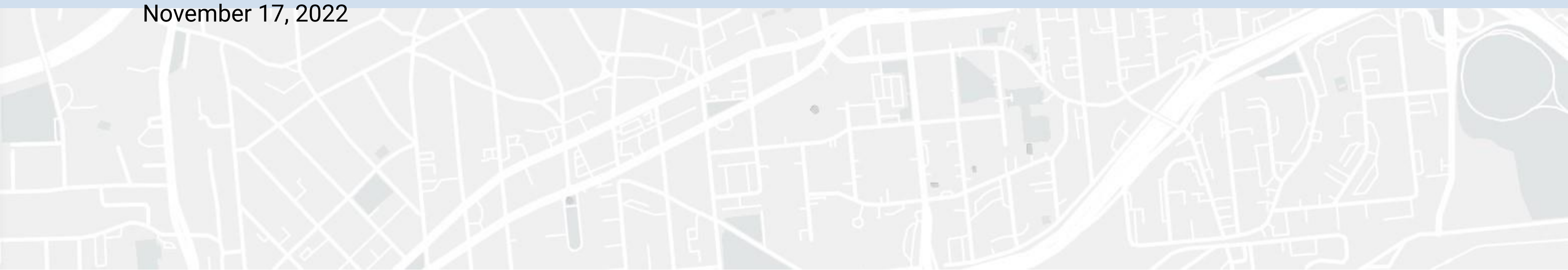
CONNECTED AND AUTOMATED VEHICLE (CAV) OVERVIEW

WHITE PAPER

November 17, 2022



Connected and Automated Vehicle (CAV) Overview – White Paper

Baltimore Metropolitan Council

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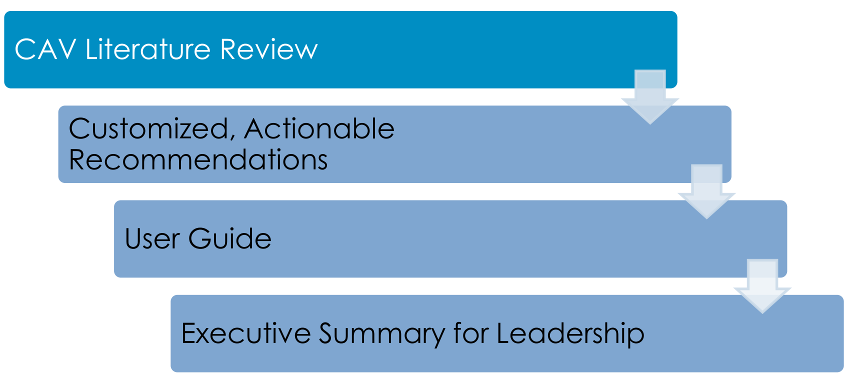
INTRODUCTION

The purpose of the *Connected and Automated Vehicles (CAV) Integration for Local Governments* project is to provide an overview of potential CAV impacts and best planning practices, and present actionable recommendations to help agencies prepare for CAV's in the Baltimore region.

To accomplish this, there are four key phases in the CAV planning process. The first step is this literature review of relevant CAV work and best practices at the national, state, regional, and local levels. It serves as the foundation for the next step, the development of specific regional and local recommendations on short-, medium-, and long-term impacts and actions to prepare for the safe, efficient, and equitable adoption of CAVs.

Next, we will create a user guide to help agency staff understand and implement the recommendations. Information from the literature review, recommendations, and user guide will be summarized in an Executive Summary for use by local agencies, leaders, and decision makers. Throughout the process, a steering committee and industry experts will provide feedback on the needs, gaps, and opportunities for transportation in the Baltimore region that could be impacted by CAVs.



The CAV literature review document is organized as follows:

- What are automated driving systems?
- How are automated driving systems being used (Connected Vehicles, Automated Vehicles, and CAV)?
- Why plan for CAVs?
- Potential CAV impacts to mobility, safety, environment, infrastructure, and equity
- Best Practices for planning for CAV impacts
- Summary of key findings attachment: Other technologies changing transportation

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The local recommendations we are creating will support Maryland's vision for CAVs, as it is defined in the Maryland Department of Transportation's CAV Strategic Framework. According to the Framework, Maryland's vision is "to uphold and enhance a Safe, Efficient, and Equitable transportation future by delivering collaborative and leading-edge CAV solutions. Maryland is open for business and eager to realize the life-saving and economic benefits of CAV technology, while ensuring safety for all. We are embracing CAV technology and innovation through continuing collaboration with partners interested in researching, testing, and implementing CAV in Maryland."

— Maryland Department of Transportation's CAV Strategic Framework

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WHAT ARE AUTOMATED DRIVING SYSTEMS?

Automated Driving Systems (ADSs) use "…electronic or mechanical devices to operate one or more functions of a vehicle without human input."[1] Automation in vehicles can range from providing driver support to performing all of the vehicle's driving functions using sensors and other technologies to understand the surrounding environment. In a driver support role, automation includes technology that requires driver supervision or interference (these are called advanced driver assistance systems, or ADAS). For example, adaptive cruise control, which utilizes radar technology to detect vehicles ahead, relies on human participation to perform other driving functions like steering, lane changing, and emergency breaking. Instances where automation performs all the vehicle's driving functions can take place in virtually any conditions but are currently most common under specific conditions. (These are sometimes called highly automated vehicles or HAVs.) For example, automated passenger shuttles have demonstrated that they can operate without a human driver at low speeds on predetermined routes.

The Society of Automotive Engineers defines the levels of driving automation (Figure 1). For this CAV planning project, we are focusing on automated driving systems, or SAE Levels 3, 4, or 5, per the National Highway Traffic Safety Administration definition of Automated Driving Systems (ADS):

"hardware and software that are collectively capable of performing the entire [dynamic driving task] on a sustained basis, regardless of whether it is limited to a specific operational design domain (ODD); this term is used specifically to describe a Level 3, 4, or 5 driving automation system."[1]

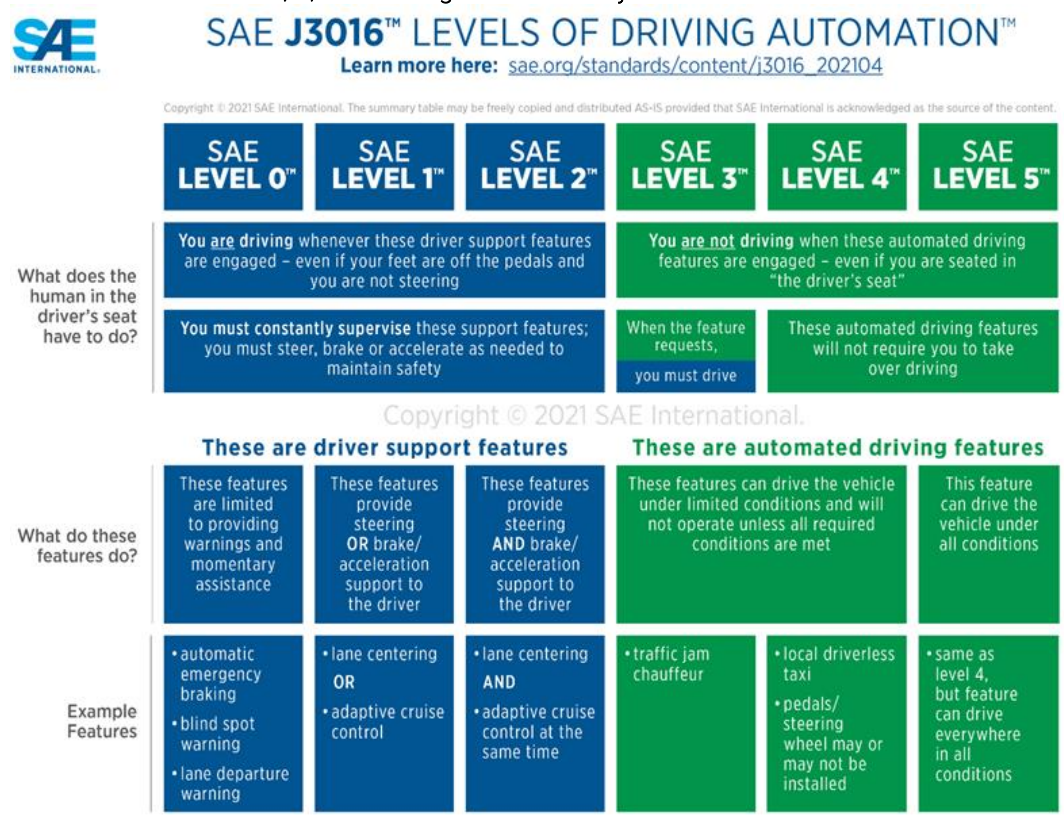


Figure 1. SAE Levels of Driving Automation

[1] National Highway Traffic Safety Administration (NHTSA), 2018. *Preparing for the Future of Transportation: Automated Vehicles 3.0* (AV 3.0).

HOW ARE AUTOMATED DRIVING SYSTEMS BEING USED?

ADS technology is being developed and tested for personal delivery devices (drones or sidewalk delivery robots), passenger cars, automated vehicle ridehail, low-speed automated shuttles, multipurpose vehicles (like some paratransit vehicles), full-size transit buses, and commercial delivery using heavy trucks.

CONNECTED VEHICLE (CV) APPLICATIONS

Connectivity is the wireless sharing of information between vehicles, roadside infrastructure (i.e., traffic signals), other modes and users (i.e., pedestrians or cyclists), and/or remote infrastructure or services (i.e., traffic management centers, cloud-based navigation). **Connected vehicles (CV)** connect to and communicate by receiving data from other vehicles, roadside infrastructure, other modes and users, and remote infrastructure to assist the driver with driving functions. Connected vehicles can also send data back to entities such as traffic management centers and navigation services to improve their ability to monitor roadway conditions.

The data from CV technologies are helping agencies better understand the safety-related performance of their transportation system by providing crash incident data in an aggregated, anonymized format to identify network deficiencies. CVs are also being tested to move vehicles more efficiently through signalized intersections and to share travel and safety information with drivers like upcoming work zones, crashes, or weather events using in-vehicle messaging.

- The first production application of a CV was as the GM OnStar system in 1996.[2]
- Transit signal priority (TSP) systems are well-established CV systems used by local agencies and transit fleets across the country. TSP lets transit vehicles communicate with traffic signal controllers to reduce delays at red lights and help transit vehicles stay on schedule.
- Wejo is one company that provides data from CVs for public agencies to use to study roadway mobility and safety. The data can be used to measure average vehicle speeds, to identify potential crash risks in locations where hard braking events occur frequently (such as interchange ramps, intersections, or work zones), and to study the impact of automated work zone speed enforcement.[3, 4, 5]
- Maryland has installed 49 roadside units (RSUs) across the state, including along US 1 in Howard County, which aim to improve roadside technology to be compatible with CAV technologies.[6]

[2] OnStar. "The Evolution of OnStar". 20 April 2022.
[3] M. Hunter, E. Saldivar-Carranza, J. Desai, J. Mathew, H. Li, D. Bullock, 2021. A Proactive Approach to Evaluating Intersection Safety Using Hard-Braking Data. Springer.
[4] Sakhare, R., J. Desai, H. Li, M. Kachler, D. Bullock, 2022. Methodology for Monitoring Work Zone Traffic Operations Using Connected Vehicle Data. MDPI Safety 2022, 8, 41.
[5] Mathew, J., H. Li, H. Landvater, D. Bullock, 2022. Using Connected Vehicle Trajectory Data to Evaluate the Impact of Automated Work Zone Speed Enforcement.
[6] Maryland DOT. US 1 Innovative Technology Deployment Corridor. November 2017.

- Maryland DOT also hosts an interactive web map of Maryland Locations to Enable Testing Sites (LETS) for CAVs, which includes locations and details on all the active RSUs.[7]

The USDOT has a library of infographics that explain the many ways CV technology is being applied to Intelligent Transportation Systems.[8] The selected examples in Figure 2 explain signal priority, advanced warning about congestion ahead or advisory speeds, and weather-responsive traffic management strategies. These infographics are good educational resources for local agencies.

[7] Maryland DOT. Maryland Locations to Enable Testing Sites (LETS) for CAV.
[8] USDOT, ITS Infographics.

Figure 2. Examples of USDOT CV Technology Infographics (*Source: USDOT*)

ADVANCED DRIVER ASSISTANCE SYSTEM (ADAS) APPLICATIONS

Advanced Driver Assistance Systems (ADAS) are technologies intended to inventory a vehicle's surroundings to provide information to the driver or to perform driving actions in the place of the driver to improve vehicle safety. ADAS provide warnings to get a driver's attention or actively control a vehicle in certain scenarios to avoid a crash or reduce the severity of a crash. ADAS are standard or optional features on many new passenger, transit, and freight vehicles. These technologies include, but are not limited to, lane keeping assist, blind spot warning, forward collision warning, and automatic emergency breaking.[9, 10] ADAS does not require connectivity.

ADAS uses sensors on the vehicle (like cameras, radar, or lidar) to constantly monitor the vehicle's surroundings. An on-board computing system processes data received from other vehicle systems including on-board sensors, communication systems, and positioning systems, and information from the vehicle's databases. Using information gathered from these other vehicle systems, the on-board computing system can make instantaneous reactions and decisions about driving functions and a vehicle's surroundings—like issuing warning alerts to the driver, actively braking the vehicle if the driver does not take proper action, parallel parking assist, and many others.

While ADAS has the potential to improve crash safety, the new vehicles with these advanced systems may not be affordable to all travelers. Additionally, the maintenance costs to upkeep these systems may also create equity barriers.

Maryland is the first state to add information on ADAS to its Driver's Manual. The state is working toward adding questions on ADAS to the licensing practice and knowledge test.[11]

CONNECTED AND AUTOMATED VEHICLE (CAV) APPLICATIONS

Connected and automated vehicles (CAV) combine automated vehicle (AV) and connected vehicle (CV) technologies including sensors, maps, and software to communicate with other vehicles, infrastructure, users, and remote infrastructure to assist in the process of performing most or all the vehicle's driving functions.

The MDOT State Highway Administration (SHA) Connected and Automated Vehicle Implementation Plan provides further clarity on the defining connected vehicles, automated vehicles, and CAVs.

Connectivity elevates *autonomous* technology to *automated* technology by bringing the benefits of connected communication to an automated driving system. Connectivity enables CAVs to better respond to sudden changes in a vehicle's surroundings by exchanging information with network infrastructure and providing updates regarding situational factors. Interoperable equipment could give local agencies opportunities to share information between CAVs and the roadway network, providing real time updates about network

[9] NHTSA, Driver Assistance Technologies.
[10] Clearing the Confusion: Common Naming for Advanced Driver Assistance Systems presented in the August 2022 Maryland Department of Transportation (MDOT) CAV Working Group Meeting

[11] Maryland DOT CAV Working Group, Leadership Notes from August 10, 2022 meeting. Page 8.

safety and conditions. CAVs have the potential to increase roadway capacity by reducing green light delays and decreasing reaction time, following other vehicles at shorter headways, and harmonizing vehicle speeds to reduce stop-and-go traffic.

An example of the combined benefits of connectivity and automation is the ability to platoon vehicles. Platooning is when vehicles follow a lead vehicle closely, whether it is automated or human driven. By improving platooning patterns, connectivity has the potential to improve and increase intersection operations and capacity and reduce emissions from idling vehicles.

While it is not a requirement for CAV technology, much of the industry is focused on the development of electric-powered CAV technology. Electric vehicles have their own unique infrastructure improvements and requirements, but when coupled with CAV technology will likely require additional infrastructure support.

Currently, high levels of vehicle automation are being tested only in fleet applications—not for personal use. ADS testing without driver input has typically been conducted in limited-access highway driving applications or in low-speed, suburban applications.

- Aurora, Gatik, Kodiak, Locomation, TuSimple, and Waabi are all existing automated trucking applications. Daimler Trucks and Torc Robotics are testing automated trucks in southwest Virginia.[12]
- The Olli automated shuttle by Local Motors was first deployed in National Harbor, Maryland in 2016.[13]

Recently, testing has started to focus on rural roads and dense urban streets.

- University of Iowa's *ADS for Rural America* is the first major research project in the US to test rural applications of automated passenger service.[14]
- *AVA: AVs For All* is a new research program led by Texas A&M Engineering Experiment Station to study CAV operations on rural roads in Texas and on urban streets in Washington, DC and northern Virginia.[15]

Other examples of CAV applications being tested or deployed include:

Transit, ridehail, and on-demand delivery service applications.

- The Connecticut DOT is testing three automated, full-size, electric transit CT*fastrak* buses on the CT*fastrak* corridor.[16]
- Waymo was the first company to offer automated ridehail service beginning in Chandler, AZ. Waymo One now operates in Phoenix, San Francisco, and is planning to start in Los Angeles.[17]
- The U.S.'s first wheelchair-accessible autonomous robotaxi fleet will be deployed in Grand Rapids, Minnesota, through a collaboration between May Mobility and Via. Via currently offers automated ridehail services in Ann Arbor, Michigan; Arlington, Texas; and Grand Rapids, Minnesota.[18]
- Lyft has partnered with Waymo, Motional, and Argo AI to deliver automated ridehail service with initial deployments in Austin, Las Vegas, Miami, and Phoenix.[19]
- Cruise provides automated ridehail service in San Francisco and plans to extend service to Austin and Phoenix. Currently,

[12] Daimler Truck. Automated Driving at Daimler Trucks.
[13] Pascale, J. 13 February 2019. Toaster-Shaped Autonomous Shuttle is First to Test on Public Roads in Maryland. WAMU.
[14] University of Iowa. National Advanced Driving Simulator. ADS for Rural America.
[15] USDOT. ADS Demonstration Grants Program Overview.
[16] APTA. 12 January 2021. Use of Automated Buses on Connecticut's CTfastrak BRT.
[17] Waymo. 19 October 2022. Next Stop for Waymo One: Los Angeles.
[18] Via. Autonomous mobility is here. Case Studies.
[19] Lyft. Partners.

the San Francisco service operates between 10:00pm to 5:30am.[20]

- Pony.ai provides robotaxi services in Irvine and Freemont, California and in Beijing, Guangzhou, Shanghai, and Shenzhen, China.[21]
- Uber Eats and Motional offer automated delivery service in Santa Monica.[22]

Personal delivery devices (PDDs or sidewalk delivery robots), which are powered devices capable of navigating shoulders, sidewalks, or crosswalks with or without active control or monitoring. PDDs are being used to transport goods in public right-of-way. They can weigh up to 550 pounds unloaded.[23]

- In 2021, Maryland passed a law allowing PDDs to operate on any roadway, sidewalk, shoulder, footpath, bicycle trail, or crosswalk in the State with certain conditions.[24]
- MDOT provides guidance for companies who want to operate PDDs in the state, including how to submit the required Emergency Response Plan to the MDOT Motor Vehicle Administration (MVA).[25]
- PDDs were first pilot tested in Maryland in 2022 by Kiwibot on Morgan State University's campus. Kiwibot also submitted plans in September 2022 to operate PDDs on Stevenson University in Baltimore County. The Kiwibot PDDs operate with Level 2 automation with a teleoperator supervising operations and taking control when necessary.

TIMELINE

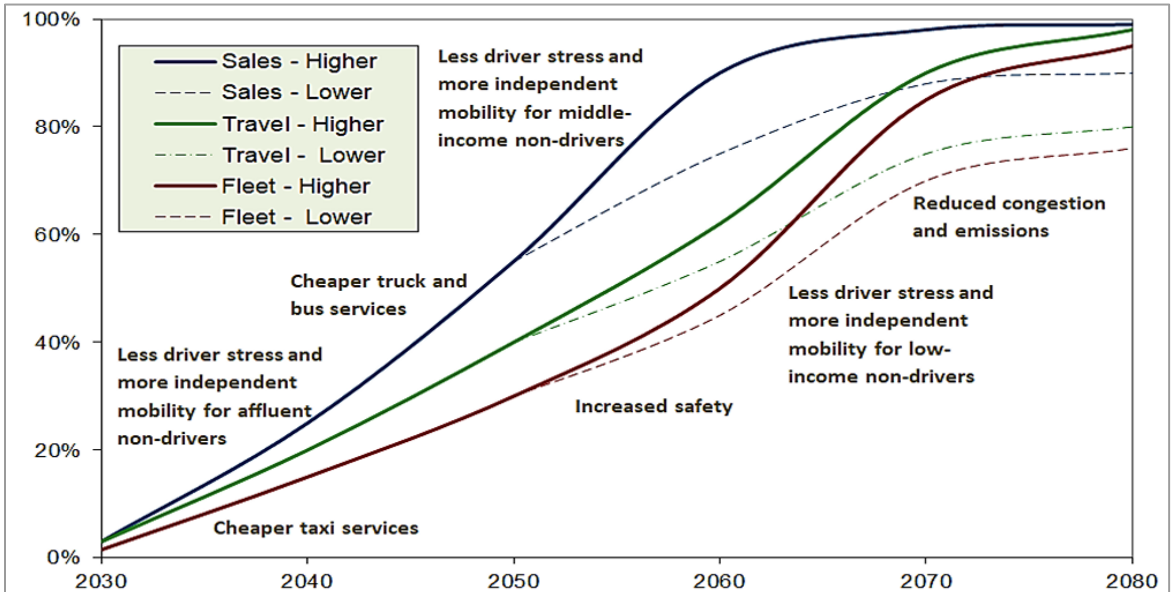
While CAV technology is being introduced to the roadway network beyond the research, development, and testing phases, it will still take time for CAVs to have significant impacts on traffic. At least 20 percent of the vehicles on the roadways will need to be autonomous in order to realize the traffic operational gains that come with connected vehicles, according to new research from Carnegie Mellon University.[26] The study found that if 20-50% of vehicles are programmed to make collaborative decisions, the delay in the overall transportation network is optimized. It will take years before CAVs are large percentages of the traffic stream. Currently, no highly automated vehicles are available for purchase by members of the public. Economist Todd Litman predicts that CAVs won't be widely adopted until the 2040s or even 2060s (Figure 3).[27]

There are signs that wide deployment of CAVs may even be further away than once thought, with profitable CAV operations even further away. Some companies have recently decided to exit the automation industry to focus instead on applications that are more near term.

- Local Motors—the US manufacturer of the Olli automated shuttle deployed in National Harbor, Maryland—shut down in January[28].
- Ford is pivoting away from AV focusing on advanced driver assistance systems instead.[29]

[20] Cruise. Where can I go?
[21] Pony.ai https://www.pony.ai/
[22] Motional. 16 May 2022. Motional and Uber Eats Launch Autonomous Deliveries in Santa Monica.
[23] Maryland General Assembly, Legislation SB0726 from July 1, 2021
[24] Maryland General Assembly, Legislation SB0726 from July 1, 2021.
[25] Maryland DOT. Personal Delivery Devices.
[26] Carnie Melon University. Mixed-Autonomy Era of Transportation
[27] Victoria Transport Policy Institute. Autonomous Vehicle Implementation Predictions: Implications for Transport Planning.
[28] Bellan, R. 13 January 2022. Local Motors, the startup behind the Olli autonomous shuttle, as shut down.
[29] Ford News. 26 October 2022. Ford Fulfills Earnings Guidance, Has Strong Cash Flow in Q3; Will Accelerate Development of L2+/L4 ADAS Technology.

- AV startup Argo AI backed by Ford and VW announced its closure in October.[30]
- Amazon and FedEx both announced the cancellation of their PDD pilots in October. Both pilots were launched in 2019.[31, 32]



This analysis suggests that it will be at least 2045 before half of new vehicles are autonomous, and 2060 before half of the vehicle fleet is autonomous. Significantly faster deployment will require scrapping many otherwise functional vehicles that lack self-driving ability. Some benefits, such as reduced driver stress and independent mobility for affluent non-drivers, can occur when autonomous vehicles are relatively costly and rare. However, most benefits, such as independent mobility for moderate-income non-drivers and affordable taxi and micro-transit services, can only be significant if they become common and affordable, and some benefits, such as reduced congestion, will require dedicated lanes to allow platooning.

Figure 3. Autonomous Vehicle Sales, Fleet, Travel, and Benefit Projections (*Source: VTPI*)

[30] Korosec, K. *TechCrunch*. 26 October 2022. Ford, VW-backed Argo AI is shutting down.
[31] Vincent, J. *The Verge*. 18 October 2022. FedEx is shutting down its robot delivery program.
[32] Vincent, J. *The Verge*. 7 October 2022. Amazon stops field tests of its delivery robot Scout.

WHY DO WE NEED TO PLAN FOR CAVS?

To date, there has not been a lot of policy work at the local level on CAVs. However, now is the optimal time for federal, state, and local governments and agencies to start monitoring progress and impacts as CAVs continue to be tested and make up more of the vehicle fleet. CAV technology has the potential to save lives and reduce the severity of injuries, improve reliability, enable new mobility service solutions, and improve the movement of commodities and service providers.[33] Decision makers need to understand how CAV applications could impact public investment and support or incentivize CAV implementation to include:

- Improved pavement condition, striping, and signage,
- Upgraded traffic signal controllers,
- More robust Intelligent Transportation Systems for travel demand management,
- Separated pedestrian and bicycle facilities,
- Increased electric vehicle charging infrastructure (to install and maintain chargers),
- Enhanced broadband communications networks,
- And more.

Maryland law[34] allows personal delivery devices (PDDs) to travel on public sidewalks. Therefore, local agencies in Maryland need to start preparing for the presence of PDDs, even if they don't plan to host a deployment of their own.

At the same time, CAV technology could be implemented in ways that do *not* meet public sector goals:

- CAVs might be more conservative than aggressive human drivers—following at longer headways and actually *decreasing* roadway capacity.
- Drivers might over rely on advanced driver assistance systems or on lower levels of automation—potentially leading to unintended safety consequences.
- CAVs might compete with public transit systems—a driver's *value of time* could decrease if they can work while commuting, or the *monetary cost* of travel in a CAV could be less than transit if drivers no longer need to pay for parking and send their CAV home between trips.
- CAVs might provide new mobility options, but they may not be equitably accessible to all (affordability and wheelchair accessibility).

Public policy will be key in shaping the outcomes we want to see in terms of safety, equity, land-use and other impact areas and minimizing the potential downsides that might come with CAVs.

[33] State of Maryland. Connected and Automated Vehicle Strategic Framework. December 2020.

[34] Maryland General Assembly, Legislation SB0726 from July 1, 2021.

WHAT IS THE ROLE FOR LOCAL AND REGIONAL GOVERNMENTS?

Governments need to plan for CAV impacts now, so their goals and needs are addressed as the private sector deploys technologies. The public sector has a responsibility to coordinate with private industry to share their goals and to discuss how services (such as mobility on demand or mobility as a service) can best serve the public. For more information, please reference BMC's Resilience 2050 Emerging Technologies White Paper.

The equity impacts of CAVs on the transportation system and industry will be influenced by policies and choices at the federal, state, and local levels to ensure the widespread use of self-driving vehicles doesn't leave behind historically disadvantaged communities.

Federal, state, and local governments have different regulatory responsibilities for CAVs.

The federal government will regulate areas where consistency across state borders is necessary (such as interstate commerce and consistency of pavement markings and traffic signs), vehicle performance (through Federal motor vehicle safety standards) and licensing the communication network.[35]

State governments will regulate licensing (of drivers or automated vehicles), vehicle rules of the road, roadway design standards, and statewide insurance and liability.[36] Maryland state policies could include certification procedures or driver/operator background checks to maximize safety and support the *Zero Deaths Maryland* initiative.[37]

Local governments are responsible for regulating land use, zoning, and permitting (except when pre-empted by state law). Local governments manage the design, infrastructure, and curbside management of non-state roads.[38] Therefore, local governments should ensure interoperable equipment, such as traffic signal controllers or EV charging stations, are available for the continued introduction of emerging CAV technologies.

[35] NACTO, 2019. Blueprint for Autonomous Urbanism, 2nd Edition.
[36] NACTO, 2019. Blueprint for Autonomous Urbanism, 2nd Edition.
[37] Maryland DOT. Zero Deaths Maryland.
[38] NACTO, 2019. Blueprint for Autonomous Urbanism, 2nd Edition.

BEST PRACTICES FOR PLANNING FOR CAV IMPACTS

This section summarizes CAV planning best practices at the national, state, regional, and local levels.

MDOT and the Maryland Department of Planning (MDP) have prepared guidance for local jurisdictions on how to prepare for, plan for, or implement CAVs and their supporting technologies. Their Connected & Automated Vehicle Toolkit for Maryland Local Jurisdictions *outlines three levels of action municipalities can take: Baseline, Medium Investment, or High Investment. Municipalities can do more than one.*

Baseline *actions are to get smart on terms and resources, to clearly establish roles and responsibilities for and within the agency, and to join the national dialogue on CAVs.*

Medium investment *includes understanding the community vision and needs, multimodal strategies, land use and zoning, workforce readiness, and attracting CAV deployment.*

High investment *includes actions related to the physical or digital infrastructure.*

The following sections describe the best practices in assessing readiness, building partnerships, training the workforce, developing policies, sharing data, preparing the infrastructure, and monitoring progress.

SELF-ASSESS

As the implementation of CAVs and other emerging technologies evolves, agencies need to frequently self-assess their ability to respond to, implement, and/or manage the technologies. The National Cooperative Highway Research Program (NCHRP) *Research Report 924: Foreseeing the Impact of Transformational Technologies on Land Use and Transportation*[39] outlines the agency's self-assessment process:

- ***Phase 1: Preparation:***
  - *Identify stakeholders,*
  - *Develop agency's vision for technology, and*
  - *Set agency's technology goals.*
- ***Phase 2: Conduct Assessment:***
  - *Inventory current agency resources and capabilities and*
  - *Identify gaps.*
- ***Phase 3: Prepare Action Plan:***
  - *Involve stakeholders,*
  - *Set priorities, and*
  - *Set milestones.*
- ***Phase 4: Monitor and Adjust:***
  - *Monitor progress,*
  - *Identify shortfalls, and*
  - *Adjust action plan.*

[39] Dowling, R. and A. Morgan, 2020. *NCHRP Research Report 924: Foreseeing the Impact of Transformational Technologies on Land Use and Transportation*. Transportation Research Board, Washington, DC.

The National Association of Counties (NACo) created the *Connected and Automated Vehicles Toolkit: A Primer for Countie*s web dashboard[40], which presents an overview of CAV technology, policy, and deployments and suggests questions local leaders should ask to assess their readiness for CAV deployments. These questions apply to any municipality considering a deployment:

- Has your county assessed its potential for CAV deployment?
- Has your county examined local traffic patterns or assessed local safety data with an eye to CAV deployment? For example, hotspots for congestion, crashes, or construction zones where real-time information to alert drivers to nearby incidents, diversions or heavy traffic could help improve transportation safety and mobility.
- Does your county have an idea of how residents and stakeholders will react to the introduction of CAVs to the market?
- Does your county already have local CAV policies?
- Has your county examined the potential implications of broad CAV deployment on its transportation system and economy?

The San Joaquin Council of Governments in Stockton, California conducted a transportation innovation planning study *that identified a major need to expand the fiber optic network to provide high-speed communications to implement advanced congestion management strategies, and to create economic development opportunities in the region.*

Their follow-up fiber optic readiness study *identified opportunities for local agencies to adopt "Dig Once" policies, to create a task force of local "fiber champions" who will communicate across municipalities to share construction and funding opportunities, and to coordinate with the state to elevate local needs to the state's strategic broadband corridors list.*

[40] National Association of Counties, 2019. Connected and Automated Vehicles Toolkit: A Primer for Counties.

BUILD PARTNERSHIPS & CHAMPIONS

Local agencies that have been successful in implementing emerging technologies have one thing in common—a champion. An **emerging technology champion** is:

- An individual or group
- Well-networked throughout the local jurisdiction(s)
- Passionate about implementing new technologies
- Motivated to push for a project's success

Pilot deployments and sustainable services take years to implement. These champions need to be dedicated and committed to the long-term efforts in the region. Even if a local jurisdiction will not be leading a pilot or deployment of its own, decision makers need to understand how CAV applications could impact public investment and be involved in planning to ensure the technology implementation supports local goals.

Partnerships are also needed across agency departments and outside the organization to best understand how to support CAV technology and share and manage data. Agencies should consider the following:

- An internal CAV working group or task force made up of planning, operations, maintenance, and IT departments.
- Agencies considering a CAV deployment may want to partner with an AV vendor or an AV service provider to find technology solutions that meet local needs.
- Agencies might also partner with transportation data providers to collect and monitor data on deployments.
- Electric vehicle-related projects (such as transit or municipal fleet electrification) might require partnerships with the utility provider, private developers, charging infrastructure companies, and vehicle manufacturers.
- Curb-management projects might require partnerships with mobility service providers, transit agencies, local business groups, and emergency service agencies.
- Consider how the improvements would be funded, which could be guided by who benefits.

The characteristics of a good partnership between a local agency and an AV provider are listed in Table 1. Jurisdictions can leverage these characteristics to incentivize productive and sustainable CAV implementations, even if the jurisdiction is not a contractual partner.

Table 1. Characteristics of a Good AV Partnership

Characteristic	Local Agency	AV Provider
Clear expectations	Define the problem(s) to be addressed, develop goals and desired outcomes	Decide whether to propose or deploy based on whether their technology can achieve the desired outcomes
Long-term perspective	Transportation decisions made today can have long-lasting effects, both good and bad.	Long-term working relationships can be mutually beneficial and avoid the need to repeat start-up processes in multiple new jurisdictions
Trust	Set communications expectations, verify outcomes through regular performance reporting	Set expectations for making adjustments to pilots based on field experiences, work through established agency processes to build community trust[41]
Nimbleness	Adopt less-formal approaches to working with AV providers funding their own pilots, empower agency staff to adjust regulations and fees within limits to adapt to evolving knowledge and technologies	Be ready to adjust pilots to adapt to lessons learned, have a plan for scaling up the pilot if the desired outcomes are met
Data sharing and project support	Maintain and provide agency datasets used by the AV technology, prioritize maintenance activities supporting the technology (e.g., refreshing pavement markings)	Provide processed data that can help support agency functions and monitor project outcomes

Source: Ryus, et al., 2022, Automated Vehicle Hosting Handbook for North Central Texas Communities, NCTCOG.[42]

[41] National League of Cities, April 2017. Autonomous Vehicles: A Policy Preparation Guide.
[42] Ryus, P., A. Morgan, J. Hicks, R. Grosso, S. Laffey, et al., 2022. Automated Vehicle Hosting Handbook for North Central Texas Communities. North Central Texas Council of Governments, Arlington, TX.

RETHINK YOUR WORKFORCE

To keep pace on the changing applications, deployments, and trends, agencies can get and stay smart by training their existing staff, hiring new staff with different skills, or partnering with experts (as discussed above).

HIRE, TRAIN AGENCY STAFF, OR RETHINK THE STANDARD ORGANIZATIONAL MODEL

Agencies need to plan for current and future workforce needs related to emerging technologies and big data. New staff may be needed to bring new skillsets to the planning process. Existing staff can benefit from a variety of training opportunities to help them respond to the changing environment. As an agency, it may be necessary to adapt the existing organizational structure and job descriptions to better reflect the changing nature of the work.

You can get free, local training by attending the Maryland CAV Working Group regular meetings to learn what's happening across the state and to hear directly from industry leaders.

You can review US Department of Transportation (USDOT) guidance including:

- What Public Officials Need to Know about Connected Vehicles
- Automated Vehicles for Safety Overview
- Connected Vehicle Infographics

Conferences are another way to help train staff on the latest CAV information. Some key CAV conferences include:

- Consumer Electronic Show (CES) produced by the Consumer Technology Association is the largest technology event in the US and is the home to many industry announcements and technology unveilings each January in Las Vegas.
- Automated Road Transportation Symposium (ARTS) is an international conference sponsored by the Transportation Research Board each Summer.
- ITS World Congress held every other year and the ITS America Annual Meeting sponsored by ITS America focus on intelligent transportation systems (ITS).
- Pennsylvania Automated Vehicle Summit held each Fall is the largest annual AV-focused conference in the Northeast.
- Transportation Research Board (TRB) Annual Meeting brings professionals across the transportation industry together in Washington, DC each January. There are a number of TRB Committees focused on CAV planning, policy, and integration.

DEVELOP THE FUTURE WORKFORCE

As an agency, it will be important to be able to attract and retain a trained workforce. This is challenging because the skills needed are changing rapidly and the technologies may not have even been invented yet. Agencies should actively participate and advocate for workforce development opportunities in the emerging technology realm. Local agencies in Maryland need to start preparing for and understanding what technologies may be deployed in their jurisdiction, even if they don't plan to host a deployment of their own or enter into a formal contractual partnership agreement with a private company.

Workforce development partnerships:

Howard University's College of Medicine received a five-year National Science Foundation grant for its "STEM Opportunities in Prison Settings (STEM-OPS)" project to provide internships to formerly incarcerated people as a part of the university's "Prison to College Pipeline" program.[43]

The Tampa-Hillsborough Expressway Authority (THEA) partnered with the Hillsborough Community College (HCC) Master Mechanic Program and the equipment vendor to offer a 6-month paid internship for HCC students to install equipment on study vehicles in the Connected Vehicle Pilot Deployment Program. THEA's deployment involved private vehicles and public transit buses and streetcars. HCC's students used the college's professional auto bays to install test equipment on vehicles under the supervision of master mechanics. The students learned technical skills that few other programs are offering. The pilot benefited from the reduced labor costs by using students for the installation.[44]

The North Central Texas Council of Government hosted a public meeting focused on workforce development and education opportunities to support automation technologies.[45] The workforce development opportunities recommended by the panel include:

- **Partner with industry** to identify industry's needs, workforce expectations, and skillsets. Tailor training and education to fit those needs.
- **Start early** to introduce students to potential career paths in transportation and automation. Local jurisdictions can work with school districts to add CAV topics into their career academies and vocational training programs. The following lesson plans are available to introduce students to transportation and CAVs:
  - Institute of Transportation Engineers (ITE) technical resources for transportation education
  - Center for Advanced Automotive Technology (CAAT) connected vehicle demonstration lesson plan for grades 9-12
  - NCTCOG K-12 lesson plans on emerging transportation technologies
- **Develop transferable skills** such as communication, as well as a foundation in STEM (Science, Technology, Engineering, and Mathematics) subjects that can be applied to many types of technology jobs. Expect that more specialized and continuing

[43] The Dig, "The Prison to Ph.D. Pipeline: Formerly Incarcerated Howard Medical Researcher Brings Graduate Education to the Recently Released". 2 February 2022. Howard University.

[44] US Department of Transportation, Connected Vehicle Pilot Deployment Program. Tampa Connected Vehicle Deployment Connects with Community Colleges.

[45] North Central Texas Council of Governments, February 2022. AV2.1 Panel on Education and Workforce Development, virtual public meeting.

training will be needed on the job as specific technologies are developed or applied.

- **Demonstrate the range of job possibilities in the industry** at job and career fairs to catch the diverse interest of students or potential applicants. For example, maintenance, operations, and administration.
- **Provide opportunities to upskill and reskill.** These efforts can focus on, for example, veterans, people previously incarcerated, and persons from affinity groups not well-represented in the industry's workforce. Computer coding is an increasingly essential skill and may be easier to teach remotely to incarcerated populations or require lower capital costs than traditional hands-on mechanical maintenance.
- **Use AV pilot projects to support education.** For example, a local agency could partner with a local trade school to learn how to install and maintain equipment during the pilot test.

DEVELOP POLICIES

Agencies will need to develop plans and policies to manage and guide existing and emerging mode impacts on the transportation network. These policies should address curb space management, street design, and land use. Local CAV policies should support achieving Maryland's CAV vision[46] for a **safe**, **efficient**, and **equitable** transportation future. Local policies should also help to implement the Statewide Maryland CAV Strategic Framework[47], which focuses on:

- Public education and outreach
- Planning and policy
- Early deployment and testing
- Infrastructure
- Workforce development

General Plan Update. *The City of Manteca, California updated its General Plan:[48] As new transportation technologies and mobility services…are implemented in Manteca and used by the public, the City shall review and update its policies and plans to maximize the benefit to the public of such technologies and services without adversely affecting the City's transportation network. Updates to the City's policies and plans may cover topics such as electric vehicle charging stations, curb space management, changes in parking supply requirements, policies regarding electric scooter use and docking, etc.*

[46] Maryland DOT. Vision for CAV in Maryland.
[47] State of Maryland. December 2020. Maryland Connected and Automated Vehicle Strategic Framework.
[48] City of Manteca. Public Review Draft General Plan

Agencies should define more specific objectives by asking questions like:[49]

- *Are parking or loading zoning requirements or other codes consistent with the current needs for automobiles, trucks, bicycles, or e-scooters?*
- *Are curbside zones and markings adequate for the new parking and pick up/drop-off patterns occasioned by new technologies, like rideshare and AVs?*
- *Do the agency's standard highway and street cross-sections and designs allocate sufficient curbside space and travel way for vehicles and pedestrians under anticipated usage patterns with new technologies such as e-bikes, e-scooters, CVs, and AVs?*
- *Do the agency's signing and striping standards support the safe introduction of new technologies such as e-scooters and AVs?*
- *Do the agency's designs support dynamic lane and curbside management?*
- *Have the agency's goals and policies been expressed in the plan in such a way that they will remain valid under anticipated trends in technology?*
- *Do the socioeconomic growth models and forecasts and travel demand models and travel forecasts upon which the regional's long-range plan is based reflect anticipated technology trends?*
- *Are provisions in place to monitor the impacts of new technologies on socioeconomic, land use, and travel demand trends?*
- *Do the plans include intermediate checkpoints where monitoring may indicate the need to revisit the plans?*

City Transportation Technology Policies and Actions. *Los Angeles, California developed a Transportation Technology Strategy that identified goals, policies, and actions for planning for transformational technologies related to data-as-a-service (DaaS), mobility-as-a-service (MaaS), and infrastructure-as-a-service (IaaS).[50] The city identified policies and actions (short, medium, or long term) for each of their five goals (Table 2).*

[49] Dowling, R. and A. Morgan, 2020. *NCHRP Research Report 924: Foreseeing the Impact of Transformational Technologies on Land Use and Transportation*. Transportation Research Board, Washington, DC.

[50] Hand, A. 2016. Urban Mobility in a Digital Age: A Transportation Technology Strategy for Los Angeles.

Table 2. LADOT Transportation Technology Strategy Goals (2016)

In 2016, the Los Angeles Department of Transportation (LADOT) released a foundational document, titled Urban Mobility in a Digital Age, that includes the goals below. In 2020, LADOT released an updated Technology Action Plan building on these goals, recognizing many goals are the same, but the tools and technologies to achieve them are still emerging.

Goal	Policies	Actions
#1: Build a solid data foundation	1. Define what can be shared. 2. Adopt privacy principles. 3. Develop a standard data-sharing agreement. 4. Create a regional blueprint for system integration. 5. Establish design guidelines for digital infrastructure.	Short-Term Actions (0–2 years) 1. Inventory available data. 2. Create a wish list for other data sets and prioritize. 3. Implement a data analysis bench contract and grow internal analytics capacity. 4. Develop a roadmap for new data resources. Mid-Term Actions (3–5 years) 1. Make the data easier to use with data dictionaries and other tools. 2. Adopt APIs [application programming interfaces] + other tools to streamline sharing. Long-Term Actions (6+ years) 1. Leverage data to manage a more flexible transportation system with public and private service providers.
#2. Leverage tech plus design for a better transportation experience	1. Create ATSAC 3.0. (The city's central traffic signal control system). 2. Enforce congestion-busting rules for safety. 3. Adopt a customer bill of rights and metrics for transportation happiness. 4. Require corridor and building designs that serve multiple modes. 5. Eliminate parking minimums. 6. Rethink parking garages. 7. Stop widening roads.	Short-Term Actions (0–2 years) 1. Code the curb to optimize access. 2. Develop customer-centered requirements for public services. 3. Integrate real-time data and tech into urban design and planning processes. 4. Publish data on EV charging station locations. 5. Advance fleet conversion to greener fuel. Mid-Term Actions (3–5 years) 1. Create a unified wayfinding program. 2. Route transit by demand where suitable. 3. Expand ExpressPark citywide. 4. Introduce a portal for employers to manage transit benefits. Long-Term Actions (6+ years) 1. Create a universal fare system for Los Angeles.
#3. Create partnerships for more shared services	1. Update regulations to include new modes. 2. Make it easier to work with the City of Los Angeles and provide a level playing field. 3. Adopt a revised transportation demand management ordinance for new developments.	Short-Term Actions (0–2 years) 1. Develop a shared mobility action plan. 2. Form a multi-discipline mobility assessment team. 3. Designate an innovation pilot project manager. Mid-Term Actions (3–5 years) 1. Bring sharing to City Hall through car sharing, bike sharing, and carpooling platforms. 2. Launch a mobility lab. Long-Term Actions (6+ years)

Goal	Policies	Actions
		1. Implement mobility-as-a-service [MaaS].
#4. Establish feedback loops for services and infrastructure	1. Become a more responsive service provider. 2. Establish a project evaluation standard.	Short-Term Actions (0–2 years) 1. Create a user experience working group. 2. Investigate new tools for the ongoing evaluation of infrastructure conditions. 3. Engage the entire community on infrastructure condition assessments. 4. Partner and support a marketing campaign on shared mobility. Mid-Term Actions (3–5 years) 1. Streamline LADOT online content and launch a project dashboard. 2. Prepare the workforce for changes driven by innovation in transportation technology. 3. Adopt a multimodal smart fare system. Long-Term Actions (6+ years) 1. Develop a methodology to move towards infrastructure-as-a-service [IaaS].
#5. Prepare for an automated future	1. Call for mobility innovation in California. 2. Collaborate regionally to promote interoperability. 3. Launch a taskforce on data monetization strategies. 4. Advocate for new approaches to financing infrastructure projects.	Short-Term Actions (0–2 years) 1. Develop a business plan for a city-owned automated fleet. 2. Create a dedicated staff position focused on connected and fully autonomous vehicle technologies. 3. Implement blind spot detection systems for public transit vehicles. 4. Expand City of LADOT connected bus technologies fleet wide. 5. Invest in lane markings that enhance effectiveness of lane departure warning and prevention systems. Mid-Term Actions (3–5 years) 1. Create better access to ATSAC (central traffic control system) data and enhance transparency of network prioritization for planning. 2. Develop a fully autonomous vehicle road network along transit and enhanced vehicle networks. 3. Launch a data-as-a-service [DaaS] program to provide real-time infrastructure data to connected vehicles. Long-Term Actions (6+ years) 1. Convert the public transit vehicle fleet to fully autonomous [AVs].

There are many resources on ordinance writing for agencies, including:

- *The National League of Cities (NLC) Model Code for Municipalities*

- *PlannersWeb.com "Drafting Clear Ordinances: Do's and Don'ts"*

When developing policies for emerging transportation technologies, agencies should regulate through incentives and set standards for equitable access and avoid technology-specific regulations.

AVOID TECHNOLOGY-SPECIFIC REGULATIONS

In the past, technology-specific regulations were appropriate for the transportation industry that was largely unchanged for several decades.

Agencies cannot afford to be technology-specific and keep up with the rapid pace of change of transportation technologies. Consider how quickly micromobility evolved from docked bikeshare to dockless bikeshare and then to e-scooters. Or consider how quickly ridehail services Uber and Lyft entered the market and significantly shifted travel behaviors. Instead, agency policies need to be technology-agnostic.

There aren't many examples yet of local government CAV policies. San Francisco is in the process of developing its first policy for automated ridehail services. Austin and Arlington, Texas are home to several AV deployments, but Texas state law prohibits local governments from regulating AV or ADS operations.[51]

City of Boston AV Policy. *In 2016, Boston established policy for AVs. The City's website provides documents for reference, including: Executive order on AVs in Boston, regional memorandums of understanding on ADS vehicles, memorandums of agreement to test AVs on public ways, and summarized safety protocols. Deployers are initially required to use a backup safety driver in the vehicle and are allowed to test only during good weather and daylight hours until they reach certain milestones. To test AVs in Boston, providers must:*[52]

- *Reach out to the City via email to make us aware of your intent*
- *Prepare a testing plan*
- *Complete an application with the Massachusetts Department of Transportation [In advance of the application to MassDOT, a testing provider needs to agree on a phased testing plan with the City of Boston.]*
- *Complete a memorandum of agreement with the appropriate parties (including the City of Boston if you plan to test within City limits)*

REGULATE THROUGH FEES AND INCENTIVES

CAVs will impact transportation finances at the federal, state, and local levels. CAVs could also help to meet local equity and efficiency goals.

Revenue Impacts and Fees

Transportation revenues could decrease as vehicles become more fuel efficient (reducing fuel tax revenue) or more compliant with traffic laws and parking regulations (reducing traffic enforcement fines). Transit fare revenues could decrease if travelers shift away

[51] Texas Transportation Code §545.452.b.

[52] City of Boston, 1 July 2022. Autonomous Vehicles: Boston's Approach.

from transit toward private automated vehicle ownership or toward automated ridehail or telework.

CAVs could offer some financial benefits such as reduced labor costs to transit agencies if automation is used, or increased ridership/fares if CAVs might serve first-/last-mile connections. Impacts in the region from the loss of wages due to automation of transit services (i.e., union jobs) that pay a livable wage may also be at risk.

Local agencies could consider incentives or monetary drivers to make sure CAV implementation meets the state and local goals for safety, efficiency, and equity, such as:

- Development impact fees
- Curbspace pricing mechanisms
- Usage-based fees (such as vehicle miles traveled (VMT) fees, electric vehicle charging fees, or congestion charges for Baltimore's urban center)

Agencies could also consider policies that provide new revenue streams if CAVs impact transportation revenues, such as:

- Public-private partnerships (PPPs or P3s)
- Transportation data access fees
- Local vehicle registration fees
- Local taxes

Example Impact Fee Policies:

Usage-Based Fees*. Usage-based fees are…. If local governments are authorized to use the, they could charge usage-based fees or VMT fees for fleets of automated vehicles. Like a utility usage fee, these AV fees could be based on the fleet size or vehicle weight. Annual fees could be adjusted at the end of the year as a refund if the fleet's VMT is less than the target or additional fees if the fleet VMT is higher.*

DFW Airport charges a $5 drop off fee for transportation network companies (TNCs like Uber and Lyft) to make up for lost parking revenue from those passengers. Those TNC fees create 13.1% of their annual parking revenue for fiscal year 2022.[53] *A similar fee could apply to AV ridehail in the future.*

Development Impact Fees. *Development impact fees are a revenue source that can help to shift public infrastructure costs onto developers instead of local governments. Economic development corporations (EDCs) act as independent public developers to develop city-owned property and to attract businesses and developers to their cities.*

Standards for Sustainable and Equitable Access

Local policy can promote sustainability and equity goals.

Example Sustainability Policy: EV Charging Infrastructure Policy. *Chicago amended its parking requirements for new construction building permit applications to require EV Supply Equipment (EVSE) infrastructure:*[54]

- *Residential Buildings: New construction of a multi-unit residential building containing five or more dwelling units where on-site parking is provided shall install equipment so that at least*

[53] Dallas Fort Worth International Airport. FY 2022 Adopted Budget.

[54] City of Chicago. Municipal Code §17-17-0251.5.

20%, and no less than one, of the parking spaces are either EVSE-Ready or EVSE-Installed.

- *Nonresidential Buildings. New construction of a building containing uses other than residential uses where 30 or more parking spaces are provided shall install equipment so that at least 20% of the parking spaces are either EVSE-Ready or EVSE-Installed.*

Equity Policies: *Chicago's updated city ordinance requires at least one EV Supply Equipment-ready space be accessible to people with disabilities per applicable property.*[55]

Baltimore's Standards for Equitable Dockless Vehicle Access require vendors to provide cash payment plans, non-smartphone plans, and low-income plans as a condition of their permit. The city's policy also sets Equitable Distribution Requirements within Equity Zones, which requires permit holders to deploy at least 3 or 4 dockless vehicles in each Dockless Equity Zone by 8:00am each day of service.[56, 57] *The city is regulating through incentive, and could revoke the permit if the vendor does not comply with these equity requirements.*

Attracting Manufacturers and Deployers

The Eno Center for Transportation found that adopting AV policies alone was not enough for most states or cities to attract manufacturers or deployments. They concluded that most AV testing starts near the manufacturers headquarters and expands to new locations that offer:[58]

- Skilled workforce
- Temperate climate (although AV developers who are further along have [begun] testing in severe winter weather)
- Local universities
- Well-maintained roads
- Permissive AV policies
- Various driving environments

From this study, Eno recommends cities prepare for AVs by forming a working group, publishing a statement of principles, and creating a roadmap.

The Maryland CAV Working Group connects and plans at the state level.

Texas has taken the most aggressive approach: by passing legislation that opens their state roads to automated testing and prohibits local governments from passing any rules related to operations of AVs.[59] In addition, Texas offers tax incentives to attract businesses and developments. That's a more aggressive approach to attract than what Eno found would happen naturally. Still, Texas is seeing similar results: the businesses they are attracting are also testing close to their new headquarters home[60].

[55] City of Chicago. Municipal Code §17-17-0251.5.
[56] Baltimore City Regulation 14.02: Dockless Vehicles for Hire. Equitable Distribution Requirements (§ 14.02.01.05.c), Standards for Equitable Dockless Vehicle Access (§ 14.02.01.09).
[57] City of Baltimore. Appendix 2: Equity Zones—Dockless Vehicles for Hire: Rules & Regulations.
[58] Rogers, G., 2018. 3 Ways that Cities can Prepare for Automated Vehicles Today. Eno Transportation Center.
[59] State of Texas. SB 2205.
[60] Dallas Innovates. Kodiak Robotics is Moving to DFW to Make Texas the Home of Self-Driving Trucks

SHARE DATA

CAVs produce detailed data about vehicle performance status that has not been previously available to analysts. These data can support agency decision making related to transportation planning, traffic monitoring and operations, traffic safety, asset inventories and mapping, roadway maintenance, and parking monitoring and policy.

Some of this data may come from the agency's infrastructure or equipment. Other data needs to be requested from industry data vendors. NCHRP *Research Report 952* provides guidance on how to manage data from emerging transportation technologies.[61]

Examples of data that an agency may have that are valuable to industry include:

- Roadway characteristic changes (like work zones and road closures to help CAVs with pre-trip navigation planning to avoid complex or high-risk traffic scenarios)
- Real-time sensor data (like a road weather information system (RWIS))
- Roadway mapping and inventory data
- Curbside management data (like parking restrictions)

Some of this data is easy for agencies to share through partnerships like the Waze for Cities data exchange program.[62] This partnership establishes two-way data sharing between local and state governments, the Waze database, and travelers. Information can be shared about congestion, crashes, work zones, road closures, and special event traffic management.

Maryland's State Highway Administration (SHA) began their partnership with Waze in 2019.[63] Municipalities can also become Waze partner cities.

Pennsylvania DOT provides information on available data feeds that can be used or requested by technology developers, researchers, agencies, or the public. The data includes real-time information on weather, work zones, and traffic incidents.[64]

PLAN FOR MULTIPLE POSSIBLE FUTURE SCENARIOS

CAV technologies and applications are still in the research and development stage. To fully understand the long-term, real-world impacts of CAVs, we need to get them in the hands of the general public to learn how they will be used and what the sustainable price point of service will be. An additional challenge is the need to plan for an evolving vehicle fleet mix. Local and regional agencies need to monitor system performance and trends to learn how CAVs are being deployed, adopted, and used and how they are impacting the region.

Because of this uncertainty, regional planning agencies like BMC need to consider multiple potential future scenarios for long-range planning.

Examples of possible future scenarios for the Baltimore region could include:

[61] Pecheau, K., et al., 2020. *NCHRP Research Report 952: Guidebook for Managing Data from Emerging Technologies for Transportation*. Transportation Research Board, Washington DC.
[62] Waze for Cities, www.waze.com/wazeforcities
[63] CBS Baltimore, 13 December 2019. SHA Partners Up with Waze to Make Driving a Little Easier.
[64] Pennsylvania DOT. Developer Resources.

- CAVs increase roadway capacity by decreasing following distance between vehicles.
- CAVs increase roadway capacity by decreasing delay at intersections by following more efficiently, taking advantage of gaps between vehicles, and reducing delays on green at signalized intersections.
- CAVs increase access to transportation for transportation disadvantaged populations (i.e., elderly, those with disabilities, and lower-income individuals). Shared AV services also improve spatial and temporal equity by filling transit gaps in underserved areas.
- CAVs shift trips to transit if they offer first-/last-mile connections to transit.
- CAVs shift trips away from transit to passenger car trips in a personal or shared ownership model.
- CAVs shift employment and population outside of urban areas because travelers may be willing to travel farther distances in a CAV if their level or stress or value of time decrease in a CAV.
- CAVs are first deployed in freight vehicles causing the capacity improvements to be seen for trucks only or for commercial vehicles. These commercial vehicles could be passenger cars like Uber Eats or DoorDash, cargo vans like Amazon delivery vans, or large trucks like Locomation or Kodiak Robotics.

Many other technologies are changing transportation modes and travel behavior. Agencies also need to consider future scenarios with other emerging technologies, including telecommuting (for work, school, medicine, etc.), micromobility (like e-bikes and e-scooters), and mobility on demand (or MOD) to name a few.

Agencies can find guidance on updating forecasting models from *NCHRP Research Report 896: Updating Regional Transpiration Planning and Modeling Tools to Address Impacts of Connected and Automated Vehicles: Volume 2: Guidance*.[65]

To understand local, real-world trends, agencies need to monitor performance. Local governments can use policies to incentivize or disincentivize trends to align with local goals. Refer to the section on Monitoring Progress for more information.

The North Central Texas Council of Governments was the first planning organization to apply the new CAV capacity adjustment factors from the Highway Capacity Manual 7th Edition[66] to a regional travel demand model. The study simulated three potential future technology scenarios: CAV impact on roadway network performance, CAV impact on intersection performance, and CAV impact on population and employment distributions.[67] The modeling concluded that CAVs alone will not solve future congestion problems, so capacity-increasing strategies will still be needed. The performance metrics studied varied between roadway functional classes and time periods, but under the three scenarios, CAVs were predicted to lead to a general increase in vehicle miles traveled (VMT) and average daily speeds and a general decrease in vehicle hours traveled (VHT) and daily delay.

[65] Zmud, J., T. Williams, M. Outwater, M. Bradley, N. Kalra, and S. Row, 2018. *NCHRP Research Report 896: Updating Regional Transpiration Planning and Modeling Tools to Address Impacts of Connected and Automated Vehicles: Volume 2: Guidance*. Transportation Research Board, Washington DC.

[66] National Academies of Sciences, Engineering, and Medicine. 2022. Highway Capacity Manual 7th Edition: A Guide for Multimodal Mobility Analysis. Washington, DC: The National Academies Press. https://doi.org/10.17226/26432.

[67] Abdelghany, K., B. Paschai, M. Chaney, A. Morgan, L. Liu, 2022. AV2.1 Scenario Evaluation Report. North Central Texas Council of Governments.

PREPARE INFRASTRUCTURE

As agencies upgrade their agency-owned infrastructure and technology, consider both the short- and long-term needs to support CAV operations. Consider the timeline of CAV adoption as well as the impacts of CAVs based on their actual market penetration rate or level of adoption. Also consider the *operational design domain (ODD)* or the "operating conditions under which a given driving automation system or feature thereof is specifically designed to function, including, but not limited to, environmental, geographical, and time-of-day restrictions, and/or the requisite presence or absence of certain traffic or roadway characteristics."[68] For example, low speed automated shuttles with a maximum speed of 25 mph are restricted to low-speed roadways, so infrastructure improvements to support a shuttle's operations can also be limited to the roads along that route.

Roadway conditions and surrounding environment can impact CAV performance. **Infrastructure and land use considerations for CAV operations include**:[69]

- AVs operate best on smooth pavements. Agencies need to work with industry to identify minimum pavement quality thresholds, and agencies need to develop a process for inspecting and repairing or resurfacing roadways that fall below the minimum pavement quality.
- CAV technology benefits from making protected left turns at signalized intersections to reduce the challenge for the automated driving system to assess gaps in vehicular and pedestrian traffic at intersections.
- Narrow lane widths may decrease an AV's operating speed.
- Glass windows, bodies of water, or other reflective objects along the roadside can confuse vehicle cameras.
- Overgrown or wind-blown vegetation along the roadside can confuse vehicle sensors.
- Tall buildings can interfere with communications or GPS signals.
- Some AVs must avoid steep gradients (such as parking garage ramps) due to battery power limitations.
- Due to electric battery range limitations, AVs may require a secure vehicle storage site along the route to reduce deadheading to a distant garage the way fuel-powered transit vehicles can.
- Battery electric AVs will require compatible EV charging infrastructure at the vehicle storage site (e.g., charging speed, type of charging cable connector).
- AV storage sites will require data transfer capabilities and vehicle maintenance services.
- Personal delivery devices (PDDs or sidewalk delivery robots) require pedestrian infrastructure (e.g., curb ramps at intersections, even sidewalk surfaces, sidewalk effective width, need/ability to request a pedestrian phase at traffic signals).

CAV manufacturers are designing their systems to operate in the current transportation environment, which may not have standardized quality or controls (such as pavement markings, pavement conditions, or traffic signal control communications).

The USDOT advises agencies to adopt its *Safe System Approach* for street design, rather than tailoring streets to CAVs.[70] This approach builds in multiple layers of protection for all road users to prevent crashes and reduce crash severity. The 2021-2025 Maryland Strategic

[68] Society of Automotive Engineers (SAE), 2021. J3016 Levels of Driving Automation
[69] Adapted from Ryus, P., A. Morgan, J. Hicks, R. Grosso, S. Laffey, et al., 2022. Automated Vehicle Hosting Handbook for North Central Texas Communities. North Central Texas Council of Governments, Arlington, TX.
[70] USDOT, What is a Safe System Approach?

Highway Safety Plan calls for a safe system approach across the state.

Nevertheless, as agencies systematically maintain and replace assets, they should consider investing in infrastructure improvements that benefit human drivers as well as CAVs (such as clear pavement markings and signage, removal of vegetation that obstructs signs, and pothole pavement maintenance). In 2017, researchers at the University of Texas Austin assessed the following needs for infrastructure and estimated qualitative costs to accelerate the adoption of advanced driver assistance systems (ADAS) that are available on many cars today, as well as CAV applications that are still being developed and tested (See Table 3).[71]

[71] Kockelman, K., S. Boyles, P. Stone, D. Fagnant, and R. Patel, 2017. *An Assessment of Autonomous Vehicles: Traffic Impacts and Infrastructure Needs—Final Report*. Texas Department of Transportation, Austin, TX. https://rosap.ntl.bts.gov/view/dot/31990

Table 3. UT Austin Assessment of Infrastructure Needs to Accelerate the Adoption of ADAS and CAV

AV Function	Infrastructure Need	Infrastructure Cost Impacts
1. Forward Collision Warning	None	None
2. Blind Spot Monitoring	None	None
3. Lane Departure Warning	Lane marks	Low
4. Traffic Sign Recognition	Traffic sign	Moderate
5. Left Turn Assist	Lane marks	Low
6. Adaptive Headlight	None	None
7. Adaptive Cruise Control	None, possible dedicated lane	Depends
8. Cooperative Adaptive Cruise Control	None	None
9. Automatic Emergency Braking	None	None
10. Lane Keeping	Lane marks	Low
11. Electric Stability Control	None	None
12. Parental Control	None	None
13. Traffic Jam Assist	Lane marks	Low
14. High Speed Automation	Lane marks, traffic sign	Moderate
15. Automated Assistance in Roadwork and Congestion	Lane marks, beacons, guide walls	High
16. On-Highway Platooning	Lane marks, traffic sign	Moderate
17. Automated Operation for Military	None	Unknown
18. Driverless Car	Lane marks, traffic sign, lighting	High
19. Emergency Stopping Assistance	None	None
20. Auto-Valet Parking	Parking facilities	High

Source: **Adapted from Kockelman et al. (2017), Table 2.4.**

In 2019, NCHRP Research Program 20-24(112) *Connected Roadway Classification System (CRCS)* developed a framework for local agencies to assess their infrastructure readiness for CAV deployments.[72] It outlines four approaches Infrastructure Owner-Operators (IOOs) could take to prepare their infrastructure for CAVs:

- Leave as is (roads build for human drivers)

[72] Poe, Christopher, et al., 2019. NCHRP Project 20-24(112): Connected Roadway Classification System Development Final Report.

- Add roadway communications (talking with road)
- Enhance roadway for vehicle sensors (seeing the road)
- Adjust geometrics, usage, and control (simplifying the road)

To support a local CAV pilot, agencies should consider **shorter-term updates**, including:

- *Roadway infrastructure* – pavement markings, signage, and updated roadway conditions databases (regulatory signage, road construction, curb management rules, etc.)
- *Routing constraints* – speed limit, lane width, pavement quality, roadway gradient, intersection control type, and surrounding environments can impact CAV performance and route selection
- *Communications infrastructure* – type of communication (such as 5G cellular or a dedicated communication channel), wireless communication bandwidth for data transfer, traffic signal priority controller communication, lane closures, and work zone mapping and messages
- *Data management infrastructure* – data sharing needs; data storage, security, and processing protocols

Longer-term CAV-supporting infrastructure improvements should consider not only CAVs and other future technologies, but also current non-CAV goals such as vehicle electrification needs. Agency **longer-term infrastructure considerations** should include:

- *Traffic signal systems* – When upgrading traffic signal controllers, procure equipment that is compatible with existing systems and supports advanced signal timing strategies, can communicate with CVs, and provides more data ports to support additional components in the future. Upgrade intersection approach detector type, number, or locations to support advanced detection of CAV platoons. Upgrade signal communications to enable vehicle to infrastructure (V2I) to support signal priority requests and signal phase and timing (SPaT) messaging to improve intersection safety and efficiency.
- *Communications infrastructure* – Fiber optic cable and small cell wireless communications are the backbone to data information sharing. CAVs have the potential to generate and request large amounts of useful data about transportation safety, efficiency, and operational performance. Investing in a communications backbone supports advanced transportation management and technology; it also supports social and economic growth for local residents and businesses.
- *Dedicated AV/CV/EV lanes* – Agencies have used dedicated lanes to prioritize or separate transportation modes for efficiency (like a bus-only lane) or safety (like a protected bike lane). Dedicated lanes might be needed to separate platooning CAV passenger cars or CAV trucks. Additionally, dedicated lanes might be needed for lower-speed electric vehicles (like personal delivery devices, e-scooters, e-bikes, and low-speed automated shuttles). If CAVs become the dominant vehicle type, agencies could consider restricting roadways to CAV-only (such as a dedicated freeway or a dedicated transit way).
- *Asset mapping* – High-resolution maps could support CAV operations if they provide information on roadway geometry, number of lanes, lane assignments, regulatory signage, parking or curb-space restrictions, intersection control, etc. However, there is not yet a standardized process for mapping. Agencies could start updating their asset management database and follow future industry guidance on standardized mapping.

When a municipality is ready to sponsor a CAV pilot test, the National League of Cities recommends the following municipal actions:[73]

- Determine the city's goals for pursuing an AV pilot project;
- Build a consortium of federal, state, local, and private partners;
- Engage the private sector as financial partners;
- Look to join or create a regional alliance with other public agencies;
- Scale the pilot appropriately to the resources available;
- Work with the state; and
- Pursue a phased plan.

There have been few public CAV deployments to date, so there is limited guidance on how to prepare infrastructure for CAVs. The Florida DOT plans to develop a CAV Infrastructure Deployment Plan to guide state initiatives.

MONITOR PROGRESS

Performance monitoring supports agency decision making and transparency. Monitoring performance is critical to understand if a CAV pilot met its goals, to understand how the transportation system is performing, and to understand the impacts of CAVs and other transportation technologies on travel behavior, safety, and land use.

For most agencies, the five-year long-range planning cycle was too long to catch changing trends in travel behavior caused first by ridehail services (like Uber and Lyft) and more recently by micromobility deployments (like e-scooters and bikeshare). New technologies are creating new data sources (like GPS data on micromobility devices like shared e-scooters or shared bikes).

Agencies can **monitor the effects CAVs have on the community and the region with respect to long-range regional transportation goals or local planning goals** by tracking the following metrics.[74] To understand if CAVs are equally accessible to all populations or if their impacts are equitable, agencies should track these metrics against underserved populations or areas.

[73] Perkins, L., N. Dupuis, and B. Rainwater, 2018. "Autonomous Vehicle Pilots Across America: Municipal Action Guide", retrieved from National League of Cities website.
[74] Ryus, P., A. Morgan, J. Hicks, R. Grosso, S. Laffey, et al., 2022. Automated Vehicle Hosting Handbook for North Central Texas Communities. North Central Texas Council of Governments, Arlington, TX. Adapted from Exhibit I-10 in Dowling, R. and A. Morgan, 2020. *NCHRP Research Report 924: Foreseeing the Impact of Transformational Technologies on Land Use and Transportation*. Transportation Research Board, Washington, DC.

- *Indicators of travel behavior or travel demand changes:*
    - Average daily ridership by travel mode
    - Average daily vehicle-miles traveled (VMT) by travel mode
    - Average daily passenger-miles traveled by travel mode
- *Early indicator of land use changes:*
    - Permits pulled
- *Early indicators of code and plan problems:*
    - Complaints
    - Code enforcement requests
    - Conditional use permits
    - Zoning variance requests
    - Comprehensive plan amendments
- *Indicators of population or employment shifts or growth:*
    - Population (total, by geography)
    - Jobs (total, by geography)
    - Employed persons (total, by geography)
    - Tax receipts (sales, property, transient occupancy, other)
    - Licenses and permits
- *Indicators of parking demand changes:*
    - Curb/lot/loading zone parking utilization
    - Median price
    - Average parking duration
- *Indicators of safety impacts:*
    - Crash rate per million VMT by travel mode
- *Equity*
    - Median monthly cost of transportation as percentage of median monthly household income
    - Usage by census block/block group/ tract or neighborhood
    - Number of wheelchair accessible vehicles and number of trips
    - Coverage area (geographic equity)

Agencies need to **prioritize key data markers and monitor them annually** to assess the impact of emerging technologies on the system. Data might include market penetration, transit ridership, crash rates, curb space allocation, parking utilization, EV charging utilization, and permits pulled.

Most agencies already track travel demand and safety performance metrics. Some municipalities are starting to track parking utilization and use that data to inform demand-based pricing through programs like SFpark in San Francisco and parkDC in Washington, DC.

TOP TAKE-AWAYS FROM LITERATURE REVIEW

This project will develop specific recommendations for regional and local agencies to take to prepare for the safe, practical, and equitable adoption of CAVs. This literature review identified the following best practices, which will be used as a starting point to develop the specific actions and recommendations for the Baltimore Regional Transportation Board and its member jurisdictions:

1. **Understand the roles and responsibilities of federal, state, and local jurisdictions** as well as the industry in regulating CAVs.
2. **Be agile, avoid technology-specific policies and regulations.** Policies and procedures will need to evolve along with the technology and business models.
3. **Build collaborative partnerships** to develop policies, prepare the infrastructure, and stay on top of technology changes.
4. **Prepare the infrastructure.** In addition to road design best practices, CAVs may require clear signage; well-marked, well-lit crosswalks; and on-road telematics that communicate safety and navigational information with driverless vehicles. For CAVs to receive and transmit information on a mass scale, infrastructure will need to account for broadband connectivity. Broadband connectivity will also support congestion and travel demand management strategies for the entire fleet—not only CAVs.
5. **Centralize data collection and distribution.** Agencies need to learn and adopt new data management practices to collect and analyze Big Data coming from CAVs and other emerging technologies. For example, data storage and analysis will migrate to the cloud because the data sets are too large for local computers to process—unlike most traditional transportation data and analysis. Data can inform decision making and is valuable to both public and private entities.
6. **Plan for an evolving workforce.** There are many needs and opportunities to train agency staff, hire staff with new skills, partner with external experts, and rethink organization structures to break down silos and collaborate across departments. Make workforce development a focus of any new pilot deployment project.
7. **Monitor state of the practice.** Researchers are uncertain as to whether automated vehicle development will improve or exacerbate congestion, sprawl, and inequitable access to travel. It is likely there will be some negative impacts with deployment, particularly with AVs, for example, AVs could have significant consequences in terms of the level of vehicle travel on urban streets, parking, and curb management needs.
8. **Use policies to incentivize real-world impacts that meet local goals.** The outcome will likely be determined by the policies adopted to guide development.

ATTACHMENT: OTHER TECHNOLOGIES CHANGING TRANSPORTATION

The purpose of this project is to develop recommendations on preparing for Connected and Automated Vehicles (CAVs). There are many other new technologies that continue to change how we travel, when we travel, the cost of travel (time or money), or replacing the need to travel at all (like teleworking or telemedicine). Emerging technologies, some intrinsically linked to CAVs, that are transforming the transportation industry, are briefly introduced below and should be monitored and planned for.

Emerging Technology	Key Considerations	Opportunities	Examples of what are others doing
Electric Vehicles (EV) Vehicles powered from batteries, fuel cells burning hydrogen, or hybrids using gasoline engines to supplement the electric motor or battery.	Incorporate EV charging needs in local planning efforts such as master, capital improvement, climate action, transportation improvement/long-range transportation, active transportation, and utility master plans, and building and zoning codes to address implementation, roles and responsibilities, anticipated challenges, and expected costs to deploy and support EV charging.	• Develop EV Readiness Plan – include utilities in process • Implement EV-ready building codes and streamlined permitting processes • Develop EV parking requirements	**City of Alexandria, VA. EV Charging Infrastructure Readiness Strategy**. Includes recommended locations for public charging and audits of zoning and building codes to ensure support for developing charging stations. **City of Middletown, CT. Building/Parking Codes**. Mandates new developments have 25 or more parking spaces to provide either Level 2 or DCFC (fast) charging stations or connections to a minimum of 3% of these spaces; additional EV charging spaces provided can reduce the total number of spaces which must be developed.
Urban Aerial Mobility (UAM) Carrying passengers or cargo by air at lower altitudes within urban and suburban areas.	UAM creates opportunities for passenger and freight mobility and could increase the capacity, safety, and efficiency of urban transportation systems. A network of locations where aerial vehicles can take off and land will need to be established. Noise and visual impacts will also need to be addressed.	• Monitor progress and plan for infrastructure needs • Consider how local regulations may impact UAM • Provide policy recommendations and comments to the FAA and state government	**FAA NextGen Office. Concept of Operations for Urban Air Mobility.** Describes the operational environment to support the expected growth of flight operations. UAM_ConOps_v1.0.pdf (nasa.gov) **Frisco, Texas, Pilot Store-to-Door**. Wing is partnering with Walgreens to pilot "store-to-door", on-demand aerial delivery. Wing Drone Delivery | Frisco, TX - Official Website (friscotexas.gov)
Highway Systems Technologies Devices used to gather and disseminate data about the status of roadways and transit systems. Devices process data in situ, immediately using that information to dynamically adjust control or devices or they send data to a remote location or private entity for processing.	Increased access to detection devices can lead to decision paralysis when considering which data to purchase, use, or share. Additionally, upgrading all devices across the network simultaneously is not practical or cost effective, potentially creating interoperability challenges.	• Develop plan to prioritize what data is needed to inform decisions related to specific goals and objectives • Develop communications standards and specifications as devices are upgraded to ensure interoperability across devices	**US Federal Highway Administration Highways for Life Initiative - Technology Partnerships Study.** Evaluates safety benefits of a solar-powered traffic signage system designed to minimize crashes on horizontal curves. Approaching vehicles, sensed by radar or other ITS device, trigger the controller that wirelessly activates the LED signs to flash sequentially to warn speeding drivers to slow down. Participating State DOTs include Missouri, Texas, Washington, Wisconsin, and Colorado. Learn more about Highways for Life Technology Partnerships here: https://www.fhwa.dot.gov/hfl/partnerships/ **North Central Texas Council of Governments. "Data Lake" Deployment**. Will allow for sharing of detection information across the region and state. This will enable control devices in a neighboring jurisdiction upstream of the detector to use the data and respond appropriately.

Emerging Technology	Key Considerations	Opportunities	Examples of what are others doing
			Los Angeles, CA. Regional Integration of Intelligent Transportation Systems – The Los Angeles Metro136 system supports real-time data sharing between freeway, traffic, transit, and emergency service agencies to improve management County transportation system.
Curb Space Management Technologies Increase the curb's functionality and improve safety and access for users - personal vehicles, transit, ride-hailing services, commercial deliveries, mobile vendors, emergency services, parking, electric vehicle charging, bicycle and pedestrian infrastructure, local businesses, and streetscape elements.	Demand for curb space continues to increase and there is a lack of real-time data on curb use.	Evaluate and define strategies for curb allocation and associated fees, technology, and partnerships. • Create a digital curb inventory • Collect data to understand curb activity • Launch a pilot program - test what types of treatments will work and how the public might respond • Consider Curbside Flex Zones – shared use mobility zones	**Omaha, NE Smart Loading Zones Pilot.** An app that provides drivers for delivery and service providers like UPS and Uber Eats incentive to load in designated locations where it is safe, efficient, and legal — all while collecting data for the city. **Boston, MA Ride Hailing Pick Up and Drop Off Zone Pilot Program**. Converted parking spaces to pick up and drop off zones in the evenings to better manage congestion I the Fenway neighborhood. Learn more here: https://www.planning.org/planning/2021/winter/manage-the-curb-with-smart-loading-zones/
Integrated Mobility Technologies Mobility as a Service (MaaS) emphasizes mobility aggregation, smartphone and app-based subscription access, and multimodal integration (infrastructure, information, and fare integration) and Mobility on Demand (MOD) emphasizes both personal travel and goods delivery as it relates to commodified transportation services.	Integrated mobility applications are most productive and cost effective in urban and suburban areas with higher density development. Policies and regulations should address equity issues, such as access for people with disabilities, unbanked and underbanked users, and people without access to smartphones or mobile internet. Standardizing technologies, security and privacy, and open data standards are needed to support multimodal integration.	• Establish data management procedures that protect customer privacy and proprietary data generated by mobility providers • Performance measures should be established to monitor progress in safety, mobility, affordability, accessibility, and other key policy goals	**Federal Transit Administration Mobility on Demand Sandbox Program.** Demonstration projects and evaluation reports for MOD concepts, such as planning and developing business models, obtaining equipment and service, acquiring/developing software and hardware interfaces to implement the project, and operating the demonstration, can be viewed here: https://www.transit.dot.gov/research-innovation/mobility-demand-mod-sandbox-program
Big Data Low-cost sensors and personal data-sharing devices that have	Data are too large and varied, and will change too rapidly to be handled by traditional data	• Develop a data management framework that allows for partnerships with others to	**NCHRP Research Report 952. Guidebook for Managing Data from Emerging Technologies for Transportation**. https://www.trb.org/Main/Blurbs/180826.aspx

Emerging Technology	Key Considerations	Opportunities	Examples of what are others doing
increased the volume, speed, and granularity of data available.	systems. Additionally, agencies may not have the resources to manage data at an organizational level. Many third-party solutions for data and data storage are based on subscription services rather than one-time purchases which can lock agencies into proprietary data vendor solution.	collect, maintain, and analyze data • Develop cybersecurity plans to protect assets and data • Budget and plan for ongoing data and staffing needs	Public agencies in Chicago and Portland, and other cities have established ordinances and other regulations requiring TNCs to share activity data to understand how their operations may be affecting transportation infrastructure. **Waze Communities Partnerships and Work Zone Data Exchange (WZDx).** Has programs as a means of sharing information across boundaries Driving Directions, Traffic Reports & Carpool Rideshares by Waze
Micromobility Small, lightweight vehicles operated by users at speeds typically below 20 mph - both human-powered and electric bicycles, scooters, skateboards, and cargo bikes	Providers are deploying adapted designs, such as hand-powered pedal bikes, electric-powered wheelchair assist, seated scooters, and seated tandem bikes, to increase accessibility for people with disabilities.		**Baltimore, MD. "Dockless Vehicle Pilot -Equity Zones."** Created geofenced zones and set requirements for the minimum number of devices that a vendor must provide within each zone. To address the logistics and emissions of retrieving dockless electric vehicles and redistributing them after charging, providers are piloting dispersed infrastructure to charge batteries and swap them out on the grid network (by trained technicians) in Russia and parts of Europe.