MINNESOTA GO

Planning Minnesota's Transportation Future

CONNECTED AND AUTOMATED VEHICLES TREND ANALYSIS

CONTENTS

SUMMARY

Automated vehicles (often called self-driving vehicles or "AVs") have been a dream for much of the 20th century. Fully self-driving vehicles are not yet developed. Many automated vehicles still require a human to monitor the roadway or drive part of the time, while other vehicles require no human intervention. Connected vehicles (CV) are vehicles that can share information with other cars, infrastructure and other technologies (like smartphones). States and the federal government believe that connecting AVs – called a connected and automated (CAV) vehicle – can enhance the safety of these technologies. The private sector is mostly advancing AV technologies without any connectivity.

Technology evolves constantly, so it is difficult to predict when self-driving cars will be on our roads. However, the amount of automation in vehicles is increasing. Twenty years ago cruise control and traction control were some of the only automated systems in a vehicle, while today vehicles can park, change lanes and keep a safe following distance without driver input. Pilots and limited deployments of more advanced automated vehicles are becoming increasingly common. However, significantly more research and testing is needed before fully automated vehicles will be widely adopted.

AVs have the potential to significantly change the way that people travel. That is why it is important to understand the implications of this technology when planning for the future of transportation. Benefits could include reducing fatalities and injuries, reduced congestion, reduced parking demand, shifts in travel behavior and others. However, many questions still remain on how AVs will impact society, such as how they'll impact equity, who is responsible in a collision, and how personal information is protected.

Minnesota is addressing these challenges and working to thoughtfully prepare for AVs and CVs through a combination of executive orders, legislative actions, pilot projects and public-private initiatives to study and invest in these emerging technologies.

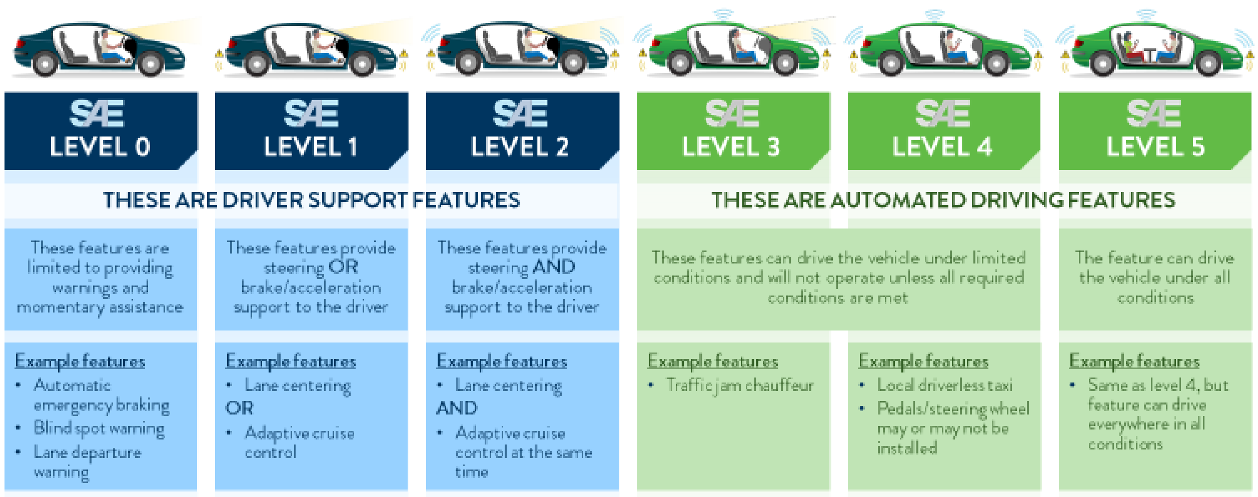
AUTOMATED VEHICLES

LEVELS OF AUTOMATION

Automated vehicles are an emerging technology that use multiple sensors, cameras and software to automate some or all of driving. The most-cited taxonomy of automated driving technology is published and maintained by the Sociate of Automotive Engineers (SAE) International.[1] SAE developed a system to distinguish the different levels of automation.[2] This provides a common set of terms around the globe. Levels 0-2 include technologies that support the driving task. Level 3, conditional automation, features technology that can drive the vehicle under limited conditions, but requires a human to operate in some conditions. Levels 4-5 are considered highly automated vehicles that don't need a driver. The levels are illustrated in Figure 1.

[1] SAE International, SAE Levels of Driving Automation Refined for Clarity and International Audience, https://www.sae.org/blog/sae-j3016-update
[2] National Highway Traffic Safety Administration, 2013 – SAE International, an engineering organization, offers an alternative classification system with a 5th level on the fully autotomized side of the scale that is achieved when cars are 100 percent self-driving in all scenarios. For the purposes of consistency, this paper will rely on the NHTSA definitions of autonomous vehicle capabilities.

Figure 1: Society of Automotive Engineers' Levels of Automated Driving



Advanced driver-assist systems (ADAS) are lower levels of automation support driving, like adaptive cruise control and automated emergency braking. Many ADAS features exist in vehicles sold today. Technology companies and auto manufacturers are developing higher levels of automation that someday may allow AVs to operate in all environments, geographies and conditions without a human driver.

LEVEL 0 – NO AUTOMATION

Level 0 vehicles require a human driver remain in control at all times. The driver remains in control of the vehicle's brakes, steering, and acceleration. While many older passenger vehicles fall into this category, there are still vehicles being produced today that are Level 0.[3]

LEVEL 1 – DRIVER ASSISTANCE

Level 1 includes technology that automates one specific driving task. The driver remains in overall control of the vehicle and is responsible for safe operation but has limited assistance from automated vehicle technology. Common examples of Level 1 automation include cruise control, electronic stability control that prevents skids and dynamic brake control that prevents rear-end collisions. Each automated system operates independently from other automated systems. The majority of vehicles sold in recent years feature Level 1 systems.

LEVEL 2 – PARTIAL AUTOMATION

Level 2 includes two or more automated technologies that can work together to support human drivers. Vehicles with partial automation require oversight from a human driver at all times. Adaptive cruise control and automatic lane centering are examples of these technologies that support the human driving task.

LEVEL 3 – CONDITIONAL AUTOMATION

Level 3 automation allows the vehicle to drive itself under certain conditions. While in self-driving mode, the vehicle steers, brakes and accelerates. If the vehicle detects a situation that requires human attention, it will notify the human driver. Vehicles with conditional automation require a human to be ready to take the wheel when required, but do not require constant oversight.

[3] Ibid.

LEVEL 4 – HIGH AUTOMATION

Level 4 automated vehicles are designed to operate without human drivers in limited environments. These vehicles must be 'geo-fenced' (programmed to operate only on certain routes) and are programmed to operate at certain speeds. The driver may have the option to control the vehicle.

LEVEL 5 – FULL AUTOMATION

Level 5 automated vehicles require no human driver. The vehicle's automated driving system (ADS) does all the driving in every circumstance – including all weather types, geographies and across jurisdictional boundaries. Zero human interaction is needed. Level 5 cars have neither a steering wheel nor pedals. While no Level 5 vehicles are on the market, several tech companies like Waymo are testing what they claim to be Level 5 technologies in California and Arizona. However, these technologies are unable to operate on gravel roads, in areas without clear pavement markings, and cannot operate during inclement weather.

AUTOMATED VEHICLE TECHNOLOGY ROLLOUT

Despite the rapid pace of technology advancement, it will be decades before a majority of the public has access to fully automated vehicles. Some experts believe we may never see widespread use.[4] In 2016, industry leaders were enthusiastic and optimistic, predicting that fully automated vehicles would be commonplace on roads in 2020. Since then, fatal AV crashes have weakened public trust and slowed down deployment.[5] The information technology firm Gartner claims that emerging technologies pass through a hype cycle, where the public's expectations of a technology vary in a predictable way over time. According to this model, automated driving technology has passed the phase of inflated expectations and is passing through a phase of disillusionment on the way to widespread adoption.[6]

Automated driving technology is progressing. Companies like Tesla, General Motors (GM), Toyota and Ford are selling Level 2 AVs. Tech companies continue to pursue Level 4 and Level 5 technologies. Cruise and Waymo are piloting driverless technology in ride-hailing services in California and Arizona.[7] AV trucking companies are deploying across the South into Texas. AV tech companies and auto manufacturers are testing in states with few regulatory barriers (like Arizona and Florida) or regions that are hubs for auto and robotics innovation (like Michigan and Pennsylvania). After several high-profile crashes in 2017, the industry shifted from an aggressive race to deliver the first fully automated car to instead focus on safety features.[8]

Most companies are focusing on developing Level 4 automation that can be used in large fleet models because the costs of development are hundreds of millions of dollars. As companies progress towards that goal, there are limited pilots of Level 4 technologies in a dozen states, such as in smaller low-speed shuttles. Except for the

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[4] Cade Metz, "The Costly Pursuit of Self-Driving Cars Continues On. And on. And On," New York Times, May 24, 2021, https://www.nytimes.com/2021/05/24/technology/self-driving-cars-wait.html

[5] Daniel Faggella, "The Self-Driving Car Timeline - Predictions from the Top 11 Global Automakers," Emerj, March 14, 2020, https://emerj.com/ai-adoption-timelines/self-driving-car-timeline-themselves-top-11-automakers/.

[6] Bill Visnic, "2020 Hype Cycle for Connected and Smart Mobility," SAE International, September 11, 2020, https://www.sae.org/news/2020/09/2020-hype-cycle-for-connected-vehicles-and-smart-mobility

[7] Andrew Hawkins, "Cruise gets the green light to give driverless rides to passengers in San Francisco," The Verge, September 30, 2021, https://www.theverge.com/2021/9/30/22702962/cruise-waymo-california-dmv-autonomous-vehicle-permit

[8] Faggella

Honda Legend in Japan, all publicly-available vehicles are Level 2 or lower, which require an attentive driver to supervise the features at all times and take over when requested.[9]

Despite technological progress, it remains extremely unclear when higher levels of automation will be deployed.[10] California and Arizona approved several driverless rideshare service pilots in 2020. However, each AV company offers competing timelines for when they will have Level 5 deployments, mostly due to the need to compete for capital to invest in their companies. Deloitte research shows that the auto industry believes self-driving vehicles will be fully deployed by 2050 whereas 1 in 5 government officials believe they never will. J.D. Power & Assocates research shows that only 1 in 3 members of the public have any knowledge of AVs, with 32% of Americans knowing nothing about the technology.

AUTOMATED COMMERCIAL VEHICLES

Automated technologies will have impacts beyond passenger travel. AVs have the potential to change long-haul trucking, at-home delivery, transit and other modes of transportation. While technology has the capacity to improve safety and efficiency in the trucking industry, labor unions are concerned that self-driving trucks would replace the jobs of truck drivers.[11] Current AV truck technology requires a human operator to physically drive the vehicle off interstates and through local areas or in inclement weather, but new technology is on the horizon. Kodiak Robotics, Waymo and Aurora are developing or testing trucks with Level 4 features.[12,13]

Some AV truck companies like Peloton and Locomation are developing platooning technologies. Platooning allows two or more trucks to use GPS and other sensors to travel in a close convoy, leading to fuel savings, reduced pollution, and minimizing driver fatigue and stress. [14] In 2019, the Minnesota Legislature authorized truck platooning in certain parts of the state without major congestion and where roads and bridges can support the weight of three vehicles convoying closely together. The law requires companies to submit a plan for approval by MnDOT and the Department of Public Safety and each vehicle must have a human operator. As of May 2022, one plan has been submitted to and approved by MnDOT.

AV technologies are also being used in automated and personal delivery. In 2020, the federal government granted the first permit for a company to produce and test a driverless delivery vehicle without a steering wheel or windshield.[15] Since then, companies like FedEx, CVS and Domino's Pizza have partnered with AV companies to deliver goods directly to customers' doors.[16] UPS and Amazon are exploring these technologies due to the increasing e-commerce and same-day delivery demands that exploded during the 2020 COVID-19 pandemic.

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[9] Colin Beresford, "Honda Legend Sedan with Level 3 Autonomy Available for Lease in Japan," Car and Driver, March 4, 2021, https://www.caranddriver.com/news/a35729591/honda-legend-level-3-autonomy-leases-japan/

[10] https://www.nytimes.com/2021/05/24/technology/self-driving-cars-wait.html

[11] Lamont Byrd, "Testimony before the U.S. Senate Committee on Transportation Commerce, Science & Transportation Subcommittee on Surface Transportation, Maritime, Freight, and Ports," May 11, 2021, https://www.commerce.senate.gov/services/files/9F7CA678-2EE7-4D6A-B5A4-A7A11BA99B7B

[12] Cristina Commendatore, "Level 4 autonomous trucks: Closer than you think," FleetOwner.com, March 29, 2021, https://www.trucks.com/2021/08/30/aurora-autonomous-driving-hardware/

[13] Jerry Hirsch, "Aurora Debuts New Autonomous Trucking Hardware," Trucks.com, August 30, 2021, https://www.trucks.com/2021/08/30/aurora-autonomous-driving-hardware/

[14] "Truck Platooning," MnDOT, accessed May 21, 2021, http://www.dot.state.mn.us/truck-platooning/about.html.

[15] Andrew J. Hawkins, "The federal government just granted its first driverless car exemption," The Verge, February 6, 2020, https://www.reuters.com/business/autos-transportation/self-driving-tech-co-aurora-test-driverless-delivery-with-fedex-2021-09-22/

[16] Nick Carey and Lisa Baertlein, "FedEx to test package deliveries with self-driving startup Nuro," Reuters, June 15, 2021, https://www.reuters.com/technology/fedex-test-package-deliveries-with-self-driving-startup-nuro-2021-06-15/

These automated delivery trends increase the need for more localized distribution centers, changing land use and freight patterns.

Not all automated delivery vehicles drive on the roadway. Several companies have deployed small robots that roll down sidewalks to make deliveries in some cities.[17] Some companies are using similar AV technologies to develop delivery aerial drones, some of which are being piloted by Amazon in California.

CONNECTED VEHICLE TECHNOLOGY

Connected vehicles use radios, GPS signals and cellular signals to communicate with other vehicles, the surrounding environment and cloud services. Connectivity allows vehicles to communicate with other vehicles (vehicle-to-vehicle communications, or V2V), infrastructure (vehicle-to-infrastructure communications, or V2I) and people walking, bicycling or rolling (vehicle-to-pedestrian or V2P). Collectively, these are known as vehicle-to-everything communications (V2X).

A recent federal ruling has changed the trajectory of connected vehicle technology. In November 2020, the Federal Communications Commission (FCC) issued a ruling on the 5.9-GHz band of the radio frequency spectrum used for transportation purposes. The ruling reallocated frequencies formerly used for Dedicated Short-Range Communications (DSRC) to unlicensed, private Wi-Fi use.[18] Before the ruling, some CVs and intelligent transportation systems used DSRC channels. The ruling, which was affirmed by the U.S. Court of Appeals in August 2021, solidifies cellular vehicle-to-everything technology (C-V2X) as the standard basis for CV communications.[19]

Connected vehicle technologies can help AVs be safer by providing redundant systems in case the AV technology fails. The American Association of State Highway and Transportation Officials (AASHTO), ITS America and state DOTs believe CV technology is essential for AVs to be successful. However, many AV companies disagree that CV is important and are developing AVs without any CV technology integration. Automated vehicles that incorporate connected technology could reduce the number of crashes and series injuries, improve traffic flow, increase transportation options, reduce travel times and allow people to make more environmentally friendly transportation choices.[20]

VEHICLE-TO-VEHICLE COMMUNICATION

V2V is the exchange of information between vehicles. The information being exchanged notifies the vehicle operator of potential incidents along their route which allows them to take necessary precaution measures. This feature has a range of more than 300 meters and can enhance crash avoidance systems that use radars and cameras to detect obstacles.

[17] Dalvin Brown, “Meet Scout: Amazon is taking its Prime Delivery Robots to the South,” USA Today, July 22, 2020, https://www.usatoday.com/story/tech/2020/07/22/amazon-taking-its-scout-delivery-robots-south/5485106002/

[18] Bill Visnic, “Vehicle safety communications landscape clarified with controversial FCC ruling,” SAE International, November 23, 2020, https://www.sae.org/news/2020/11/fcc-5.9-ghz-cv2x-decision

[19] AASHTO, ITS America Reiterate 5.9 GHz Needs in Court,” AASHTO Journal, January 28, 2022, https://aashtojournal.org/2022/01/28/aashto-its-america-reiterate-5-9-ghz-needs-in-court/?utm_source=rss&utm_medium=rss&utm_campaign=aashto-its-america-reiterate-5-9-ghz-needs-in-court.

[20] “What Are Connected Vehicles and Why Do We Need Them?,” Intelligent Transportation Systems Joint Program Office (United States Department of Transportation), accessed May 21, 2021, https://www.its.dot.gov/cv_basics/cv_basics_what.htm.

VEHICLE-TO-INFRASTRUCTURE COMMUNICATION

V2I technology communication is the exchange of information between public roadside infrastructure (traffic signals, stop signs, guard rails, etc.) and the vehicle operator. Communication between the vehicle and public infrastructure elements could prevent crashes and improve traffic flow. V2I messages could include warnings about red lights, work zones, school zones, or icy pavement.

VEHICLE-TO-PEDESTRIAN COMMUNICATION

Vehicle-to-pedestrian (V2P) communications allows vehicles to 'talk to' or detect people walking, bicycling, rolling, and in the vicinity of the connected vehicle. This advances safety for all users and promotes mobility outside traditional passenger vehicles to deliver safety, mobility and environmental benefits for all users.

POTENTIAL IMPACTS

Connected and automated vehicle (CAV) technology has the potential to change almost every facet of human life. Exactly how CAV affects society will depend on how we prepare for CAV. Federal, state, and local governments can harness CAV's potential through smart laws, policies, and investments. Even though CAV technology changes quickly and that policy decisions can shape the future, experts agree on what some of CAV's likely impacts will be.

TRAVEL BEHAVIOR

IMPROVED SAFETY

AV technologies are likely to reduce the number and severity of crashes. Human error is at least partly to blame for more than 90% of crashes.[21] Machines do not get distracted, tired or intoxicated, so the technology has the potential to prevent most crashes. If AVs are widely deployed, it is possible to eliminate thousands of the lives lost each year in traffic collisions. Recognizing the importance and potential impacts of these technologies, the National Highway Traffic Safety Administration (NHTSA) now oversees AV safety and testing and rules. NHTSA now reviews auto makers' crash-avoidance technologies[22] and is requiring auto manufacturers to include some lower-level automated features like automatic emergency braking (required to be standard in all vehicles by 2022).[23] The 2021 Infrastructure Investment and Jobs Act requires new cars to be equipped with technology to prevent impaired driving.[24]

INCREASED ACCESSIBLITY AND MOBILITY

Fully automated vehicles can offer the convenience and flexibility of personal automobile use for more people. Many older adults, young people, people with disabilities and people with low incomes cannot drive, cannot afford to own a personal vehicle or limit the amount they drive. Although some people would face mobility challenges even with AVs, the new technology would bring the benefits of increased accessibility and mobility to more people. AVs could provide more transportation options to supplement paratransit services, which can be cost prohibitive and time-exhaustive. Many people with disability have problems finding and keeping a job as well

[21] "Human Factors," Federal Highway Administration, https://highways.dot.gov/research/research-programs/safety/human-factors
[22] "Ratings," National Highway Traffic Safety Administration, accessed May 21, 2021, https://www.nhtsa.gov/ratings.
[23] Ibid.
[24] Neil Vigdor, "Drunken-Driving Warning Systems Would Be Required for New Cars Under U.S. Bill," The New York Times, November 10, 2021, https://www.nytimes.com/2021/11/10/us/drunk-driving-system-mandate.html

as participating in social and community activities due to a lack of transportation.[25] Intentionally designed AVs could help solve this challenge. For example, the U.S. DOT created an Inclusive Design Challenge in 2020 to make it easier for people with disabilities to use automated vehicles.[26]

MORE DRIVING, MAYBE LESS CONGESTION

Vehicle-miles traveled (VMT) could increase by 10 to 50% because of fully automated vehicles. This is for several reasons. People who can't drive a car right now might choose to use AVs in the future. Empty vehicles will need to drive to pick up a passenger before a trip or drive to a parking space after a trip. As AVs would get in fewer crashes and require less space between vehicles while moving, existing road capacity could increase enough to avoid increases in congestion. Congestion pricing or distance-based user fees are policies that would reduce VMT and congestion.

MORE CARSHARING AND RIDESHARING

Fully automated vehicles may make alternative vehicle ownership models more viable. Shared mobility is the shared use of a vehicle. The vehicle can be a scooter, bike, car, van or other travel mode. Ridesharing is when two or more customers seeking to travel a similar route use a vehicle at the same time. Carsharing is when a single customer has sole use of a vehicle for a set amount of time.

Experts predict that use of AVs and shared mobility will increase at the same time. Currently, most vehicles are owned privately, and sit idly most of the time. By allowing people easy and affordable access to vehicles when they need it, shared automated vehicles would result in more people choosing not to own personal cars. Research suggests that each shared automated vehicle would replace between two and ten personal vehicles.

Automated vehicles may make alternative vehicle ownership models more viable. Private ownership may decrease if consumers are able to summon an automated vehicle to pick them up and deliver them to their destination. The costs of personal vehicle ownership are high, especially in lower-income communities. According to the National Household Travel Survey, motor vehicles in Minnesota are parked about 97% of the time.[27] If vehicles are more available, accessible, and affordable people may choose not to own personal cars.

More discussion of potential shifts in ownership structure is covered in the Shared Use Mobility Tend Analysis.

VEHICLE DESIGN

AVs could look different from conventional private vehicles. For instance, shared automated vehicles would likely be smaller than vehicles on the road today. Consumers often purchase vehicles large enough to carry the most cargo and passengers they can imagine needing to transport. This means that personal vehicles are usually bigger than they need to be for most trips. The average vehicle occupancy in Minnesota is less than two, and most motor vehicles have space for five to seven passengers. Depending on what kinds of ownership models emerge, a person could summon a vehicle that's just as big as they need for that trip. Smaller vehicles would increase road capacity and be safer around pedestrians and bicyclists.

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[25] Abigail L. Cochran, "Impacts of COVID-19 on access to transportation for people with disabilities," Transportation Research Interdisciplinary Perspectives, November 2020, https://doi.org/10.1016/j.trip.2020.100263.

[26] U.S. Department of Transportation, "DOT Inclusive Design Challenge." https://www.transportation.gov/accessibility/inclusivedesign

[27] There are 4.98 million vehicles in Minnesota, which take 4.54 billion trips each year, and the average trip is 19.2 minutes long. That means the average car in Minnesota is driving 3.3% of the time.

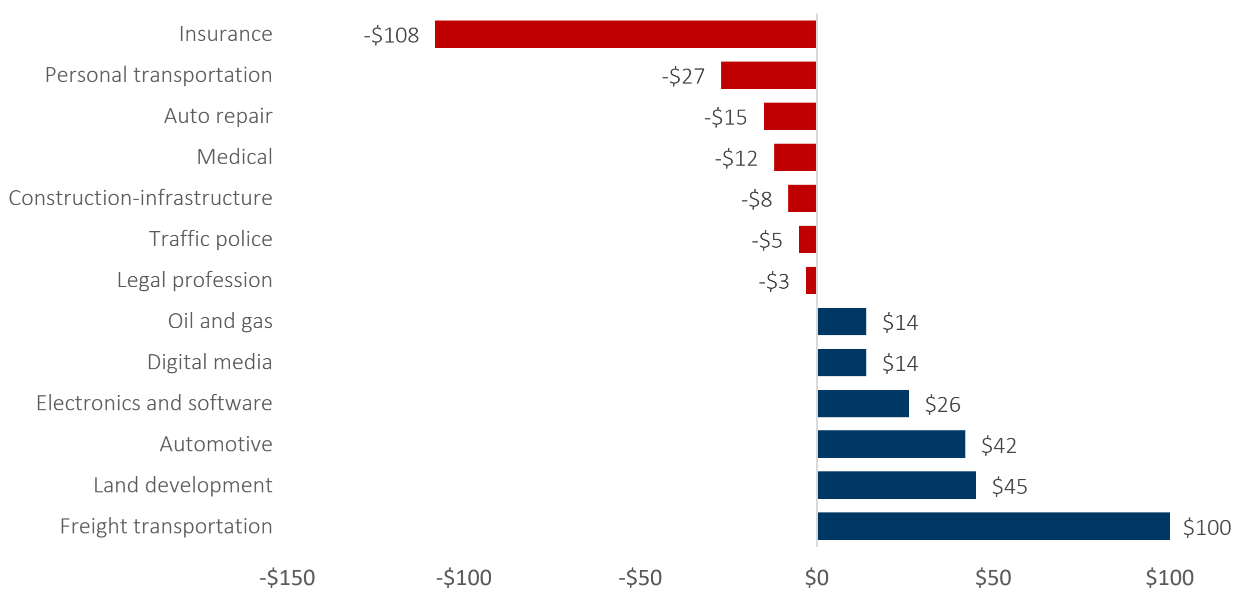
Vehicle design could change in other ways, too. Wheelchair securement, lifts and ramps, and level boarding would increase accessibility of new vehicles for people who have difficulty walking. Without the need for traditional driver controls, vehicles could use bucket or stadium seating. Some futurists envision a world where recreational activities could be conducted in AVs without the need for a driver to concentrate on the road or operate a steering wheel.

ECONOMICS

LABOR AND WORKFORCE

Experts estimate that AVs could cause the U.S. economy to grow by $1.2 trillion per year. Reduced crashes could save almost $500 billion per year, and increased productivity could save more than $400 billion per year. Researchers predict that AVs will have different effects on different industries, but that the overall impact will be positive. The technology could cause freight transportation, land development, automotive and electronics industries each to grow by more than $25 billion. But AVs could cause other industries to shrink, including insurance, personal transportation and auto repair. Figure 2 shows the forecast effects of connected and automated technology on U.S. industries. Planning and strategic workforce training can minimize AV’s disruptions to the workforce and ensure that the benefits are enjoyed by all.

Figure 2: Forecast Annual effects of CAV on U.S. industries (in billions)[28]



COSTS

AVs will cost more than traditional vehicles, but the average cost of an AV trip could be lower. Automated vehicles require expensive equipment, driving up the cost: sensors, automated controls and communication networks and

[28] Lewis Clements and Kara Kockelman, “Economic Effects of Automated Vehicles,” in Transportation Research Record, 2017, http://dx.doi.org/10.3141/2606-14

software. Further, shared automated vehicles would require dispatching and fleet management, business administration, security, cleaning and repairs.

On the other hand, AVs have benefits that drive down the cost of a trip compared to conventional vehicles. Fewer crashes mean lower insurance premiums and less wear-and-tear. Studies suggest that these cost savings are enough to make shared automated vehicles cost 75% less per mile than a human-driven taxi. Shared automated vehicles would be slightly less expensive than a private vehicle, without factoring in the additional value of the passenger being able to relax instead of having to drive the vehicle.

LAND USE AND THE BUILT ENVIRONMENT

FEWER PARKING FACILITIES

Fully automated vehicles could reduce demand for parking space, but much depends on the ownership model of the vehicles. Privately-owned automated vehicles could make single-occupancy vehicle trips more convenient and comfortable. At the end of a trip, the passenger could get out at their destination and the vehicle could drive, empty, to a parking space. So, while demand might decline for parking spaces very close to popular destinations, demand for regional parking facilities would remain high, or possibly increase.

Shared automated vehicles have a greater potential to reduce the number of cars on the road and the number of parking facilities. A shared AV, whether it carries multiple passengers on the same trip or multiple passengers in the same day on different trips, would spend more time carrying people and less time in a parking space than a private vehicle. Depending on the ownership model, 100 new AVs could replace between 117 and 1,000 conventional vehicles.

ROADWAY DESIGN

Adoption of AVs may result in changed roadway design and reallocation of space. Because AVs are able to safely follow vehicles more closely than human-driven vehicles, the capacity on roadways could increase. Privately-owned AVs would require the same parking spaces as conventional vehicles, but the adoption of shared AVs might free up parking spaces in front of homes, businesses, schools, and workplaces. Whichever ownership model prevails, the adoption of AVs would likely allow communities to reallocate roadway space toward parks, sidewalks or bike lanes.

Connected automated vehicles depend on new infrastructure. Traffic signals need the ability to communicate with vehicles. Other sensors and roadside units may be needed to relay important travel information.

RESIDENTIAL DISPERSAL

People may choose to live farther from their place of work because of AVs. Fully automated vehicles could make long commutes more attractive, either by reducing the cost of a trip or by providing a more comfortable experience. This could lead more people to move to communities with lower housing costs or greater amenities. These longer commutes may become easier and less environmentally damaging in the future. On the other hand, a network of shared automated vehicles could make urban locations more attractive by complementing walkable neighborhoods and reducing the inconveniences of parking and traffic.

EMISSIONS AND ENERGY CONSUMPTION

On the whole, connected and automated vehicle technology is likely to reduce energy consumption of ground transportation. Many developers of AVs are using electric drivetrains. Even though AVs will increase vehicle miles traveled by allowing non-drivers to travel independently, the technology will consume between 11% and 55% less energy depending on drivetrain electrification.[29] Shifting the powertrain to from gasoline to electricity is the largest reduction of energy consumption, compared to today's vehicles. Other energy savings could come from better route choices, smoother driving cycles, vehicle right-sizing and smart intersections. More information about energy consumption is available in the Vehicle Electrification and Alternative Fuels trend paper.

GOVERNANCE

DATA PRIVACY & CYBERSECURITY

Connect and automated vehicle technology will require the collection and transfer of lots of information. This increases the risk of hackers manipulating the system for malicious purposes. Without sufficient cybersecurity, a bad actor could gain unauthorized access to a vehicle or valuable information. Attacks could both harm the victims and reduce diminish trust in the technology. The Cybersecurity and Infrastructure Security Agency published a guide analyzing security risks unique to AVs. The guide also provides strategies to mitigate the risk of attacks on vehicles and AV enterprises, including:

- Develop and implement employee training and exercises to ensure on-the-ground personnel are aware of interconnected cyber-physical risks.
- Ensure physical access points to networks and systems are secure.
- Conduct vulnerability assessments.
- Conduct application, network, firmware, and hardware cybersecurity testing.
- Implement recommended vehicle software updates regularly.

Privacy is a related but distinct concern. Companies and government entities that collect AV information need to protect the privacy of users. One way to do this is through data anonymization. Data anonymization removes personally identifiable information from data sets, so that the data are useful for analysis without revealing private, personal information about travelers. Over the past few years, lawmakers have been pursuing legislation that imposes more stringent cybersecurity standards on automakers and establishes performance standards for automakers that include hacking protection, data security and hacking mitigation. See the Big Data and Cybersecurity Trend Analysis for more information on data privacy.

LIABILITY

In traditional vehicles, if a malfunction occurs, consumers can sue auto makers under products liability lawsuits, which are costly and take many years to resolve. However, there are more entities that could be liable with the many companies and manufacturers developing the sensors, software and systems that go into the development of an AV. If the technology malfunctions, there is no clear consumer protection standard or regulation, leading consumers to be at a disadvantage from large tech companies and auto makers.

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[29] Jooyong Lee and Kara Kockelman, "Energy Implications of Self-Driving Vehicles" in Transportation Research Board, January 2019. https://www.caee.utexas.edu/prof/kockelman/public_html/TRB19EnergyAndEmissions.pdf

In addition, it may be extremely difficult for law enforcement to interact with AVs, particularly in a collision or when attempting to pull them over for traffic law infractions. In California, it took three state patrol vehicles to surround a Tesla using L2 technologies to pull it over because the system did not have a mechanism to slow down once auto pilot was turned on. Law enforcement also face challenges downloading data from AVs and having the expertise to review AV data.

Deployment of AVs will not occur all at once, meaning many years of mixed human-operated and fully automated vehicles. This raises questions regarding liability and insurance. Outstanding questions of liability in crash events represent an additional challenge. It is unclear how will fault be determined in AV crashes and how will those events in turn affect automobile insurance practices. To-date there are few insurance companies that insure AVs, leading many of the manufacturers to self-insure, increasing insurance costs. Depending on ownership models, automobile insurance as we know it today could change entirely with the adoption of AVs.

EQUITY

Who benefits from connected and automated vehicles? It depends. If the dominant ownership continues to favor the purchase of a car, it is likely that low-income Minnesotans will not reap the same safety and convenience benefits that wealthier vehicle owners will. If AVs are not designed to be wheelchair-accessible or easily used by people with cognitive or sensory difficulties, then AVs could reinforce existing inequities for people with disabilities. Further, if vehicles are not programmed to drive safely around pedestrians and bicyclists, then the most vulnerable road users could be negatively impacted. Rollout may happen in larger urban areas first and reach rural areas later.

But there could be equity benefits as well. If more buses, rideshare vehicles or small transit vehicles have connected and automated vehicle technology, then people with lower incomes would see greater mobility. This would make benefits more accessible to more roadway users. Some groups, including women and LGBTQ+ communities, experience street harassment more frequently than others. AVs, whether shared or privately owned, could offer private and secure transportation to these groups.

CAV IN MINNESOTA

In 2018, Governor Dayton issued Executive Order 18-04 recognizing the need for Minnesota to plan and prepare for an AV future, which established the Governor’s Advisory Council on Connected and Automated Vehicles. The Advisory Council develops recommendations for changes in state law, rules and policies to prepare for the widespread adoption of automated and connected vehicles. The Advisory Council’s vision is to build a future transportation system that is safe, equitable, accessible, efficient, healthy and sustainable. Their mission is to collaborate with stakeholders, partner with academic institutions and private industry, and engage communities to prepare for a future with emerging transportation technologies.

MnDOT is the lead state agency focusing on CAV policy, planning, research and testing, with the establishment of the Office of Connected and Automated Vehicles in April 2018. CAV-X supports the Advisory Council and the Interagency CAV Team – a statewide body that represents all levels of government and universities in Minnesota on matters of public policy.

In May 2020, the Advisory Council established the CAV Innovation Alliance to coordinate statewide CAV efforts. The Alliance is comprised of five committees which coordinate on CAV safety, infrastructure investment, data and connectivity, outreach and education, and labor and workforce development.[30]

MnDOT and its interagency partners have coordinated efforts and initiatives to advance CAV in Minnesota. In 2019, MnDOT adopted the Connected and Automated Vehicle Strategic Plan was adopted in 2019. Many parts of the department have been working on advancing the plan's 65 strategies to advance CAV infrastructure, research, maintenance, policy, data, outreach, communications and long-range planning.

MnDOT is testing CAV technology across the state and implements the Minnesota CAV Challenge, an innovative public-private partnership program. Public and private entities can propose CAV solutions to improve safety, efficiency, equity, outreach and mobility. Some examples of selected CAV Challenge projects include:

1. A pilot Level 4 automated shuttle service in Rochester.
2. Snowplow priority traffic signals.
3. LiDAR research.
4. Fiber optic feasibility study.
5. Automated truck-mounted attenuator "crash cushions" to enhance safety for roadside workers.

Counties in Minnesota also are preparing for CAV. The Minnesota County Engineers Association has a CAV committee, which meets regularly to coordinate on CAV topics. Olmsted, Goodhue and Dakota Counties are partnering with MnDOT on the Highway 52 CAV corridor study pilot.

At the city level, MnDOT and the City of Hastings are discussing fiber planning efforts when major highway reconstruction takes place. The League of Minnesota Cities has representation from local elected officials and League staff on the Governor's Advisory Council and is involved with the Minnesota CAV Innovation Alliance. In 2020, the City of Minneapolis developed policies and built digital infrastructure to support CAV. In November 2020, the Minneapolis City Council adopted the Transportation Action Plan, which includes a strategy to harness technology for citywide benefits that support safe street operations.

NEXT STEPS

The CAV landscape is constantly shifting and evolving with technological breakthroughs and legislative action. CAV technologies are being integrated into many modes of transportation, including scooters, buses, drones and trucks. As this landscape evolves, MnDOT will collaborate with partners, monitor both public and private initiatives and update the approach as needed. MnDOT's CAV-X Office is tasked with helping the state plan and prepare for emerging transportation technologies and will continue to explore new ways to advance this work across the state.

RELATED TRENDS

- Aging Population
- Big Data and Cybersecurity

[30] State of Minnesota Executive Department – Executive Order 18-04: Establishing the Governor's Advisory Council on Connected and Automated Vehicles

- Logistics
- Shared Use Mobility
- Transportation Behavior

Minnesota's vision for transportation is known as Minnesota GO. The aim is that the multimodal transportation system maximizes the health of people, the environment and our economy. A transportation vision for generations, Minnesota GO guides a comprehensive planning effort for all people using the transportation system and for all modes of travel. Learn more at MinnesotaGO.org.

REVISION HISTORY

Date	Summary of revisions
April 2016	Original paper.
May 2022	Updated with new information.