators	−	++	+	++
Achieve Vision Zero	+	++	+	++
Support centers and energy-efficient economic growth	−	++/−	+/−−	+/−
Build a MaaS network	−	+	+/−	++
Serve everyone and increase access to opportunity	−	+	−	++
Share data and respect the individual right to privacy	−	+/−	−−	+

Legend:
++: Significant progress
+: Progress
−: Regression
−−: Significant regression
++/−: Significant progress in some areas, regression in others
+/−: Progress in some areas, regression in others
+/−−: Progress in some areas, significant regression in others

Source: DVRPC 2020.

Initial Recommendations to Prepare for HAV Deployment

These draft recommendations to prepare for HAVs are organized by the draft HAV deployment goals. There are two primary types of recommendations. The first, universal strategies, are recommendations that are beneficial across a range of plausible AV futures. Universal strategies are broken into short-term, low-risk strategies that are unlikely to have any significant regret and won't set the region on any negative path dependence or technology lock-in directions. The second type of universal actions are generally a heavier lift, which would require medium- to long-term implementation phasing. The second type of recommendations are adaptive actions, which are specific to each scenario and should be considered for implementation if the future appears to be headed in the specific direction of the scenario. Many of these recommendations are more generalized and geared toward further supporting DVRPC's long-range plan's vision and goals. A partnership developing a vision and strategies for deployment may want to focus on actions with a more explicit connection to HAVs. It would be helpful to create some type of graphic that overlays the HAV scenarios, vision and goals, and recommendations.

State and federal agencies are already undertaking many activities to prepare for HAVs, and won't want different regional or local approaches. It will be critical to coordinate and work across the different levels of government, with the private sector involved in developing HAVs, and the general public—who will eventually use these vehicles. In general, the federal and state governments should lead on many of these activities, given local governments have mostly limited resources at their disposal. A major challenge to implementing any of these recommendations will be figuring out how to fund them, given the long-term revenue shortfalls relative to existing transportation infrastructure.

Help Governments Prepare for HAV Deployment

- Delayed Expectations –Much of the time governments spend on preparing for HAVs could have been better spent dealing with a myriad of other problems—particularly given highly constrained resources. Although, some benefits come out of these efforts such as enhanced safety and road conditions.
- People Power – The federal government takes the lead in rolling out HAVs and CV technology, working closely with other levels of government and the private market.
- Technology in the Driver's Seat – Industry-friendly federal legislation removes most safety regulations and allows AVs to be dropped on streets in advance of governmental or infrastructure readiness. As the private market takes on the leadership role in HAV deployment, it builds out CV technologies, which some automakers use while others focus on independent, autonomous operations. The public has less input into HAV deployment causing widespread disagreements on how to address problems, crises, regulations, and safety standards, which reduces social acceptance, and even leads to protest and pushback against the technology.
- Inclusive Tech – Public-private partnerships help governments to work closely with developers in advance of deployment. These partnerships work to increase public awareness of HAV technologies and understand user expectations in advance of deployment. They also work collaboratively on developing connected vehicle technologies. However, these partnerships may fall short in addressing equity concerns in decision making, especially for communities with limited political power.

Recommendations to Help Governments Prepare for HAV Deployment

The federal government should take the lead, recognizing that local government capacity is limited. Governments at all levels should work with the HAV industry on these actions. Public involvement can reduce skepticism and allow people to influence technology development and deployment, and help ensure the resulting system is planned and built for all members of the community. HAVs create uncertainty for the transportation planning process, especially for long-range planning, travel demand models, and financial projections.[760]

HAV developers will need to help inform governments, DOTs, transit agencies, and other infrastructure owners and operators on what can be installed now during construction and rehabilitation projects to ensure that compatibility and capacity is present and available once connected and autonomous vehicles begin to take off in popularity. If a certain type of guardrail coating or line painting or sign coating is better detected by cameras attached to vehicles, and all other items are equal, the region should be future-proofing its current investments as best as we can. This could extend all the way up to insisting on intelligent transportation systems infrastructure to be installed as often as possible, and to ensure that additional fiber capacity is available so as not to need to tear up and replace every single cable in the region. We know extensive amounts of data will be generated from each vehicle, and even with 5G wireless connections, data still needs to enter a "pipeline" at some point in the process.

<u>Short-term and no- or low-regrets actions:</u>

Local governments should:

- ☐ Continue to study what's happening around the world and learn from other regions' best practices.

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[760] Smith, *How Governments Can Promote Automated Driving.*

- ☐ Appoint an AV-point person or task force, gain understanding of AV technology, applications, and activities, as well as cultivating expertise of complex technical and social systems.[761]
- ☐ Work with state governments to advocate at the federal level for public input and involvement into the legislative process around AVs. Include low-income and minority populations, specifically to identify their needs and preferences and develop policies to address them.
- ☐ Analyze how existing laws and regulations impact HAV deployment.
    - ▷ Conduct a legal audit and identify laws, rules, and regulations relevant to all types of vehicles, facilities, services, dealerships, and insurance.[762]
    - ▷ Ambiguities identified in the legal review may require legislative acts, administrative regulations, executive orders, legal interpretations, policy statements, or other mechanisms.
    - ▷ Use existing legal tools in lieu of new regulations such as: prohibitions against driving recklessly and operating an unsafe vehicle, directives that empower departments of motor vehicles to register safe vehicles and revoke unsafe vehicle registration; crash reporting requirements; and requirements that make private insurers indirect vehicle safety regulators.[763] Determine if policies obscure data or distort the cost of either conventional or automated driving, particularly by limiting what auto insurance writers can and cannot do when setting rates.
    - ▷ Identify existing enforcement discretions, where regulations such as freeway speed limits, minimum following distances, centerline restrictions, and general rules about vehicular interactions may be routinely violated by an ADS without penalty.[764]
- ☐ Create detailed plans for safe testing and deployment.
    - ▷ Undertake more pilot projects. For example, test a small-scale rollout of HAVs and analyze impacts within that area of study.
    - ▷ Encourage public safety cases where a developer publicly makes the case that its system works and shows how it actually performs.
    - ▷ Continue research and rigorous testing in real world situations with different road and weather conditions to establish HAV abilities and limitations.
    - ▷ Have either the NHTSA or an independent third party create a gated certification program before allowing the commercial sales or use of HAVs (see Universal Recommendations).
    - ▷ State DOTs should work with DVRPC's Incident Management Task Force to develop a plan for responding to HAV incidents.
        - ○ Identify who should respond and how, and what data and evidence will need to be kept.
        - ○ Foster cross-collaboration between industry, policymakers, and emergency response so AVs communicate with incident responders.
- ☐ Coordinate regionally to ensure interoperability across boundaries. The Greater Philadelphia commute shed extends over two states—Pennsylvania and New Jersey—nine counties, and more than 350 municipalities. Ensuring interoperability across all these jurisdictions will be critical to successfully rolling AVs out in this region. Government responses to HAVs will need to be coordinated between federal, state, and local governments, and include all users, stakeholders, and diverse groups in decision making processes.
    - ▷ Coordination should include local transit agencies, in order to keep the transit agency aware of potential HAV-related infrastructure or policy changes that could affect the transit service

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[761] Smith, *How Governments Can Promote Automated Driving*.
[762] Smith, *How Governments Can Promote Automated Driving*.
[763] Smith, *How Governments Can Promote Automated Driving*.
[764] Smith, *How Governments Can Promote Automated Driving*.

as well as keeping local governments aware of transit agency plans or ideas for deploying HAVs as part of their service.

- ☐ Focus on land use and transportation policies that perform well across a range of AV scenarios. For example, deregulating minimum parking requirements provide benefits across a range of deployment outcomes, while widening freeways and expanding suburban high-capacity transit do not.

Medium- and long-term actions:

- ☐ Prioritize state-of-good repair and maintenance and meet basic HAV infrastructure needs:
  - ▷ Pavement must be smooth and well maintained as potholes and other bumps could cause equipment to become misaligned or malfunction.
  - ▷ Develop a lane markings management system database to track conditions.
  - ▷ Upon clear guidance from FHWA, states, and the MUTCD, look to replace all signs within operational design domains to increase clarity, readability, and achieve standardization across the state or ideally the nation, as needed. This may require additional tree trimming to ensure visibility and removing extraneous signs to simplify the driving task.
  - ▷ Roadway geometry design standards will likely be revised, see each scenario's adaptive recommendations for additional considerations. For example, shoulders along the roadway where HAVs can safely stop when their operating capabilities have been compromised may become critical. This puts current investments in part-time shoulder use projects at risk.
  - ▷ Transportation Systems Management and Operations (TSMO) is the application of technology, robust planning, improved preparedness, and extensive inter- and intra-agency coordination. TSMO strategies are a first step toward automating roads, particularly through managed lanes, ramp metering, and traffic signal prioritization.
  - ▷ Ensure roadway personnel are following the appropriate rules when they are working near active roadways.
  - ▷ Encourage robust cellular, wireless, and satellite network communications infrastructure deployment.
  - ▷ Work with states to tie together asset management databases with stop sign locations, work zone locations, and bridge clearance heights with deep learning to create a road classification system for CAV readiness.
- ☐ Governments must continue to keep up with technological development and update policies and regulations so they match technological innovation.
  - ▷ Update driver's license requirements to incorporate education about HAV capabilities, limitations, operations, and how to share the road with other modes.[765]
  - ▷ Identify model HAV ordinances and legislation for local and state government.
  - ▷ Identify insurance requirements for ADS vehicles.[766]
    - ○ Ensure insurance companies have access to the data needed to set rates.
  - ▷ Update planning processes to consider uncertainty and potential implications of disruptive technologies, such as HAVs, on major capital projects, land use plans, building codes, and budgets.
  - ▷ Anticipate and manage the broader implications of automation and connectivity. AVs will be one of only many technologies that will present policy challenges and may require job

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[765] Hedlund, PhD, *Preparing for Automated Vehicles: Traffic Safety Issues for States*.
[766] Hedlund, PhD, *Preparing for Automated Vehicles: Traffic Safety Issues for States*.

retraining and managing unemployment and underemployment to ease economic transitions for individuals and industries.
    - ▷ Be public and transparent about governmental efforts. Communication encourages dialogue about what governments are and what they should be doing; helps AV developers decide where to expand or deploy technologies; builds credibility across the country, which will be critical in the event of a major incident, and manages public expectations about AV technologies and applications.
- ☐ Set standards for ODDs, ADS updates, and driver interaction.
- ☐ Evaluate HAV policies and programs frequently and revise as needed.

Adaptive actions

Delayed Expectations:

- ☐ Prioritize and focus on more pressing political problems.

People Power:

- ☐ Seek opportunities to deploy automated passenger shuttles and support truck platoons and automated goods movement.

Technology in the Driver's Seat:

- ☐ Maintain public control over roadways.
- ☐ Use public-private partnerships to help fund and speed application CV and AV transportation infrastructure technologies along roads.

Inclusive Tech:

- ☐ Consider how a community jobs program could be used to further the vision of an integrated, multimodal transportation network.

Engage and Educate the Public, and Train HAV Operators

- Delayed Expectations – Education efforts backfire in the face of extremely slow rollout, as public distrust of the technology increases.
- People Power – The slow rollout of HAV technologies is giving time to grow public awareness and better understand user expectations. Some technologists are impatient for deployment and are pushing for products coming out before the general public is convinced ADS's are ready—potentially risking the trust that is being very carefully cultivated with a wider audience.
- Technology in the Driver's Seat – Not enough time was spent in advance of deployment increasing awareness of AV technologies and understanding user expectations. There is widespread public frustration with new technology, particularly as it takes away human control and occasionally proves to be challenging to use.
- Inclusive Tech – Community-based jobs create a potential workforce for engaging and educating the public; rapid development of Level 5 capabilities simplifies training needs.

Recommendations to Engage and Educate the Public, and Train HAV Operators

The HAV industry should lead on these efforts, while working with governments at all levels.

Short-term and no- or low-regrets actions:

- Governments should conduct extensive public engagement and education to identify a big picture vision for HAV deployment and ensure a smooth and safe rollout of AVs.
- Conduct training for all ages to raise awareness of AVs and how to interact with them.
  - Develop driver education materials.
  - Provide more information on the benefits and advantages of AVs, including how they will enhance safety.
  - Determine when individuals are able to rely on an HAV and be freed up to do other things, as advertised by AV manufacturers. Educate on ODDs for Level 3 and 4 HAVs.
  - Inform bicyclists and pedestrians of their rights and how to share the road with HAVs.
- Work with state DOTs to conduct training on AV testing operations:
  - In-vehicle fallback drivers (safety drivers) for on-road safety testing. Begin with classroom instruction with a high degree of testing to ensure comprehension.[767] This training should include defensive driving, driving etiquette, situational awareness, and specific instruction on the ADS that will be tested. Classroom training should be followed with simulator training that prepares drivers for the road. After that, in-vehicle training should start on a closed track, and if all goes well there should be further training on public roads.
  - Early-Stage Test Drivers should be prepared to routinely deal with vehicles and systems that are still being developed, thus more likely to disengage. These drivers should have training in emergency handling and evasive driving techniques, and need quick reflexes so they can readily retake control of the vehicle in any unsafe situation, whether caused by the ADS or a change in road conditions (such as inclement weather).
  - Late-stage test drivers should still be trained to retake control in unsafe situations, but should not need to do this as often; these drivers don't need as much training in emergency handling as a result.
  - Provide training on forming and operating platoons and instruction on safe operations as well as how to share the road with road users not in a platoon, and vice versa, for truck drivers.
  - Train emergency responders and law enforcement on how to interact with HAV technologies.
  - When violations and crashes occur, crash investigators should record any automated features on a vehicle, including its AV level and whether an ADS was operating when the crash occurred.[768]
  - Train those who will work on HAVs about required maintenance and repair needs.

Medium- and long-term actions:

- Conduct training on AV operations:
  - Instruction on how to operate HAVs, and how to interact with other road users, for those who will be 'passengers' in them.
    - This should include the limitations of ADAS and lower level HAV systems, which may not recognize and brake for certain objects in the road as one example.[769]
  - Inform wide audiences on how all modes should interact with AVs on the road.

[767] Hyatt, "Roadshow Explains the SAE's New Self-Driving Testing Guidelines."
[768] Hedlund, PhD, *Preparing for Automated Vehicles: Traffic Safety Issues for States*.
[769] Zmud et al., *Advancing Automated and Connected Vehicles.*

- ▷ Continue to train emergency responders, law enforcement, and repair technicians on the technology as it advances.

<u>Adaptive actions:</u>

Delayed Expectations:

- ☐ Use slow HAV rollout for additional public discourse and building political will around solving current problems.

People Power:

- ☐ To be determined.

Technology in the Driver's Seat:

- ☐ To be determined.

Inclusive Tech:

- ☐ To be determined.

Achieve Vision Zero

- Delayed Expectations – Nonexistent HAV rollout means an opportunity was missed to increase safety.
- People Power – HAVs are being carefully developed and refined in ways that address the most critical safety issues, enhance detection mechanisms and reduce default rates. This slows the technology's rollout and potentially delays obtaining Vision Zero, but may mean society has more time to intentionally build the safest possible driverless cars, buses, and trucks, thereby increasing public trust and confidence in these vehicles.
- Technology in the Driver's Seat – Level 4 HAVs reduce crash rates, but increased VMT risks more risk exposure and limits the decline in total crashes, serious injuries, and fatalities.
- Inclusive Tech – Cooperative Level 5 HAVs significantly reduce crash, serious injury, and fatality rates.

Recommendations to Achieve Vision Zero

<u>Short-term and no- or low-regrets:</u>

- ☐ Follow forthcoming revisions to the Manual on Uniform Traffic Control Devices (MUTCD) and state guidance on roadway lane marking widths, broken line length and gaps, and dotted lines on all exit and entrance ramps and use of chevrons to create clear demarcation of marked pavement areas where the edge lines of the mainline and ramp either converge or diverge (known as gore areas).[770] Fully remove old lane markings and ensure that 'ghost' markings aren't left behind causing confusion to HAVs and Level 2.5 AVs currently operating.
  - ▷ Many of these items are maintained with operating budgets that are already stretched thin. Additional funding sources may need to be identified.
- ☐ Reduce speed limits to slow down all vehicles, including AVs, to enhance safety.
- ☐ Incorporate pedestrian- and bike-only phases to intersection controls.[771]

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[770] Robert Dingess, "Driverless Cars are Stuck in a Traffic Jam."
[771] National Association of City Transportation Officials, *Blueprint for Autonomous Urbanism*.

- ☐ Governments at all levels should use their procurement power to advance EV and ADAS deployment.

Medium- and long-term actions:

- ☐ All HAVs must be able to detect humans and animals by their physical characteristics, such as heat signatures; humans and animals should not be expected to carry a transponder or other digital device in order to be recognized by ADSs.
  - ▷ Local governments should not substantially alter their built environment to make up for the shortcomings of HAV technology. For example, if HAVs have a difficult time seeing pedestrians in an urban area, the solution to this problem should not be to restrict pedestrian movement.
- ☐ Work with state DOTs to create and implement a statewide Vision Zero policy that sets an ambitious goal for fatality reduction, identifies when, where, and what actions will be taken to achieve the target, and identifies performance measures to track results.
- ☐ Calibrate and enforce existing laws:
  - ▷ Facilitate uniformity across jurisdictions by extending regulatory reciprocity. This is preferential for mass produced products; although tailored approaches can be beneficial for pilots, demonstrations, and local deployments.
  - ▷ Legally distinguish passengers from drivers to simplify the framework for driverless systems. If this change is not or cannot be made, states could expressly allow the use of digital devices, such as smartphones, in Level 3 or higher AVs.
  - ▷ Formalize regulatory or statutory exemption authority to provide developers with some level of certainty without reducing flexibility. Allowing an AV pilot project in specific communities may reveal unforeseen legal impediments, which could be initially waived prior to larger reforms and provide key lessons learned.
  - ▷ Clarify enforcement discretion priorities, practices, and protocols and ensure regulations are applied evenly.
    - ○ More automated enforcement of speed laws. If AVs are programmed to follow the speed limit and all other rules of the road, they will be at a disadvantage to human-driven vehicles that are less bound by the law. While unpopular, automated speed enforcement could slow vehicles down, increase safety, and reduce this differential.
    - ○ Enforce intoxicated and distracted driving laws, particularly regarding texting. This could enhance safety for everyone, with increasing benefits for AV users. Additional enforcement may be needed for those who believe ADAS and other safety interventions can compensate for impairment.
    - ○ Enforce and update seatbelt laws. These will still be necessary in HAVs, which may have to take evasive action to avoid obstacles. Laws should be updated to remove restrictions about when and for what purpose automotive manufacturers can provide evidence that a plaintiff was not wearing their seatbelt.
- ☐ Work with states to advocate for the NHTSA to create a gated certification process for AV software and hardware and establish that they provide reasonable safety and protection for both vehicle occupants and other road users.[772]
  - ▷ Licenses could be based on the AVs autonomy level for use within designated operation areas, speed limits, and road and weather conditions.[773]

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[772] Jason Levine, "The Case for Certifying AVs before they Take to the Road," *Axios*, January 11, 2019, www.axios.com/case-for-certifying-avs-before-they-take-the-road-58089da8-b8ef-4fa6-b7a7-c6c3320f4ca7.html (accessed February 17, 2019).
[773] Levine, "The Case for Certifying AVs before they Take to the Road."

- ▷ A panel of third-party experts or a federal licensing authority could be funded by industry fees and conduct an evaluation using test scenarios, the scope of simulation, and safety criteria conformity.[774]
  - ○ The panel could then use its findings to make an informed decision about whether or not to permit future on-road tests.[775]
- ☐ Have HAVs identify themselves so other road users can recognize them, including ways to clearly indicate when a vehicle is in self-driving mode. This may be similar to student driver signs or running lights for sailboats under motor power.
- ☐ Use sensor and CV technologies to report near-misses in real time.
- ☐ Use government procurement power to support HAVs deployment. Governments at all levels own an estimated 1.5 million vehicles, 500,000 buses, and 1.5 million trucks; and they purchase around 350,000 total vehicles each year. Using their joint procurement power, governments can work together to advance HAV systems.

<u>Adaptive actions:</u>

Delayed Expectations:

- ☐ Focus on a goal of Vision Zero through use of readily available safety technologies, such as:
  - ▷ More conventional traffic calming and engineering.
  - ▷ Enhance vehicle safety by promoting ADAS systems.
  - ▷ Reduce driver distraction by and safety risks from in-vehicle entertainment systems.

People Power:

- ☐ To be determined.

Technology in the Driver's Seat:

- ☐ Work with federal and state governments to mandate and fund CV infrastructure.

Inclusive Tech:

- ☐ To be determined.

Support Centers and Energy-Efficient Economic Growth.

- ■ Delayed Expectations – The stagnant economy is creating a push factor toward centers, which provides better access to opportunity, though Hurricane Theresa in the early 2030s starts an exodus of population from the region.
- ■ People Power – Desire to expand housing affordability has meant considerable federal investment in making suburban areas more walkable and transit oriented through infill development. Growth spreads evenly throughout Greater Philadelphia. Increased land protection has slowed greenfield development, and the region is embarking on the construction of many new fixed-guideway transit routes.
- ■ Technology in the Driver's Seat – The Digital Revolution continues to centralize growth and development through the 2030s, after which the growing presence and use of Level 4 HAVs brings back sprawling development patterns. Despite major efficiency gains in individual HAVs,

[774] Levine, "The Case for Certifying AVs before they Take to the Road."
[775] Levine, "The Case for Certifying AVs before they Take to the Road."

total energy consumption and GHG emissions continue to rise. Expansion of roads and increased dominance of the car further reduce the social function of the street.

- Inclusive Tech – As decentralized technology allows more people to work remotely, much of the region's and nation's growth has been shifting to smaller towns and regions with good weather, easy access to open space, and lower cost of living. It remains challenging to adapt technologies to dense, historic urban areas. A carbon tax helps to bring total GHG emissions down.

Recommendations to Support Centers and Energy-Efficient Economic Growth

Short-term and no- or low-regrets actions:

- ☐ Better understand the implications of HAV deployment for suburban and rural communities.
- ☐ Reduce or eliminate parking minimums.
- ☐ Create mobility hubs that combine a transit station with carsharing, bikesharing, scooter sharing, and TNC and taxi pick-up and drop-off areas.
- ☐ Dedicate curb space for pick-up and drop-off zones to ensure safe vehicle and building egress as more trips become door-to-door.
  - ▷ Supports taxi and TNC operations in advance of HAV deployment, and promotes shared vehicle use.
  - ▷ Geofencing could be used to improve curb management, and potentially price curb space.
  - ▷ Measure curb use and program effectiveness, use data to optimize space management.

Medium- and long-term actions:

- ☐ Build out public EV infrastructure to support EVs on the road today and help ensure the HAVs of tomorrow will be electric as well.
  - ▷ Municipal grids may need significant investment to upgrade distribution infrastructure to support large numbers of fast-charging electric vehicles, particularly in urban areas where there is a lack of garages and individually-owned parking spaces.[776]
- ☐ Continue to preserve sensitive environmental and agricultural lands to reduce sprawl and guide development into areas with suitable infrastructure and multimodal transportation in place.
- ☐ Strengthen the enforcement of air quality laws. Air pollution from vehicles is estimated to be the cause of 50,000 deaths each year in the U.S. even though just 25 percent of vehicles cause 90 percent of the pollution. AVs are likely to reduce pollution by reducing crashes and resulting congestion, smoothing speeds and traffic flow, and enabling fuel-saving truck platoons.
- ☐ Convert streets into shared space restricted to low-speed vehicles (including automated shuttles, e-bikes, e-scooters, and similar vehicles), bikes, and pedestrians, as appropriate.
- ☐ Enforce air quality laws.

Adaptive actions:

Delayed Expectations:

- ☐ To be determined.

People Power:

- ☐ To be determined.

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[776] McKerracher et al., *An Integrated Perspective on the Future of Mobility.*

Technology in the Driver's Seat:

- ☐ Offer on-street parking priority to shared vehicles.

Inclusive Tech:

- ☐ To be determined.

Serve Everyone and Increase Access to Opportunity

- Delayed Expectations – Failure to develop and deploy HAVs is a missed opportunity to improve transportation for all.
- People Power – Focus on deploying readily available technologies expands access and opportunities.
- Technology in the Driver's Seat – HAVs are initially owned mainly by the most well off, though as costs come down over time they become more affordable to more people. Opportunity largely centralizes through agglomeration economies that form within large regions and a handful of innovation hubs—meaning access to opportunity is highly uneven across the nation.
- Inclusive Tech – Regulations drive innovation with equity in mind. Shared mobility services, offering a variety of right-sized vehicle types, better serve everyone and expand access to opportunity.

Recommendations to Serve Everyone and Increase Access to Opportunity

Short-term and no- or low-regrets:

- ☐ Community engagement should make extra effort to obtain input from low-income and other slow adopter neighborhoods, and identify prime locations to use HAVs to make better first- and last-mile connections to existing transit stations.
- ☐ Spread infrastructure improvements across all areas, despite political agendas or wealth.

Medium- and long-term actions:

- ☐ Ensure HAVs are ADA accessible.
- ☐ Identify ways that HAVs could solve entrenched problems or create new opportunities.
- ☐ Require equivalent or higher levels of shared transportation service in low-income areas, and provide incentives or subsidies for doing so. At the very least, subsidize lower cost modes, with some other form of financial incentives for disadvantaged communities to utilize automated shuttles.
- ☐ Develop prepaid or digital banking options.
- ☐ Provide alternative on-demand ride-hailing methods: concierge, corner store, phone call, kiosk, text message, or others.
- ☐ Work with state and federal regulatory agencies to ensure that algorithms and predictive mathematical models used in HAVs, elsewhere in transportation, and in other sectors, do not perpetuate hidden biases.

Adaptive actions:

Delayed Expectations:

- ☐ To be determined.

People Power:

- ☐ To be determined.

Technology in the Driver's Seat:

- ☐ To be determined.

Inclusive Tech:

- ☐ To be determined.

Build an Integrated, Multimodal Mobility-as-a-Service (MaaS) Network

- Delayed Expectations – Car dominance largely remains, and the fast warming climate reduces the appeal of active transportation modes.
- People Power – The federal government focus on transportation investments in walkability and transit expansion helps to reform the role of the street within the community. Truck interchange ports are built at key highway interchanges to support automated middle-mile truck movements. Human drivers conduct truck movements between origin and destination and interchange ports.
- Technology in the Driver's Seat – HAVs are able to operate under specific conditions within a geofenced area—generally limited access facilities and major suburban arterials. Their ability to operate in shared mobility services is somewhat restricted by their ODD. There is a fundamental shift in willingness to travel longer trip lengths in HAVs, as in-vehicle time can be used to do things other than drive.
- Inclusive Tech – Collaborative efforts and more multimodal transportation expand the social function of the street, but this progress is limited somewhat by the chaos that arises with so many different types of HAVs. Safe street design for a mix of wide-ranging vehicle types is particularly challenging. There is a fundamental shift in willingness to take more trips and share space in HAVs, as in-vehicle time can be used to do things other than drive.

Recommendations to Build an Integrated, Multimodal MaaS Network

Building a MaaS network will require incentives to use the most efficient modes and discouraging the potential adverse impacts HAVs could have on transit, road congestion, and urban sprawl.

<u>Universal short-term and no- or low-regrets actions:</u>

- ☐ Pursue transit-first strategies, such as transit signal priority, off-board fare payment, and dedicated bus lanes.
    - ▷ Use Big Data, on-demand, and automated technologies to optimize bus routes to better meet demand by time and location.
    - ▷ Improve transit first- and last-mile connections.
- ☐ License private shared mobility services to operate only if they serve everyone, share data with a designated public or non-profit data management entity, integrate with transit and other shared mobility providers, follow curb regulations, and meet safety standards. Renew licensing on a routine basis only so long as these requirements are being met.

<u>Universal medium- and long-term actions:</u>

- ☐ Create a roadmap for moving from the current private-vehicle-ownership transportation model to an HAV-based MaaS network. This roadmap will need to be adaptive to different levels of HAV availability (such as Level 4 vs. Level 5).

- ☐ Price transportation systems in ways that internalize the cost of driving, ensure stable and growing transit funding, and provide needed subsidies to low-income groups.
  - ▷ Use revenues to fund HAV infrastructure needs, transit, safety enhancements, multimodal projects, travel vouchers, income assistance, and other virtuous improvements.
  - ▷ Reduce parking subsidies, including free or low-cost on-street parking and minimum parking requirements with each new residential unit or per square foot of commercial space.
  - ▷ Raise insurance minimums to make the true cost of driving more apparent.
- ☐ Continue to plan for and build a multimodal network.
  - ▷ Construct more shared streets and woonerfs (or "living street"), complete streets, pedestrian plazas, pedestrian priority at signalized intersections, (protected) bike lanes, wide sidewalks, coordinated land use planning, and modal integration so all transportation options function together as a single system.
  - ▷ Limit investment in system expansion, recognizing that the rebound effect means additional capacity will spur additional demand.[777] Roads with fewer lanes and slower speeds are more comfortable for bicycles and pedestrians.
  - ▷ Develop an open source digital, multimodal travel information and payment platform. This may consist of either a uniform backend server that is maintained by a public or nonprofit entity and accessible by any party that wants to connect to it; or a public or non-profit app that contains both the backend server and public facing frontend.

<u>Adaptive actions</u>

Delayed Expectations:

- ☐ With limited revenue available for roadway improvements, and a vast backlog of maintenance and preservation needs, strategies to reduce congestion should focus on eliminating bottlenecks consistent with the region's Congestion Management Process (CMP).
- ☐ Increase safety, mobility, and accessibility by improving conventional transit services.

People Power:

- ☐ Focus on separate rights-of-way for AV trucks and automated shuttles to ensure safe transportation for all users.
  - ▷ Use may change by the time of day or day of week.
  - ▷ Explore ways to allocate space for truck platoons, such as removing cars from truck lanes on the NJ Turnpike, designating truck-only lanes on other limited access facilities, or building toll-based new facilities.
  - ▷ Identify AV shuttle deployment zones and geofence them to restrict movement to specific areas. Some potential testing grounds for new technologies include the Cornwell Heights train station parking lot, an expanded sidepath connecting NRG station with the Navy Yard, private campuses, and emerging developments, such as Schuylkill Yards.

Technology in the Driver's Seat:

- ☐ Use NACTO's *Blueprint for Autonomous Urbanism* to guide street design.
- ☐ Consider restricting limited-access facilities to Level 3 or higher HAVs, restricting human driving on them to emergency situations only.

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[777] Jeff Speck, "Autonomous Vehicles & the Good City: 10 Rules of Mayors," *United States Conference of Mayors*, May 25, 2017, www.youtube.com/watch?v=2kBEvg8bftE (accessed April 26, 2018).

- ☐ Increase tree canopy to reduce noise from drone and eVTOL operations and identify emergency landing sites in urban areas.[778]

Inclusive Tech:

- ☐ Use shared HAVs to help solve the first-mile and last-mile access to transit problem as a way to better connect people and opportunity.
- ☐ Consider changing state laws that restrict automated shuttle operation to dedicated facilities and allow them to operate in mixed traffic roads.
  - ▷ Experiment with policies, technologies, materials, and street designs in preparation for a much wider variety of vehicle types competing for limited road space.
- ☐ Make travel lanes flush with sidewalks and medians, and use bollards, accessible textured pavers, or other cues to demarcate modes, instead of markings.
- ☐ Restrict certain vehicle types from specific roads, in a fashion similar to truck routes, as a way of dealing with complex movements of a wide variety of vehicle types.[779]
- ☐ Identify new traffic calming techniques and ways to protect the safety of vulnerable pedestrians and bicyclists that work with a variety of vehicle types, sizes, and operating speeds. NACTO's *Blueprint for Autonomous Urbanism* may be a starting point.
- ☐ HAV-only limited access facilities could provide opportunities to narrow lanes and increase the number of through lanes.
  - ▷ Consider ways AI, road butlers, AVs, and other transportation technologies can help to address other issues—litter, crime, harassment, reporting broken sidewalks and potholes—where feasible.
  - ▷ Consider restricting limited-access facilities to Level 3 or higher HAVs, and restricting human driving on them to emergency situations only.

Share Data and Respect the Individual Right to Privacy

- ■ Delayed Expectations – Bad data and variety of different reads on available data obscures understanding of the world. There is little effort to protect individual privacy.
- ■ People Power – Severe restrictions on data collection mean privacy is respected, but there is little data to share.
- ■ Technology in the Driver's Seat – Private companies claim proprietary protections over data collection, with little sharing or privacy protection.
- ■ Inclusive Tech – A Data Bill of Rights expands individual privacy protection and offers micropayments in exchange for data collection. Open source data is widely shared.

Recommendations to Share Data and Respect the Individual Right to Privacy

<u>Short-term and no- or low-regrets actions:</u>

- ☐ Local governments should determine data needs for HAV operations and regulation, and develop open data standards with oversight and/or storage that requires all mobility service providers to collect and seamlessly share data in order to use it to enhance the transportation network's performance.

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[778] Townsend, "Fables of the Driverless Revolution."
[779] National Association of City Transportation Officials, *Blueprint for Autonomous Urbanism*.

- ▷ Tie data sharing agreements with operating permits. Any such system will still need reasonable government oversight to address poor sharing of data and reporting standards. Require licenses to be renewed on a routine basis based on meeting all requirements.
- ▷ Build data management and processing capacity. Continually analyze data and use findings to adjust in real time as needed.

- ☐ Determine who among law enforcement, insurers, and others should have access to ADS data, and how access will be granted.
- ☐ Work with state departments of motor vehicles (DMVs) to find ways to track automation levels in state vehicle registration databases, on crash forms, and other relevant documents. In Pennsylvania, this requires a different classification to be titled under, and may require a statute change. One challenge is how to automatically update databases when over-the-air updates could increase vehicle automation levels near instantaneously.

Medium- and long-term actions:

- ☐ Standardize and share data for roadway, crash, and construction management; use data to inform HAVs when and where the rules of the road have changed.[780]
- ☐ Support efforts to create a 'Data Bill of Rights' or similar legislation to better protect personal privacy in the digital age, including in the use of CVs and HAVs.

Adaptive actions:

Delayed Expectations:

- ☐ To be determined.

People Power:

- ☐ To be determined.

Technology in the Driver's Seat:

- ☐ To be determined.

Inclusive Tech:

- ☐ To be determined.

Parking Lot for Strategy Ideas

These are concepts that were identified during the dialogue and research but would need to be better fleshed out and understood before making actual recommendations. Some of them may be strongly fought against by the industry. The Futures Working Group made a series of conflicting recommendations around consistent policies at the federal, state, and local levels versus allowing lower levels of government to experiment and identify innovative policy responses.

Some other suggestions:

- Put a disengagement mechanism in each HAV that can be operated by the passenger(s). It's not clear what a disengagement mechanism would turn off—the motor? The connection to the

[780] Aarian Marshall, "Why Self-Driving Cars *Can't Even* With Construction Zones," *Wired*, February 10, 2017, www.wired.com/2017/02/self-driving-cars-cant-even-construction-zones/ (accessed February 13, 2017).

Internet? A motor switch, if possible, may be useful to emergency responders. The ability to shut off connection to the Internet could benefit personal privacy, but this may come at a cost of reduced safety. While it could increase passenger comfort, it could potentially be used by malicious actors if it's available to everyone. It's not clear that such an action would actually increase safety.

- Use AV trucks as safety billboards and to signal drivers.
- Apply speed governors or limiters to AVs.
- Create a centralized mobility management government agency that coordinates private shared mobility services.
- Ban personal ownership of AVs.
- Prioritize shared-AVs, CVs, and transit and transit-like operations. It's not clear how to do this, or whether it is preferable to prioritize these vehicles over transit, biking, or walking.
- Work with state and federal governments to provide tax credits or incentives for replacing older, less safe personal vehicles with newer ones equipped with ADAS safety components or HAVs, once they are available. This is likely to be regressive, overly benefitting those who can most afford a new vehicle, and could reinforce the culture of ownership counter to the vision of more shared mobility.
- Create a marketplace that balances private benefits from automation with public costs. This is an interesting idea that could be better fleshed out.

Appendix E. Acknowledgements

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Preparing Greater Philadelphia for Highly Automated Vehicle Deployment

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ABSTRACT: *Preparing Greater Philadelphia for Highly Automated Vehicle Deployment* is a companion to *Dispatches from Alternative Futures* (DVRPC Publication #20012). This report explores the future of transportation through the lens of vehicular automation. It reviews the technologies being used to create highly automated vehicles (HAVs) and where they are in their development. It then extends the exploratory *Dispatches* scenarios to consider different ways HAVs could roll out in the future. Five key takeaways emerge from the analysis: (1) There is a need to better understand the uncertainty associated with HAV development, deployment, and in the potential outcomes from their deployment; (2) HAVs that can drive themselves in specific areas and certain conditions will likely be operating on the region's roads within the next few years, but HAVs that can drive themselves anywhere in all conditions may still be decades away; (3) HAV deployment is likely to expand the role of the private market in transportation services and potentially infrastructure development; while further eroding transportation gas tax revenues and increasing demand for infrastructure investment; (4). The region needs to articulate a clear vision for how it would like HAVs to be deployed, and use that to guide strategies and policies for HAVs; and develop new partnership(s) to better coordinate and prepare for technology deployment; and (5) There are short-term strategies that can be implemented now in advance of the vision, which can provide benefits beyond HAV deployment.

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