North Central Texas Council of Governments

KITTELSON & ASSOCIATES

AUTOMATED VEHICLE HOSTING HANDBOOK

FOR NORTH CENTRAL TEXAS COMMUNITIES

September 2022

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PREPARED FOR:

North Central Texas Council of Governments

616 Six Flags Drive

Arlington, TX 76011

PREPARED BY:

Kittelson & Associates, Inc.

100 M Street SE, Suite 910

Washington, DC 20003

202.450.3710

PROJECT MANAGER:

Abby Morgan, PhD, PE

Associate Engineer

PROJECT PRINCIPAL:

Gibran Hadj-Chikh

Senior Principal Planner

AUTHORS:

Paul Ryus, PE, Abby Morgan, PhD, PE, John Hicks, AICP, Rachel Grosso, Sean Laffey, PE, Richard Dowling, PhD, PE, Shannon Warchol, PE, Alek Pochowski, PE, Gibran Hadj-Chikh, (Kittelson & Associates); Darcy Bullock, PhD (Purdue University)

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01 INTRODUCTION

Technology impacts all aspects of transportation, and these technologies are ever evolving. North Central Texas communities will need to incorporate emerging technologies into the transportation planning process.

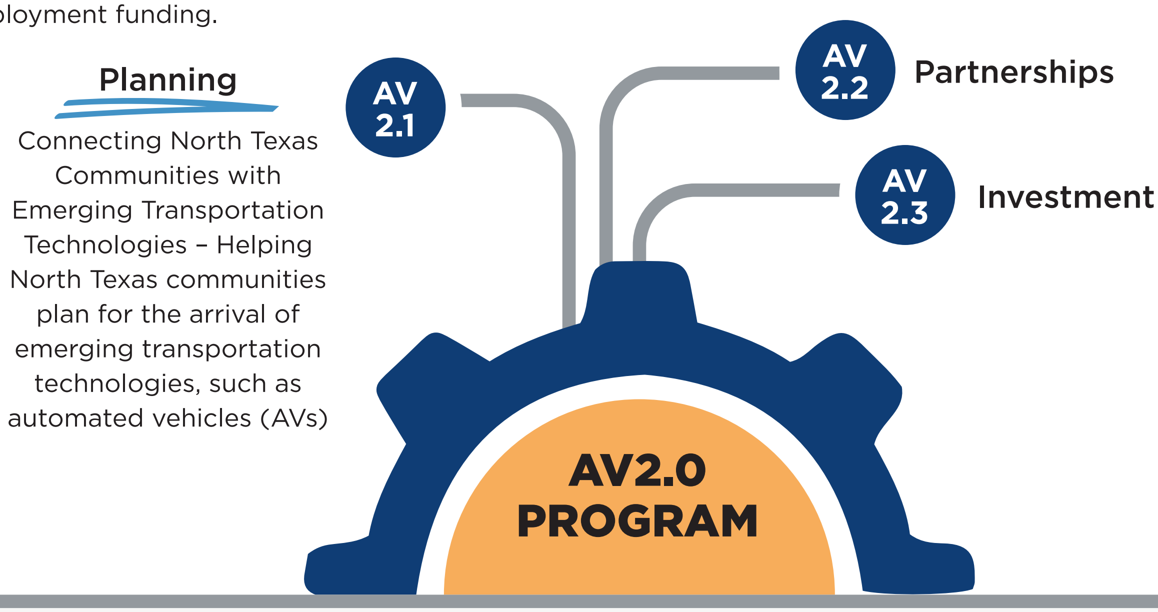
WHAT IS THE PURPOSE OF THIS HANDBOOK?

Automated transportation solutions are part of the long-term transportation strategy for North Central Texas Council of Governments (NCTCOG).

NCTCOG is preparing for emerging transportation technologies through a three-phase Automated Vehicle 2.0 (AV2.0) program. AV2.0 will advance the North Texas region through planning, partnerships, and investment into new transportation technologies like automated vehicles (AVs).

The first phase of the AV2.0 program is AV2.1: Conduct a Planning Process to Help the North Texas Region Prepare for Automated Transportation & Related Technologies. This project will develop guidance for local agencies to proactively plan for the effects of emerging transportation technologies. This understanding and readiness will help the region design successful pilots and apply for federal, state, or local deployment funding to deploy or support new technologies.

The other phases, AV2.2 and AV2.3, support the advancement and adoption of automation through pilot deployment funding.



WHAT IS THE CURRENT STATE OF AV TECHNOLOGY?

New technologies are transforming 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). These changes to travel patterns and behaviors can lead to changes in land use patterns (such as where people live or work, or the locations of freight distribution centers).

Some transformational technologies are in use today and are already impacting travel behavior and land use patterns. For example, many North Texas residents, students, and employers quickly adopted telework or virtual learning due to the COVID-19 pandemic. Some technologies are in pilot phases (such as TxDOT's Connected Freight Corridor, Arlington's RAPID AV ride-hail program, Wing's drone delivery pilot, and sidewalk delivery robot pilots on several college campuses in the region). Some technologies will require local government support (such as Dallas' e-scooter and e-bike micromobility pilot) or government funding and incentives (such as electric vehicle charging infrastructure deployment).

Despite the media hype surrounding automated vehicles, most of the technology is still in the development and pilot testing phase. Most pilots have been temporary, and none are cost-sustainable yet. Nevertheless, automated vehicles could create opportunities for access to new travel options for people who cannot drive; they could help to improve the safety, affordability, and environmental efficiency of transportation; and they might help to improve roadway capacity by reducing delay at intersections or following other vehicles more efficiently than humans can.

WHAT DO CITIES NEED TO KNOW ABOUT AVS?

Cities need to understand that **technology is changing rapidly**. As a result, the planning process should be flexible to adjust to changing technologies, business models, regulatory frameworks, and market conditions. Cities and local agencies should focus on planning for applications of technology, rather than specific technologies, which may change over time.

Additionally, cities need to understand that **AVs alone will not solve the region's future congestion problems.** Additional travel demand management and capacity increasing strategies are needed to meet current and future transportation needs.

Public investment is needed to incentivize some emerging technologies (such as expanding electric vehicle charging stations). Public investment might also be needed to support technologies like automated vehicles (such as maintenance costs to update poorly maintained pavement, lane marking or crosswalk striping, and signage).

By engaging with residents through public meetings and focus groups, we learned that North Central Texas communities are concerned about the amount of traffic, delays from construction and train crossings, few transportation options, and access to high-speed internet. Younger respondents are more willing to consider using the emerging technologies. As household income increased so did the willingness to use emerging technology.

HOW CAN CITIES PREPARE FOR AVS?

There is a lot of uncertainty surrounding the timeline, cost, and uses of automated vehicles. This leads to many potential scenarios that we might see in the future. Currently, planners do not have enough data to assign probabilities to potential future scenarios. To start preparing for AVs, cities can:

- Lay the groundwork early. Engage with stakeholders to understand common challenges, build partnerships, and establish strong relationships to deliver transportation access needed today while preparing for future technological changes.
- Develop AV goals that address local transportation problems. Agencies should use technology as a tool to address local problems, rather than finding a solution and then looking for a problem.
- Manage the increase in the quantity of data. Public agencies will need to develop new data management approaches to collect, analyze, manage, share, and utilize data to understand and improve the transportation system.
- Plan for multiple possible future scenarios. Many technologies are still in the research and development stage. Until the technologies are in the hands of the general public in real-world use, and until the sustainable price point of the new technologies or services is known, the long-term, real-world impacts of emerging technologies remain unknown. Agencies need to consider multiple potential future scenarios and monitor system performance and trends to learn how these new technologies are impacting the region.
- Collect data and monitor performance from real-world deployments to determine if future scenario assumptions in the regional travel demand model are correct or need to be revised.
- Actively engage with local communities to understand their needs and to learn if technologies are helping to solve problems or if technology is unintentionally creating new barriers.

EXAMPLES

The North Central Texas region is a leader is supporting automated transportation technology testing and deployment. Some of the pilot deployment projects in the region include:

Local agency automated mobility pilots in North Central Texas include:

- Frisco Drive.ai Automated Vehicle Pilot
- Arlington Milo Low-Speed Automated Shuttle Pilot
- Arlington Drive.ai Automated Vehicle Pilot
- Aurora autonomous ride-hailing fleet testing to prepare for 2024 deployment

Established long-term deployments in North Central Texas include:

- Arlingon RAPID Automated Microtransit Pilot with Via
- Skylink - DFW Airport Automated People Mover

Automated freight testing and commercialization efforts in North Texas include:

- Kodiak Robotics, TuSimple, Aurora, Einride, Embark, and Waymo are developing and testing automated trucking in the Texas Triangle (triangle formed by the state's four main cities, Austin, Dallas-Fort Worth, Houston, and San Antonio.
- Starship Robotics sidewalk delivery bots are being tested by UT-Dallas to deliver in Frisco, Plano, and Richardson, and Southern Methodist University in Dallas.
- Gatik has expanded autonomous truck operations to Texas, focusing on moving goods from large distribution centers to retail locations.[1]
- AllianceTexas' Mobility Innovation Zone (MIZ) provides a facility for testing and innovation of many new technologies, including automated trucking and unmanned aerial system (UAS) testing.[2]

Additionally, NCTCOG recently awarded local deployment projects under the AV2.2/2.3 program.

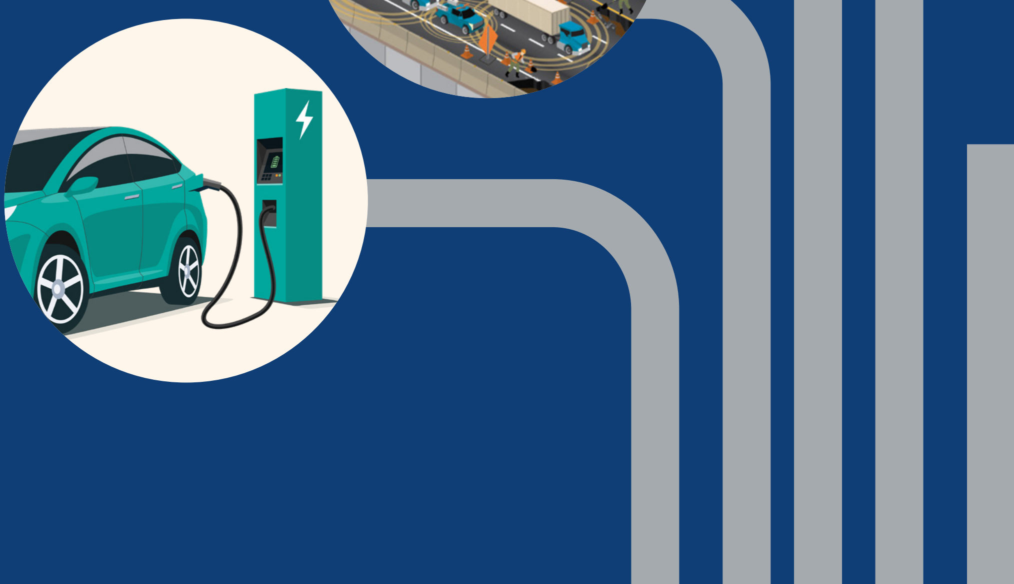
In addition to automation, NCTCOG is preparing for emerging technologies by:

- Collaborating on TxDOT's Connected Freight Corridors Project.
- Leading a **Freight Optimization Project** to improve freight flow.
- Standardizing work zone reporting using the **Work Zone Data Exchange** Specification.
- Utilizing **connected vehicle data**—especially video—that is curated using A.I. to improve roadway maintenance, operations, and safety.
- **Advancing electrification** to support automated vehicles.
- Calming traffic, **creating safer streets for all people**, including for bicyclists and pedestrians, that will improve operational environment for automated vehicles.
- Leading **Uncrewed Aircraft System (UAS)** education, planning, and pilots.

The US Department of Transportation (USDOT) provides guidance including:

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

More information on automated vehicles is available on the NCTCOG AV2.1 project website: **www.connectntxfutures.org/Resources**.



Check out topic infographics at https://www.its.dot.gov/infographs/

HOW IS THIS GUIDEBOOK ORGANIZED?

Ch 4 – Building Partnerships
Guidance on building partnerships with AV vendor and service providers.

Ch 3 – Developing Policies
Guidance for developing local policies to help shape the benefits of AVs .

Ch 2 – AV Applications
Background information on available technologies.

Ch 5 – Sharing Data
Guidance on sharing data from emerging technology pilots and permanent deployments.

Ch 6 – Preparing Infrastructure
Guidance on preparing an agency's infrastructure as technologies evolve.

Ch 7 – Workforce Training
Guidance on providing an understanding of and expertise with AV technology to the agency's and region's future workforce.

Ch 8 – Monitoring Progress
Guidance on monitoring trends and impacts from new technologies compared to agency goals.

AV HOSTING BEST PRACTICES HANDBOOK

02 AV APPLICATIONS

This section defines "automated vehicles" and related terms, introduces different types of AVs and the technologies that make AVs possible, and describes potential use cases for AVs.

When envisioning the AV2.1 program, NCTCOG used the following terminology:

"Automated Vehicle" or "AV" refers to both connected and autonomous vehicles. The term is inclusive of technologies that are precursors to the introduction of AVs, such as emerging modes of micromobility and rideshare, and related to AVs, such as vehicle-to-infrastructure technology.

DEFINITIONS

AUTOMATION

Automation is the "use of electronic or mechanical devices to operate one or more functions of a vehicle without direct human input." [1]

Virtually any type of vehicle—for example, personal vehicles, trucks, buses, mobility scooters, or aerial drones—has the potential to incorporate automation functions. However, the adoption of automation will likely occur faster for some vehicle types and use cases, due to greater potential for cost efficiencies; fewer technological, legal, or liability challenges; or other reasons.

Automation can provide a driver-support role, where it assists a person in driving the vehicle, but the person must supervise the automated feature and perform other driving functions. For example, an adaptive cruise control system uses on-board sensors, such as radar, to detect the distance to the vehicle ahead. The system then makes decisions to slow the vehicle down if needed to keep a safe following distance, or to accelerate and then maintain the maximum speed set by the driver when no vehicle is ahead. The human driver must be prepared to brake for other reasons, such as a red light, and must perform many other driving functions, such as steering, changing lanes, and observing conditions ahead, behind, and alongside the vehicle using the vehicle's mirrors and/or cameras.

Automation can also perform all of a vehicle's driving functions, either under specific conditions, or under any condition. For example, automated passenger shuttles have been demonstrated that operate on-street without a human driver, but only at low speeds, on pre-determined routes, and with an operator on board to monitor vehicle operation and intervene when necessary. Driverless rail vehicles have been used in transit applications for decades, such as the automated trains that connect terminals in many large airports (e.g., SkyLink at DFW Airport), and the high-capacity automated metro lines found in many cities worldwide. On-street automation is not as advanced as fixed-guideway or rail automation due to the complexity of interacting with other vehicles, pedestrians, and cyclists, sometimes in unpredictable manners.

CONNECTIVITY AND CONNECTED VEHICLES

Connectivity is the wireless sharing of information between vehicles, roadside infrastructure such as traffic signals, other road users such as pedestrians or cyclists, and/or remote infrastructure or services such as traffic management centers or cloud-based navigation services.

Connected vehicles (CVs) receive data sent by other vehicles, infrastructure, and/or services to assist a person with performing driving functions, such as navigation. CVs can also send data the other way, for example, to provide vehicle speed information that traffic managers and navigation services can use to monitor roadway conditions.

Connected and automated vehicles (CAVs) use a combination of on-board maps and sensors, two-way communication, and software to perform most or all of a vehicle's driving functions, to interact with nearby vehicles and infrastructure, and to provide status information to remote infrastructure and services.

VEHICLE TECHNOLOGIES

ON-BOARD SENSORS

A variety of sensor technologies are in use today on-board AVs. These sensors collect information about a vehicle's immediate surroundings that the vehicle's computer then uses to help make decisions about how to perform the driving functions it controls.

Examples of sensor technologies include:[2]

- **Cameras** (visible light and infrared) are used for detecting the presence of nearby vehicles, persons, and objects. When combined with computer-vision technology, the vehicle's computer can process the camera image to identify the type(s) of object(s) being detected and to "read" traffic signs, traffic signals, and pavement markings.
- **Radar** emits radio waves and senses the waves reflected back to the vehicle. It is used to detect the presence of objects, along with their distance from the vehicle and their speed relative to the vehicle.
- **Lidar** operates using similar principles as radar, but senses reflected laser pulses instead of radio waves. It can create a 360-degree map of the objects around the vehicle and computer-vision technology can be used to identify the types of objects.
- **Ultrasonic sensors** use reflected sound waves to detect objects very close to the vehicle.

The more complex the driving functions an AV is capable of, the more types of sensors an AV is likely to have, both to allow the AV to perform more functions and to provide redundancy, where one sensor type compensates for the weaknesses of another sensor type. For example, radar and lidar can detect objects at night that a visible-light camera might miss.

Importantly, all of these sensors work on a line-of-sight basis. If there is a truck in front of an AV, for example, none of these sensors would be able to detect objects directly in front of the truck, because the truck would block the sensors' forward field of view. (A possible exception are radar sensors, which are often mounted lower on an AV, and which might be able to partially "see" ahead under the truck's higher ground clearance.)

POSITIONING SYSTEMS

Positioning system technology helps an AV determine where it is. Examples of this technology include:[3]

- **Global positioning system (GPS)** antennas receive the signals sent by different GPS satellites. The GPS system processes these signals to determine the vehicle's position on Earth with relatively high accuracy.
- **Inertial positioning systems** use on-board equipment such as accelerometers, gyroscopes, speedometers, and altimeters to continuously calculate the vehicle's speed, acceleration, horizontal direction, vertical angle (e.g., uphill or downhill), and altitude. The vehicle's computer can use this information to determine the vehicle's current position relative to a known starting point.

GPS and inertial positioning systems complement each other. GPS signals can be reflected off of tall buildings, resulting in lower accuracy in the centers of large cities, and the signals can be completely blocked by tunnels, parking garage structures, and the like. Inertial systems are better at measuring movement over very short time intervals, as well as a vehicle's altitude (e.g., whether a vehicle is located on an overpass or underneath it, or an aerial drone's height above ground level).

DATABASES

A variety of databases can help an AV navigate its environment, anticipate upcoming changes in conditions, and help comply with traffic laws. Examples of the types of databases that could be incorporated into an AV include:

- **Large-scale maps** of the roadway network, including information about speed limits, vehicle restrictions (e.g., truck height or weight limits), tolls, etc. The vehicle's computer can use this information to plot driving routes from any origin to any destination.
- **Detailed maps** of a specific area, such as a freight yard or the route used by a low-speed passenger shuttle. These maps can provide the exact locations of stops, obstacles, and other positional information required by the automated driving system.
- **Curbside usage databases** indicating where passenger and freight loading and unloading is allowed. Automated ride-hailing and freight delivery vehicles could use this information to more efficiently route themselves to a location near their destination where they can legally stop, and to identify an alternative stopping location if the first choice turns out to be completely full when the vehicle arrives.
- **Curb ramp and traffic signal location databases** could be used by automated sidewalk delivery robots (also known as personal delivery devices, PDDs) or mobility scooters to route themselves safely to their destination.
- **Airspace databases** could be used by aerial drones to avoid prohibited airspace (e.g., around airports), to maintain safe vertical and horizontal distances from obstacles, and to identify approved landing areas.

COMMUNICATIONS TECHNOLOGY

Although communication technology is not a requirement for an AV, the ability to receive and/or transmit information can greatly expand an automated driving system's capability. Communication technology can be divided into two groups: technology that supports applications requiring continuous, high-speed communication, and technology that supports applications that require only occasional communication.

Examples of communication technologies include:

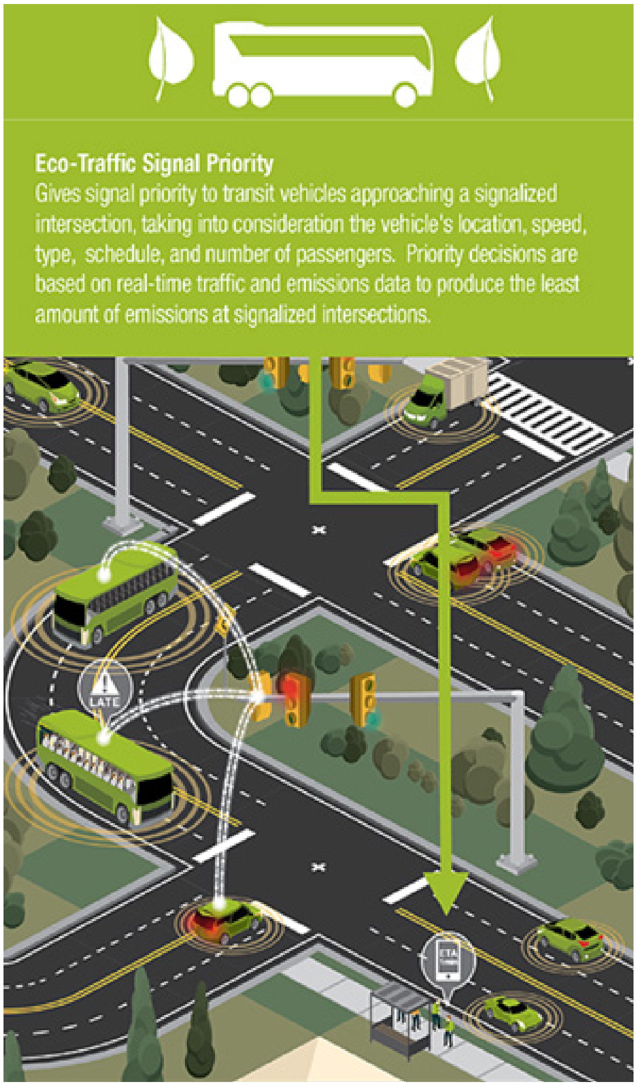
- **Dedicated short-range communication (DSRC)** provides continuous, near-instantaneous communication between AVs, including vehicles beyond an AV's direct line of sight. DSRC supports cooperative-driving applications, such as vehicle platooning and cooperative lane-changing and merging, as well as providing advance warning of potential hazards in the AV's vicinity but not yet in its line of sight.[4] However, the Federal Communications Commission (FCC) decided in 2020 to phase DSRC out of transportation communication and to reallocate its spectrum to cellular vehicle-to-everything (C-V2X) and unlicensed uses (e.g., Wi-Fi).[5]
- **Broadband cellular (e.g., 5G, C-V2X)** can today support applications that do not require an instant response, or any response at all, taking advantage of the existing cell tower network. Potential applications include an AV notifying a traffic signal controller of the vehicle's approach to the intersection (to influence the controller's signal timing decisions) or notifying a traffic management center about roadway hazards (to enable notifications to other AVs and to dispatch a maintenance crew).[6] Applications requiring very low latency (e.g., emergency braking notifications, vehicle platooning) require direct device-to-device (D2D) communication that avoids the need for relaying messages through a cell tower or base station. Standards to support these applications are still evolving. D2D technology using 5G will need to address its relatively short communications range and potentially high vehicle densities and speeds. The combination of these factors will require a connected vehicle to frequently and rapidly update its information about the other vehicles within its communications range and the radio frequencies they are using.[7]

- **Personal electronics wireless technologies (e.g., Wi-Fi, Bluetooth)** could be used to update the vehicle computer's operating system or databases while the vehicle is parked at its home base.

Transit signal priority is an example of how communications technology is currently being used to improve bus speeds and schedule reliability. However, it is also an example of how all the technological pieces need to work together seamlessly to provide the desired functionality. The general idea of transit signal priority is that an on-board computer continuously monitors the bus's location. When the bus approaches a traffic signal, a priority request is sent to the signal controller. The signal controller then decides whether priority can be granted, based on rules programmed into the controller. If priority is granted, the signal remains green long enough for the bus to make it through the intersection, or turns green sooner if the signal was already red.

Depending on how the system is implemented, transit priority can be requested from the bus directly to the signal controller at the next intersection, or indirectly from a central bus dispatching system that tracks bus locations and sends requests as needed to a central traffic signal system, which then processes, and relays approved requests to the appropriate intersections. A variety of vendors produce system components, which are not always compatible with each other. This can result in buses that can communicate with traffic signals in one city but cannot do so once they cross into another city, due to incompatible equipment or the lack of necessary equipment in the signal controller to receive and process priority requests. Tens of thousands of detection, control, and information devices exist across North Central Texas. Interoperability of devices is important. Agencies should develop and implement communications standards as devices are upgraded to ensure interoperability across devices.

Transit Signal Priority (USDOT)



All the technological pieces need to work together seamlessly to provide the desired functionality.

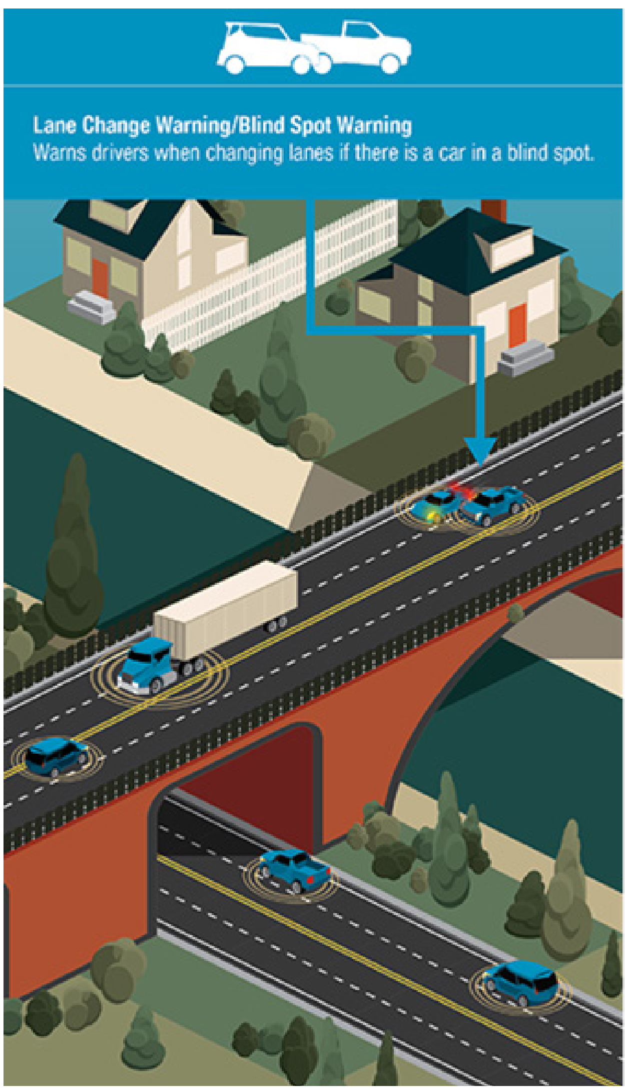
ON-BOARD COMPUTING SYSTEM

The vehicle's on-board computing system processes the data received from its on-board sensors, positioning systems, and communication systems, along with drawing from the data stored in its databases. The computer then uses this information to make instantaneous decisions about how to perform its driving functions and how to react to changes in its surroundings.

Automated driving functions that potentially can be controlled by an AV's on-board computing system include the following:[8]

- **Warnings and emergency assistance**: lane departure warning, blind spot warning, forward collision warning, automatic emergency braking (Figure below).
- **Driver support features:** lane centering, adaptive cruise control, parallel parking assist.
- **Autonomous driving:** under limited conditions, with the human driver taking over when the conditions no longer exist (e.g., traffic jam, chauffeur); when the vehicle is restricted to operating within specific environmental conditions, traffic conditions, and/or roadways (e.g., local passenger shuttle); or in any condition.

Blind Spot Warning & Forward Collision Warning (USDOT)



POWER

Although an AV can in theory operate with any power source, several factors suggest that AVs primarily will be electric vehicles. One reason is the move of the automotive industry worldwide toward electric vehicles as a means to address the emissions and greenhouse gas impacts of gasoline- and diesel-powered vehicles. Another reason is energy efficiency. It is more efficient to operate an AV's on-board technology directly from electricity, rather than burning gasoline to generate electricity.[9] In addition, direct motors and electronic valves are more efficient than mechanical powertrains and hydraulic or pneumatic systems (e.g., brakes, electronic stability control).

EVs may get their power from batteries or fuel cells burning hydrogen. Some motor vehicles may be hybrids, using gasoline-powered internal combustion engines to supplement the electric motor and/or the battery.

As of 2019, there were 1.2 million EVs on the road in the US. Sales of EVs in the US that year accounted for less than 2% of new car sales in the US; however, the number of EVs sold in the US soared 80% between 2018 and 2019.[10] Under current public policies, the International Energy Agency (IEA) anticipates EVs reaching 7% of the global vehicle fleet by 2030.

Toyota has a large presence in the North Central Texas region with its North American headquarters in Plano, and it is considering building a new $1.29 billion factory for hybrid and fully electric vehicles in the state.[11] General Motors is also planning to build a new EV factory in Fort Worth, with production starting in 2023.[12]

Tesla has built its second US manufacturing plant, Gigafactory Texas, in Austin. It started production on Model Y cars in late 2021,[13] and will expand production in 2022 to Tesla's Cybertruck, the Semi, and Model 3 cars.[14]

Electric vehicle manufacturers Polestar and Karma also have dealerships and Kandi automotive has a headquarters in Dallas.

Dallas-Fort Worth Clean Cities Coalition provides electric vehicle registration data by vehicle model, county, and city in North Texas. As of March 29, 2022, there are 43,072 electric vehicles in North Texas. Westlake, Texas has the highest percentage of all registered vehicles in a city with 5.56%

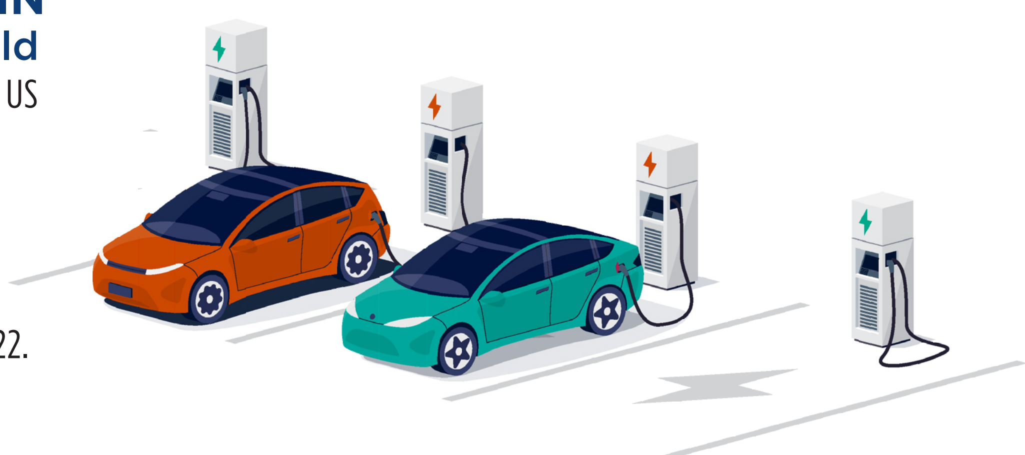
VEHICLES

PASSENGER CARS

Some advanced safety technologies are available today in passenger cars. Advanced driver assistance systems are standard or optional features on many new passenger vehicles. Technologies such as lane keeping assist, blind spot warning, forward collision warning, and automatic emergency braking help drivers avoid crashes or slow down to reduce the severity of a crash.

80% INCEASE IN
electric vehicles sold
between 2018 and 2019 in the US

Over **43,000**
electric vehicles
in North Texas as of March 2022.

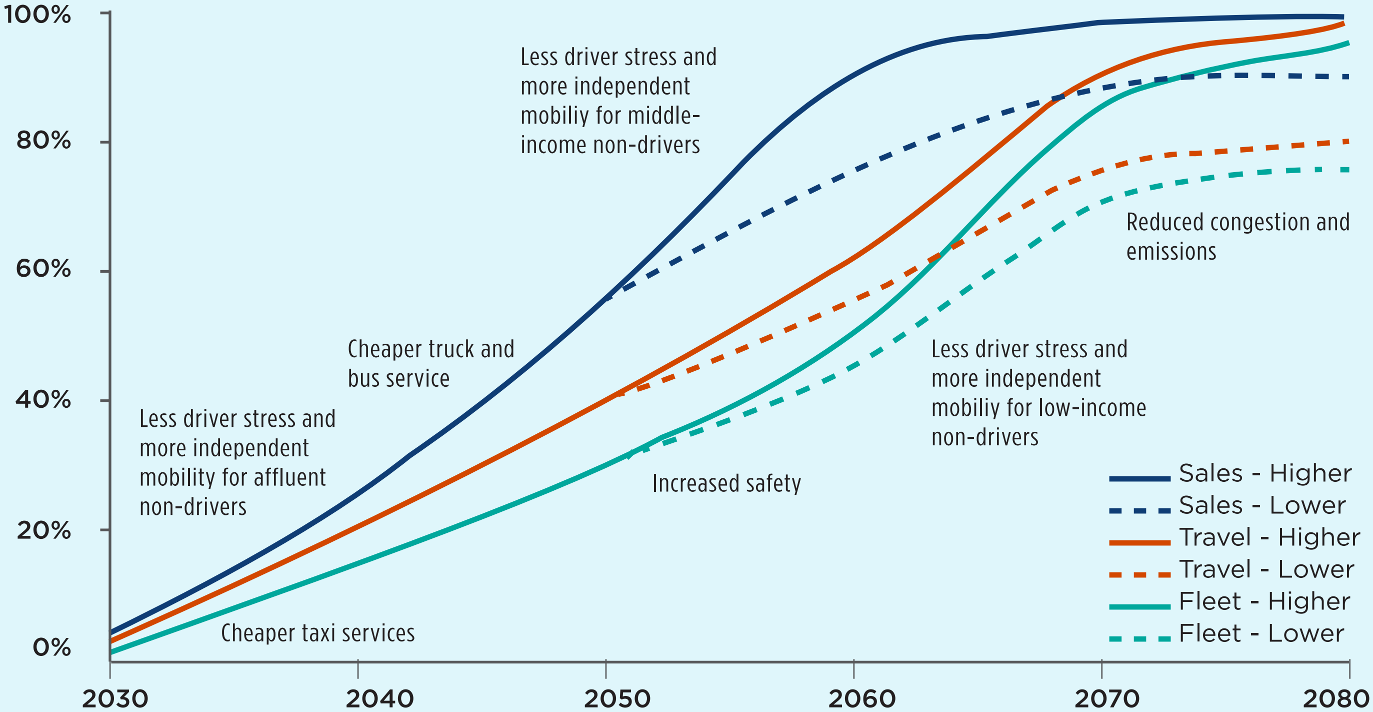


High levels of automation are being tested only in fleet use. Automation testing without driver input is being conducted mostly in highway driving applications or low-speed, suburban applications. However, some testing is starting that focuses on rural roads and dense urban streets. Currently, no highly automated vehicles are available for purchase by members of the public.

AV Market Penetration Projections graphic below shows a conservative, yet realistic, forecast for AV sales, travel, and fleet adoption in the US.[15] Researcher Todd Litman (Director, Victoria Transport Policy Institute) anticipates that AV applications for personal travel that impact safety and mobility may not be achieved until 2035-2060 when AV fleet penetration rates near 40%. This is the horizon timeframe that transportation decision-makers are currently planning for. Starting from when AVs become available, it may take another 40 years or more until we see high fleet penetration rates of AVs that could increase roadway capacity to reduce congestion or vehicle emissions.

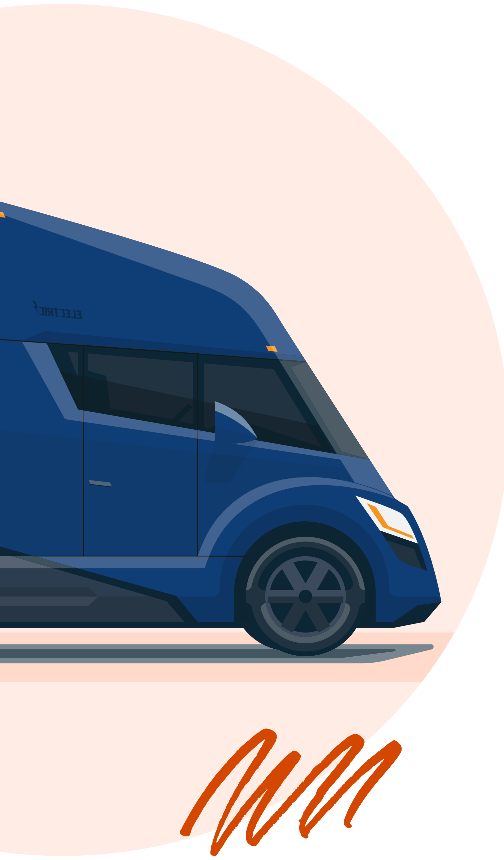
The greatest uncertainty in planning for AVs today is the sustainable price for these technologies. To be transformational, AVs will need to offer service that is faster, cheaper, more reliable, or more accessible than a traveler's current modes of transportation. Another unknown for AV planning is the ultimate use cases (e.g., will AVs be individually owned or used only by fleets like robotaxis).

AV Market Penetration Projections



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.

Source: Todd Litman (2022). Autonomous Vehicle Implementation Predictions: Implications for Transport Planning. Victoria Transport Policy Institute.



TRUCKS

The trucking industry may be an early adopter of automation. As with other fleet applications, automation is attractive to freight shippers because of its cost-savings potential from improved vehicle utilization of and increased fuel efficiency.[16] In addition, removing the human driver allows a truck to stay on the road for longer periods of time, as human drivers have legal limits on the amount of "in service" time they can operate a commercial vehicle before taking an extended rest or sleep break.

The AV-friendly regulatory environment in Texas and its large freight hubs attract AV developers to test their automated fleets in Texas.[17] Dallas-Fort Worth is a hub for a number of AV truck fleet companies. Automated freight testing and commercialization efforts in North Texas include:

- Kodiak Robotics, TuSimple, Aurora, Embark, Einride, and Waymo are developing and testing automated trucking in the Texas Triangle (the region between Dallas-Fort Worth, Houston, and San Antonio).
- Gatik has expanded autonomous truck operations to Texas, focusing on moving goods from large distribution centers to retail locations.
- AllianceTexas' Mobility Innovation Zone (MIZ) provides a facility for testing and innovation of many new technologies, including automated trucking and unmanned aerial system (UAS) testing.

PUBLIC TRANSIT AND MICROTRANSIT

Public transit and microtransit services using AVs are currently being tested. Transit applications include low-speed automated shuttles operating on a designated route. Microtransit applications being tested include robotaxi service concepts, where no human operator may be present, or a human driver is present in the vehicle to take over if necessary, but the vehicle normally operates in an automated mode from passenger pick-up to drop-off.

Some early local agency automated mobility pilots in North Central Texas have included:

- Frisco Drive.ai Automated Vehicle Pilot[18]
- Arlington Milo Low-Speed Automated Shuttle Pilot[19]
- Arlington Drive.ai Automated Vehicle Pilot[20]
- Aurora autonomous ride-hailing fleet testing to prepare for 2024 deployment[21]

Established long-term deployments in North Central Texas include:

- Arlington RAPID Automated Microtransit Pilot with Via [22]
- SkyLink - DFW Airport Automated People Mover

More recent pilots receiving support from NCTCOG are listed in on page 67 in the "Examples" subsection of the "Building Partnerships" section.

SIDEWALK DELIVERY ROBOTS

Sidewalk delivery robots (or personal delivery devices) are small, lockable cargo boxes on wheels that can deliver packages, groceries, prepared food, and similar items over relatively short distances. They operate on sidewalks and pedestrian paths and are programmed to move at typical pedestrian speeds and to avoid collisions with other sidewalk users. In North Central Texas, Starship Robotics sidewalk delivery robots are being tested by UT-Dallas to deliver in Frisco, Plano, and Richardson and at Southern Methodist University in Dallas.[23]

UNMANNED AERIAL VEHICLES

Aerial mobility is an emerging concept envisioning a futuristic multi-use air transportation network for passenger mobility, cargo delivery, and emergency management. Historically, aerial vehicles with an on-board pilot have been used to transport passengers and cargo long distances. Compared to existing aviation services, aerial mobility typically refers to smaller, highly automated, lower-altitude vehicles making short trips. Recent developments in aerial mobility technology and airspace regulations offer new businesses and the average consumer opportunities to utilize the airspace.

Unmanned aerial vehicles can be controlled by a remote pilot or piloted autonomously by a computer without any human interaction. As of October 2021, the Federal Aviation Administration (FAA) allows remotely piloted aerial vehicles, but not autonomous aerial vehicles. Most tests being conducted in the US utilize remotely piloted vehicles, but these tests build a foundation so these vehicles can become autonomous.

In Frisco, Wing is partnering with Walgreens to test "store-to-door" on-demand aerial delivery. This test is the first commercial drone delivery service in a US metro area.[24] In addition, Texas has been advancing aerial mobility by working with NASA and other government agencies to consider how emerging cargo-carrying drone and passenger-carrying air taxi services can best be included in civic transportation plans, creating a Mobility Innovation Zone proving ground in North Texas, successfully setting up low-altitude airspace monitoring service in Arlington, and allowing Flytrex to deliver food in Granbury .

USE CASES

This section introduces potential AV applications in the areas of personal mobility, freight movement, and data collection. A number of challenges will need to be overcome to realize the full potential of these applications, both on the part of AV developers and public agencies. Later sections in this handbook describe strategies that public agencies can follow now to begin to overcome these challenges.

Personal Mobility (Moving People)

PRIVATE VEHICLES

Automation

Automated vehicles could reduce the time cost of travel for drivers, who would experience less stress riding in an AV compared to driving a car. Travel demand is likely to increase if the time cost of travel decreases, either because roadway capacity increases or because driver stress levels decrease. Vehicle miles traveled (VMT) could increase as demand increases, or because AVs or shared-use vehicles make empty or zero-occupancy trips.

Local agencies may need to control the increased demand with policies that discourage increased VMT. Changes to the built environment (e.g., land use density supportive of transportation and housing goals, improved accessibility to transit, modernization of land use and zoning laws) are among the most significant and critical factors in reducing VMT. Road- and parking-pricing policies can have a significant impact on VMT while providing revenue for infrastructure maintenance in proportion to use. Examples of policies that impact VMT are mileage-based pricing strategies as an alternative to the gas tax (particularly as electric vehicles become a larger portion of the vehicle fleet), congestion pricing in dense urban centers, and demand-based parking.

Vehicle-to-Vehicle (V2V) Communication

Connected and automated vehicles (CAVs) with V2V communication capabilities have the potential to work cooperatively. In theory, CAVs would be able to form platoons that would be able to travel safely at shorter vehicle spacings than humans can do safely. The V2V communication would allow vehicles to inform each other of upcoming actions (e.g., braking, lane changing) and to react accordingly, faster than if relying solely on on-board sensors. In an environment with 100% CAVs, platooning could increase freeway capacity by about one-third and signalized arterial capacity by about one-half, compared to the capacity with 100% human-driven vehicles. This increase is a result of CAVs' ability to communicate with each other and with the roadside environment.[25]

V2V communication can also share travel and safety information to drivers through in-vehicle messaging. It can potentially help a driver to “see” around blind spots and allow emergency braking to be activated, providing safety benefits to road users.

Vehicle-to-Infrastructure (V2I) Communication

V2I communication capabilities can be used to optimize traffic signal operations, for example. Vehicle-location information communicated to the signal controller can help the controller optimize signal timing to minimize delays. Information about when the signal will next turn green can be communicated back to the vehicle, allowing an AV approaching a red light to slow in a fuel- or power-efficient way that keeps it from having to stop entirely.[26]

V2I technology is being tested in a variety of applications Arlington, including:

- Red-light violation warning application.
- Driver information alerts, such as pedestrian proximity, upcoming school zones, active railroad crossings, and approaching fire trucks.
- Advanced traveler information system providing drivers with real-time signal data, anticipated wait time, and suggested travel speed.

Vehicle-to-Everything (V2X) Communication

V2X communication is communication between the vehicle and conceivably anything connected to cloud-based services. One current example is navigation information received through a smartphone app that is displayed on a screen inside the vehicle, with vehicle speed and location data being communicated back to the internet service for use in updating travel time estimates. A service such as OnStar® that automatically calls for help if the system detects that a crash has occurred, and that can track stolen vehicles, is another example. Eventually, vehicles might be able to communicate with pedestrians or cyclists through safety communications applications.

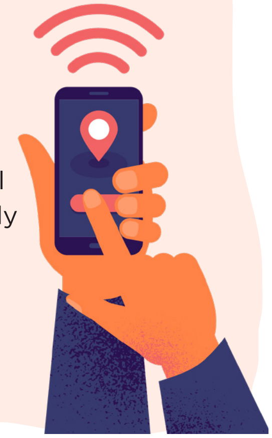
Possible Timeline

Early benefits may begin in the 2030s (such as independent mobility for affluent non-drivers), but most impacts of automation (such as reduced traffic and parking congestion, independent mobility of low-income travelers, and safety) are not expected to begin until AVs become more affordable and widely adopted in the 2040s or 2050s.[27]

RIDE-HAILING

Because a major part of the cost of ride-hailing services is the labor cost of the driver, automated ride-hailing (or robotaxi) services are expected to cost less than current ride-hailing services. The lower cost would tend to increase the number of ride-hailing trips taken and decrease the usage of competing modes (e.g., public transit, personal vehicle, active transportation).[28]

Automated vehicles are expected to be considerably more expensive than conventional vehicles when first introduced. As a result, an early AV application is expected to be ride-hailing. Transportation network companies have already developed the software supporting ride-hailing and would be able to put their AVs to use up to 24 hours a day.[29] In addition, car manufacturers such as General Motors and Ford have created ride-sharing subsidiaries, which gives them a ready market for the AVs they produce.[30]



Automated ride-hailing vehicles would benefit from the same communications technology described above for private vehicles.

PUBLIC TRANSIT

Buses will continue to be able to transport considerably more persons per roadway lane per hour than automated passenger cars—even platooned passenger cars—especially if some of the passenger cars are empty. Transit excels at efficiently moving people wishing to travel in the same direction at roughly the same time. While transit systems that have substituted on-demand for fixed-route service have experienced higher overall ridership, this has come at the cost of lower ridership per vehicle hour than the previous service.[31]

On-demand services also present new challenges, as the fleet size and service areas need to be optimized to maintain reliable wait times. With this in mind, it can be useful to start with an initial pilot area before scaling up to cover an entire service area. Arlington began its on-demand operations in a smaller zone before expanding to cover the entire municipality. Similarly, Denton County Transportation Authority began service with two zones--one in Denton, one in Lewisville, to understand demand and better determine how (and where) to add additional service.

Similar to other fleet applications, labor costs are a significant portion of the total cost of operating transit service. Eliminating that expense would allow transit agencies to offer service to more areas and/or offer more frequent service for the same operating budget as at present. The need to retrain bus drivers who lose their jobs to automation is discussed in the "Equity" subsection of the "Developing Policies" section and in the "Workforce Training" section.

Because urban buses generally operate on fixed routes, they do not need to be capable of operating everywhere, but only along the roadways used by their routes, which means they could be developed and adopted faster than AVs designed to go anywhere. Designating more road space for transit-only use would reduce potential conflicts between vehicles, improving safety and potentially reducing transit operators' liability costs.[32]

Another potential future role for transit agencies is as the regional mobility manager, providing one-shop access to a variety of mobility services for different travel needs. The transit agency might continue to operate its higher-capacity fixed-route bus and rail services but serve as a coordinator for other types of services, such as ride-hailing (including services for persons with disabilities), on-demand microtransit, or micromobility options such as bikeshare and scooter sharing. A mobility manager role would also help transit agencies direct mobility options to cities that do not pay into a regional transit agency.[33] Public transit agencies may be good candidates for the mobility manager role, with established staffing, operations, and maintenance structures already in place. Agencies can also define general rules, roles, and regulatory structure to ensure participants in the mobility ecosystem work cooperatively to meet public goals. In North Central Texas, for example, Dallas Area Rapid Transit's (DART's) GoPass App provides a starting point. DART (including on-demand GoLink service), Denton County Transportation Authority, Trinity Metro, and STAR Transit all currently participate in the GoPass app, enabling multimodal trip planning and booking across multiple providers.

In concept, a person could use a single app to book and pay for a trip consisting of a ride-hailing vehicle from one's house to a major transit stop or station, transit for the long-distance portion of the trip, and finally a shared bike to complete the trip. Both public and private mobility providers could provide their own versions of this "single app," using open data standards to share service data with the regional mobility manager to plan customer trips and to communicate with other service providers as needed to book customer trips. For example, Pittsburgh has launched the MovePGH app that enables residents to pay for transit, rent micromobility devices, or rent a car under the umbrella of the city's existing Transit app.[34] However, as discussed in the equity portion of the "Developing Policies" section, alternatives to apps should be available for planning and booking trips on mobility services, to serve people without smartphones (or who have difficulty using one), and those without credit/debit cards. For example, DART's GoPass allows travelers to add funds to their transit account with cash at participating retail locations, if they do not have a credit/debit card.

AERIAL PASSENGER SERVICES

As of October 2021, aerial vehicle use has been limited in the US. Public and private partners have tested cargo deliveries, but local passenger movement has not been tested. Aerial vehicles have been used to inspect bridges and airplanes with special permission from the Federal Aviation Administration.

Once moving cargo and passengers through the air within or traversing across a metropolitan area becomes a standard procedure, the aerial mobility industry is expected to grow. Industry experts expect regular air shuttle services along specific routes to be operational by 2028.[35] Estimates anticipate that the aerial mobility market capitalization can grow from $16.8 billion in 2025 to $110 billion in 2035, showing the potential explosive growth of this market.[36]

Freight

INTERSTATE AND REGIONAL SHIPPING

Automation in trucking is being developed and tested for several specific applications. Several years ago, platooning was the focus of several truck manufacturers (like Daimler Trucks) and system developers (like Peloton). In a trucking context, the lead truck in a platoon could be automated or human-driven, with its followers being automated. Platooning can improve the fuel economy of the trucks in the platoon due to decreased wind resistance, while removing human drivers reduces labor costs.

While some companies such as Locomation continue to pursue the platooning model, others have shifted away from platooning to full automation. Platooning continues to remain a focus for military applications. Other automated trucking developments have focused on specific applications for first-mile deliveries (to distribution centers), middle-mile (interstate regional or long-haul travel), or last-mile deliveries (to businesses).

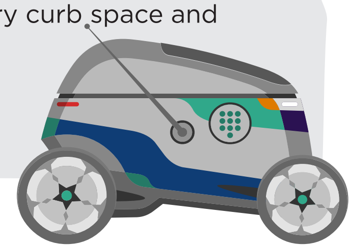
NCTCOG is pursuing a freight vehicle optimization project to improve regional freight vehicle movement efficiency and reliability. The project will identify main freight routes and will combine Green Light Optimized Signal Advisories to truck drivers with adjustments to the signal timing plans along these routes to provide priority to trucks. The project will cover up to 500 intersections in the region.

The TxDOT Texas Connected Freight Corridors project is deploying connected vehicle technology on I-35, I-45, and I-10 and in more than 1,000 commercial vehicles to reduce truck-related crashes and reduce the time trucks spend in congestion.[37] .

BUSINESS-TO-BUSINESS DELIVERIES

Another potential application for automated trucks is for the delivery of goods on regular routes, such as between distribution centers and stores. Similar to fixed bus routes, the trucks used for these deliveries would not necessarily need to operate everywhere, but only on the selected routes (and on designated alternate routes in case of road construction or other situations requiring detours).

Trucks used for business-to-business deliveries might be smaller than the tractor-trailers typically used to make commercial deliveries, requiring less on-street delivery curb space and smaller on-site maneuvering areas. Smaller vehicles would also be easier to maneuver in dense urban areas.[38]

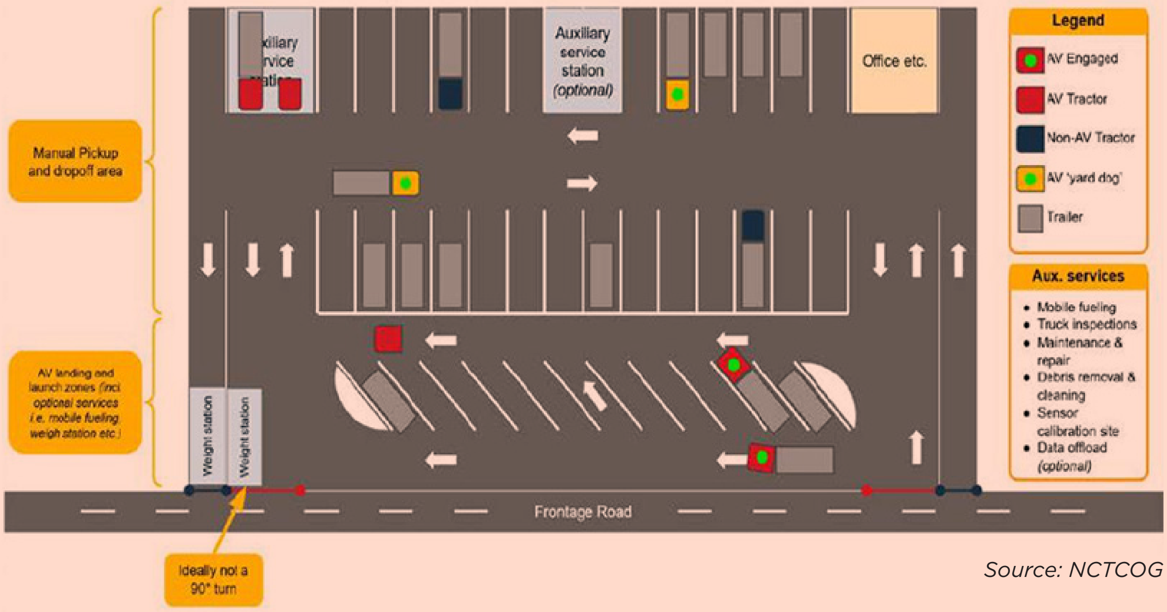


INTERMODAL TRANSFERS

A promising area for automated trucks is freight yard applications, such as moving containers within a port or rail yard. The operating area can be well-defined, and the potential conflicts are far fewer and at lower speeds than with on-highway applications.

NCTCOG awarded an AV2.2/2.3 grant to the City of Fort Worth for the Tarrant AV Truckport, which will be located in northwest Fort Worth (I-35W/SH-170). The purpose is to build and operate the nation's first AV truckport where AV freight companies can swap trailers between long-haul, middle-mile interstate AV tractors and local, first-/last-mile human driven tractors.

Example Truckport Layout



Source: NCTCOG

RURAL FREIGHT DELIVERY

Unmanned aerial vehicles have potential delivery applications in rural areas, because these vehicles generally would not be flying over people, ground vehicles, or homes. However, they may be more constrained than automated ground-based vehicles in terms of cargo size and weight, and the weather conditions in which they can operate. Because of the greater distances and travel times involved with rural freight delivery, both aerial and ground-based AVs offer significant operating cost-savings potential for shipping freight to rural customers.

URBAN FREIGHT DELIVERY

Several models have been suggested for how packages and other deliveries could be delivered to urban customers in the future.

Amazon Hub Locker + Location in Philadelphia

Remote Distribution Center to Customer

This model would be similar to how package delivery companies currently operate, but it would take advantage of automated driving functions to operate delivery vehicles more safely and reduce demands on delivery employees. Delivery vehicles would be loaded at distribution centers outside cities and would deliver packages to customers in defined areas. A human employee would still be required to take the package from the vehicle to the customer.[39]

Consolidation Center to Customer

In this model, package delivery companies would jointly or separately operate neighborhood consolidation centers. Automated trucks would bring packages from a remote distribution center to the consolidation center, where they would be transferred to smaller vehicles for last-mile delivery.[40] The neighborhood consolidation centers could be permanent establishments where customers could pick up packages that arrived when they were not home, or could be informal on-street or parking-lot locations for package transfer only.

Electric cargo bikes with human drivers are used in some European cities to handle last-mile delivery under this model, and companies have found that their bike-based employees can make more deliveries per day than their van-based employees. [41]

Another potential option for last-mile delivery would be to use sidewalk delivery robots, but cargo size and weight limitations might make this option less efficient than other options, and they require a sidewalk network that is continuous/complete and sufficiently well-maintained.

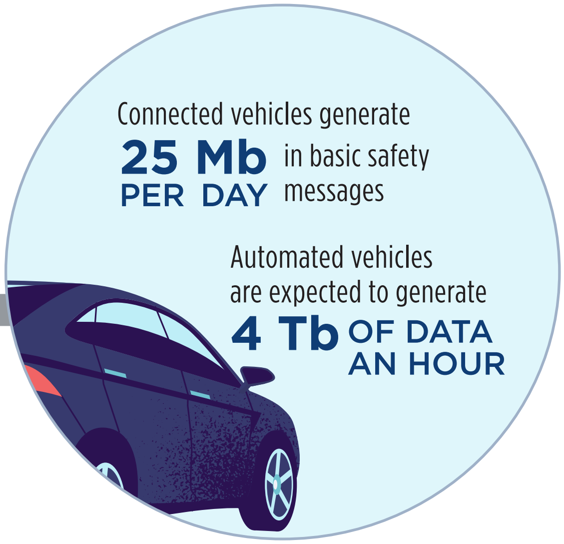
Local Business to Customer

Businesses could use AVs to make deliveries to customers in their local area. Options could include human couriers riding in AVs, sidewalk delivery robots, and (for small, lightweight packages) aerial drones.

DATA COLLECTION

Data availability is a critical element of transportation planning. Low-cost sensors and personal data-sharing devices (like smartphones and wearables) have proliferated, and their sensing and computational power has advanced. Connected vehicles are already generating 25 MB of data per day per vehicle in basic safety messages. Automated vehicles are anticipated to generate around 4 terabytes of data every hour as they move throughout a city, excluding data associated with booking travel, parking, and other transactions associated with automated transportation systems.[42] ,[43]

While the sources and applications of data to automated transportation are limitless, there are four dimensions to data management and utilization that warrant special attention.



- **Crowdsourcing and data sharing.** The most successful applications of new datasets provide a feedback loop between users and application developers, allowing products and services to respond quickly to changes in user needs. In crowdsourcing applications such as Waze and Moovit, users are encouraged to contribute their own input to a dataset, enriching it with insights that may not have been possible using conventional data capture techniques. Data-sharing applications include open data platforms where data compiled from different agencies and regional stakeholders are made available to one another and to third parties, allowing each stakeholder to enrich the compiled data with their own data and applications.

- **Vehicle-to-Everything (V2X).** V2X technologies allow for data sharing between vehicles, transportation infrastructure, and other road users. These data can be used to optimize personal and regional travel, as well as to generate traffic operations data that can inform capital planning and programming decisions. Much of the data generated by V2X systems are not publicly available and must be obtained by subscriptions to third-party solutions such as HERE or INRIX (who, in turn, are partnered with the vehicle Original Equipment Manufacturers).

- **Cloud, Fog, and Edge Computing.** The volume of data generated by automated transportation systems will make it increasingly difficult to transmit and process data quickly enough to allow for responsive decision-making from a centralized traffic control center. The on-site data storage systems used by agencies may be unable to scale up quickly or cost-effectively enough to meet increasing data needs. New data architectures will be needed that can take advantage of cloud solutions (off-site, large-scale data storage and analytics), edge solutions (data analysis performed in the field at the sensor, reducing the lag time associated with transmitting data for analysis to a control center), and fog solutions (strategies that filter data needs between the edge and the cloud). The evolution of data solutions will require agencies to rethink how Traffic Management Centers (TMCs) are operated and maintained. The increased volume and velocity of data may require TMCs to transition from traditional, on-site data storage and analytics to data architectures better optimized for interfacing with large volumes of sensors in the field. Machine learning may supplement (or ultimately replace) many activities currently carried out by TMC staff. However, machine learning may also generate new staffing needs or require re-training for existing staff to operate and maintain advanced traffic management systems.

- **Data analytics**. New analytic systems ("Big Data" solutions, such as IBM Watson) have been developed to take advantage of the volume, variety, and velocity of data being generated by modern systems. Such analytic systems represent a paradigm shift from traditional data-processing applications (e.g., spreadsheets) and will require new investments in training, software, and data management strategies to take advantage of their full benefits. Data analytics produces the information used to evaluate the outcomes of AV implementations, as discussed in the "Monitoring Progress" section.

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03 DEVELOPING POLICIES

There is general agreement that if a local agency is not already developing policies to help shape the benefits of AVs and avoid undesired outcomes, it should begin now.

There are several reasons why developing policies around AVs is important:

- AVs are already being tested; and educating and engaging stakeholders, decision-makers, and the general public will take time.[1]
- Agencies need to develop a new mindset about planning, anticipating, and responding to rapid technological change and its effects on society more quickly than they ever have.[2]
- The issues raised by AVs, and their potential impact, "remain almost entirely outside the knowledge base or skill set of the vast majority of city staff or leadership."[3]
- Failure to consider or address the consequences of past decisions during times of rapid transportation system change has worsened community inequities. AVs offer the potential to address some of these inequities, but also to worsen them if potential AV adverse impacts are not addressed through policy.[4]
- Cities are the largest markets for AV technology. Implementing policies proactively can help cities achieve the transportation and land use outcomes they want.[5]

Agencies should expect a continual process of policy evaluation and refinement as knowledge is gained through AV deployments and technologies evolve. Nimbleness and flexibility are essential to respond to new opportunities, address negative outcomes as they arise, support positive outcomes as they are identified, and avoid unnecessary obstacles to the continued development and deployment of AV technology.[6]

This section starts by describing the AV-related areas that local agencies in Texas can and cannot address through policy. Next, it identifies necessary first steps to get educated about AVs, their potential benefits, and their potential impacts prior to developing AV policies. Much of the remainder of the section then describes potential local agency AV policy considerations across a variety of topic areas. Finally, the section concludes with guidance on monitoring progress and examples of how local agencies have implemented AV policies.

The process of developing policies to support a transition to AV technologies includes four steps:[7]

1. Prepare.
Become familiar with AV technologies and agency regulatory powers, develop the agency's vision for technology, and set technology-related goals.

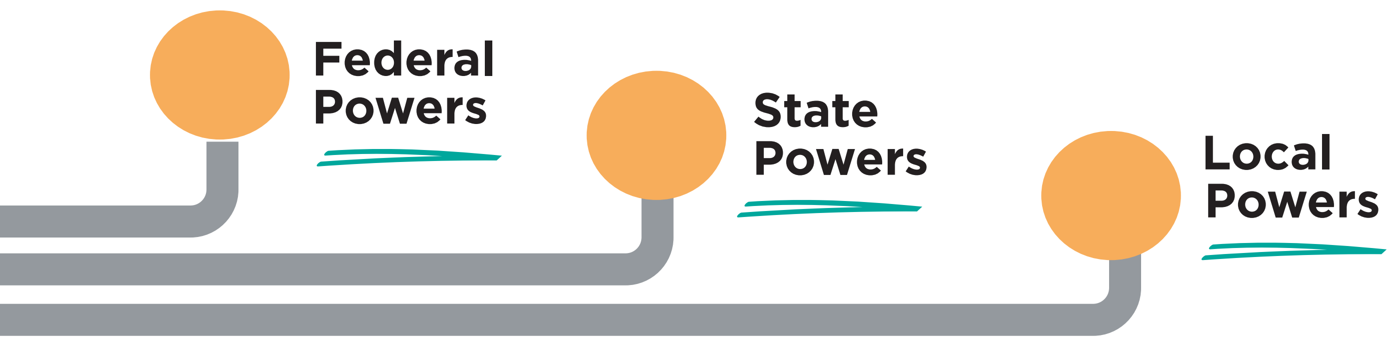
2. Self-assess.
Review the agency's staffing, resources, capabilities, organization, policies, and plans. Identify needs and courses of action.

3. Take action.
Address the policy gaps identified in the self-assessment. Identify and/or develop funding sources to address resource gaps. Train or hire new staff, or partner with others with the necessary expertise, to address capability gaps.

4. Monitor and adjust.
Monitor progress toward achieving the agency's technology-related goals and adjust programs, plans, and actions as necessary to meet the goals.

AGENCY REGULATORY POWERS

The power to regulate AVs and AV-related technology is divided among three levels.



Federal Powers

The federal government regulates areas where consistency across state borders is necessary, such as interstate commerce, vehicle crashworthiness, licensing the airwaves used for communication, and the design of traffic signs and pavement markings.[8]

With respect to AVs, the US Department of Transportation has developed six principles for shaping federal policy:[9]

- **Prioritizing safety for all road users,** while acknowledging and addressing the potential for new safety risks.
- **Remaining technology-neutral,** adopting flexible policies that promote competition and innovation as means for achieving safety, mobility, and economic goals.
- **Modernizing regulations** that may unnecessarily impede AV development; supporting voluntary, consensus-based technical standards; and seeking performance-based, non-prescriptive approaches when regulation is needed.
- **Encouraging a consistent regulatory and operational environment** so that AVs can operate seamlessly nationwide.
- **Preparing proactively for AVs** by providing guidance and best practice, supporting pilot programs, and offering other assistance, while not assuming that any particular approach will be adopted nationwide.
- **Protecting the ability of people to have and make mobility choices,** including the freedom to drive their own (non-automated) vehicle.

State Powers

The states generally regulate driver licensing, vehicle codes, insurance, and liability statewide, as well as set design standards and speed limits for state-owned roadways. A state may also pre-empt local jurisdictions in other areas, to promote regulatory consistency across the state.[10]

In Texas, the state regulates the following aspects of AVs:

- **Senate Bill 2205 (2017)** permits AVs to operate in Texas with or without a human operator physically present in the vehicle, when the vehicle operates in compliance with applicable traffic laws, is equipped with a recording device, has an automated driving system compliant with federal laws and standards, is registered in Texas, and has vehicle liability insurance. The bill also specifies that "a political subdivision of this state or a state agency may not impose a franchise or other regulation related to the operation of an automated motor vehicle or automated driving system."[11]

- **House Bill 1791 (2017)** allows the use of connected braking systems to maintain "an assured clear distance or sufficient space" between vehicles.[12]

- **Senate Bill 969 (2019)** regulates "mobile carrying devices" and "personal delivery devices" (e.g., sidewalk delivery robots). The latter has an automated driving system monitored by a human, while the former is under the control of a human operator located within 25 feet of the device. They can operate on sidewalks at speeds up to 10 mph and on roadway shoulders at speeds up to 20 mph. They are subject to laws directed at pedestrians, must "yield the right-of-way to all other traffic, including pedestrians," must not "unreasonably interfere with or obstruct other traffic, including pedestrians," must operate with lights at night, and must not carry hazardous materials. Local jurisdictions may enact additional regulations for these devices that are not inconsistent with state regulations, including reducing the allowed maximum speed on sidewalks to as low as 7 mph.[13]

- **House Bill 3026 (2021)** exempts AVs from motor vehicle equipment laws and regulations that "relate to or support motor vehicle operation by a human driver; and are not relevant for an automated driving system."[14]

Local Powers

Except when pre-empted by state law, local agencies control zoning and other land use regulations, and permit regulations. They also manage street design, roadway infrastructure, and curbside use on the roadways under their jurisdiction. In some states, local agencies can also set speed limits on roadways under their jurisdiction.[15]

When setting AV policy, it is important to focus on the things under a local agency's control (e.g., roadway infrastructure, traffic signal systems, enforcement), rather than the things that are not (e.g., technology adoption timelines, vehicle licensing). There are many areas that a local agency can influence and therefore require policy direction. These areas include land use, curb management, equity, pricing, contracting, and data sharing. To the extent that a local agency in Texas is helping fund a pilot project, operating and safety policies that will form the basis of negotiations with the AV operator are also essential.

> Local agency require policy direction in areas including land use, curb management, equity, pricing, contracting, and data sharing.

GETTING AND STAYING SMART

An important first step to developing AV policies is for agency staff and decision-makers to become familiar with AV technology, its current status, and its potential benefits and problems.

This handbook and the documents it references are a good starting point. Other options for building agency expertise and capability include:[16]

- Partnering with other agencies. This option includes both agencies with direct experience with AVs (e.g., large cities, the MPO, the state), as well as departments within the local agency (e.g., public works, emergency responders, IT) that could be affected by AVs or AV-related policies. The Building Partnerships section discusses how to identify these organizations and provides guidance on bringing them to the table.
- Establishing a new advisory committee focusing on AVs and AV impacts. This committee can draw members from existing advisory committees (e.g., transportation, planning, older adults, persons with disabilities) as well as invite new members with particular expertise on one or more AV-related topics.
- Hiring new staff and/or training existing staff. This option builds the agency's internal capabilities. As discussed below, once a basic capability has been established, it will be important to keep staff up to date with changes in technology, operating experience, and regulations.
- Partnering with educational institutions. This option can provide access to expertise not initially available among agency staff and, as discussed in the Building Partnerships section, provide potential opportunities for internships and local workforce development once AV deployments begin to happen. Some universities may also offer extension courses related to AV technology.
- Hiring an outside expert. A consultant can also provide expertise not initially available among agency staff for a period of time specified in the agency's contract.
- Partnering with AV companies. In this option, the private entities building and/or deploying AV technology provide the expertise, and agency staff gain experience with the technology over the course of the deployment.

Once a basic level of knowledge has been established, it is important to keep the knowledge up to date. Conferences and exhibitions that address the latest technological developments and/or AV operating experience include:[17]

- Consumer Electronics Showcase
- ITS America Annual Meeting
- Automated Road Transportation Symposium (ARTS)
- Transportation Research Board Annual Meeting
- American Public Transportation Association Mobility Conference

POLICY ASSESSMENT

Once an agency has familiarized itself with AV technology, it is ready to begin thinking about how agency policies and procedures may need to change in preparation for the arrival of AVs. Agencies can influence how new technology is adopted in a number of ways, including:[18, 19]

- Setting regulations for the use of AV technologies, to the extent permitted by state law.
- Providing financial support for AV services that support an agency's broader goals.
- Setting policies for service and reporting requirements for AV operators seeking financial support from the agency and, to the extent permitted by state law, setting similar regulations for other AV operators.
- Setting street design standards and curb management policies that prioritize desired travel modes and vehicles.
- Setting land use policies and permit regulations that encourage desired development and travel patterns.
- Setting fees for public services used by AV operators, and levying taxes on the services provided by AV operators.

The Policy Development subsection that follows provides suggestions for topics to assess across a variety of policy categories (e.g., land use, equity, public works). This subsection covers bigger-picture topics on connecting policies to agency goals, being technology-neutral when developing AV-related policies and regulations, and preparing policies for different stages of AV development and deployment.

Connecting Policies to Goals

Widespread personal vehicle ownership in the US following World War II significantly changed land use and travel demand patterns, along with the transportation services and facilities supporting these patterns. The effects of these changes were also widespread, both positive and negative. AVs have the potential to be similarly disruptive. Connecting AV-related policies to broader community goals can help AVs support the changes the community desires, while avoiding outcomes the community does not desire.

AVs and their supporting technology can help support a variety of community goals in areas such as equity, livability, safety, efficiency, health, and climate change. An agency can set policies that direct how its various departments should conduct business in a way supportive of community goals. An agency's regulations can also provide preferential treatment when a particular technology contributes more to achieving community goals than do existing technologies.[20]

For example, Seattle's Comprehensive Plan has a transportation goal to "promote healthy communities by providing a transportation system that protects and improves Seattle's environmental quality." A technology-related policy that was adopted to support this goal was "encourage the use of electric-powered vehicles and the provision and expansion of electric-vehicle charging stations."[21] Follow-up actions the city could take to implement this policy could include requiring that a certain number of EV charging stations be installed as part of development or redevelopment projects, and supporting the installation of public and/or privately owned on-street EV charging stations at locations around the city.

Developing Technology-Neutral Policies and Regulations

Multiple AV technologies (as well as non-technological solutions) may be capable of achieving the same desired outcome. As technology continues to evolve, new technologies may appear that are not on the radar today. Writing technology-neutral policies and regulations provides flexibility to accommodate multiple technologies and avoid the need to create new policies each time a new technology is deployed. Technology-neutral policies are outcome-based, and technology-neutral regulations are performance-based, rather than being focused on a specific technology.[22]

For example, rather than regulating "sidewalk delivery robots" specifically, Texas law defines "mobile carrying devices" that carry cargo and are controlled by a human operator within 25 feet of the device, and "personal delivery devices" that are human-monitored automated cargo carriers designed to operate on sidewalks and roadway shoulders. The law describes the required operations and safety characteristics and insurance requirements for these devices. Any technology fitting these characteristics and meeting these requirements is then allowed to operate in Texas.[23]

The challenge in creating technology-neutral regulations is balancing an agency's desire to accommodate new technologies with the need for language that is clear and specific enough to be enforceable. Describing the applicable technology characteristics and the desired performance is a way to accommodate both needs.[24]

Policy Timeframes

AV-related policies need to consider short-, medium-, and long-term conditions.

Short Term

POLICIES FOR THE SHORT TERM

In the short term, AV technology is being introduced to a community and is still in a testing and development stage. Policies for this stage can be crafted to remove potential regulatory roadblocks to testing the technology, while ensuring that testing occurs safely and that both the agency and the community are kept informed of the progress and outcomes of the testing. If a community desires to attract AV pilot projects and deployments, it can also develop policies to support this goal.

Medium Term

POLICIES FOR THE MEDIUM TERM

The medium term is a transitional period, where the first generations of commercial AVs have been deployed, but many human-driven vehicles are still in use. Typical estimates of the length of this transitional period range from 30 years after AVs become commercially available to 50 years or more.[25] Importantly, much of the planning period for local and regional transportation plans will occur within this transitional period.

During the transitional period, the benefits and disbenefits of AVs will become more apparent. Local agencies can begin to set policies now to encourage or take advantage of the expected benefits, while avoiding the potential negative outcomes. Due to the lack of actual operating experience with commercial AVs, these initial policies will need to be informed by educated guesses about how AV technology will be adopted. Risks associated with uncertainty about how future conditions will evolve can be mitigated by focusing on incremental actions. Agencies should expect to need to revisit and update AV-related policies relatively frequently as experience is gained.[26]

One option for reviewing policies is to do so on a set schedule, for example every five years. At these check-in points, the agency can review past assumptions about how and when AV technology will be deployed, incorporate findings from ongoing monitoring to identify positive and negative outcomes, and adjust policies accordingly. Another option is to set triggers for when a policy review is needed; for example, a specified number of years after a certain type of AV (e.g., commercial vehicle, private vehicle) becomes commercially available or after AVs form a certain percentage of the vehicle fleet.[27], [28]

Long Term

POLICIES FOR THE LONG TERM

In the long term, AVs have replaced the vast majority of human-driven vehicles. Seeing a human-driven vehicle on the road is as uncommon as seeing an antique or classic car is now.

When and how this future will occur is impossible to predict. However, agencies can set long-term policies now that describe the kind of community they want to evolve into over time and how AVs might help support that process. In the long term, the policy monitoring and adjustment process that has occurred throughout the medium term will culminate in eliminating policies that are no longer relevant in an AV future and refining other policies based on the decades of acquired experience the agency has gained with AV operations.

POLICY DEVELOPMENT

This subsection describes areas where local agencies may need to update their policies and regulations to address AVs and related technologies. This process should be "transparent, inclusive, and collaborative," considering the input of both those responsible for implementing the policy (a range of agency departments) and those affected by the policies (specific stakeholders and the community at large).[29] The Building Partnerships section that follows provides guidance on identifying these partners and bringing them to the table.

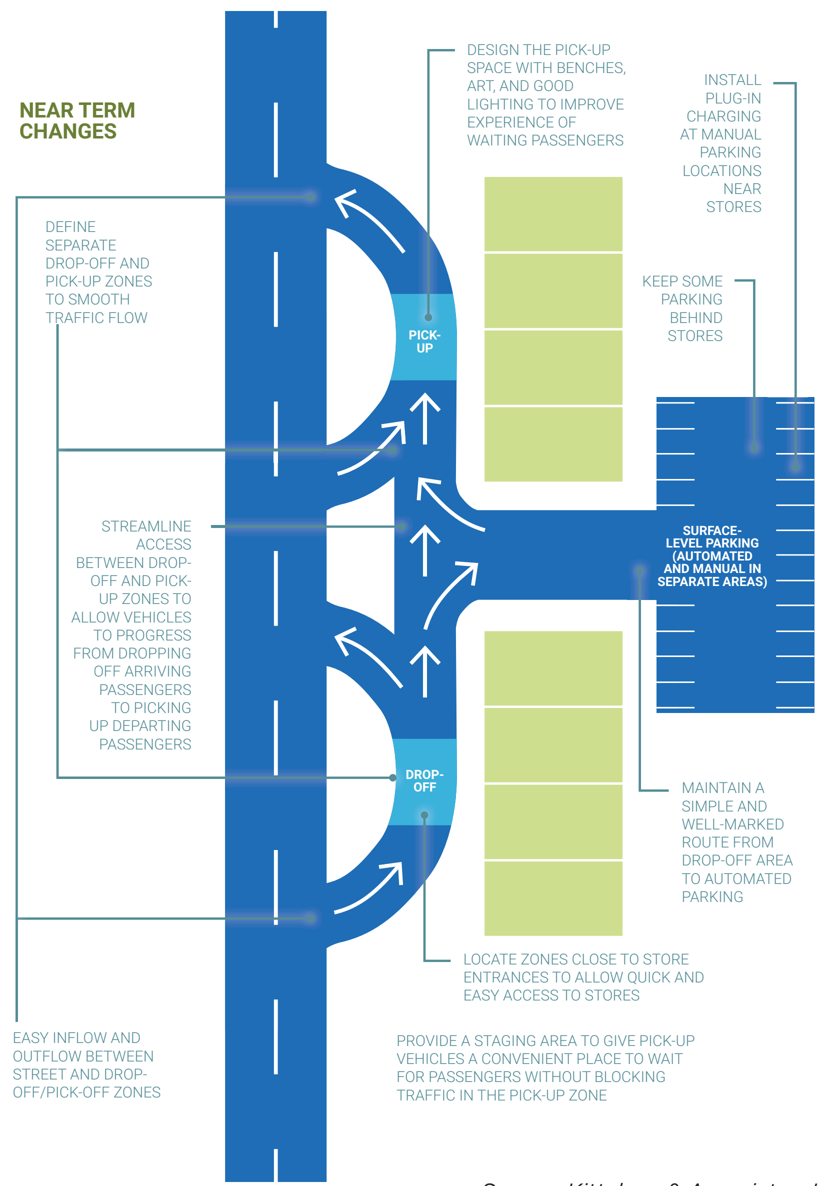
Land Use and Development

ON-SITE PARKING REQUIREMENTS

One important way that AVs are expected to affect the transportation system is in the area of parking. There may be less need for on-site parking at the non-home ends of trips, as an AV's occupant(s) are dropped off at their destination, but the AV goes elsewhere afterwards. Similarly, if shared-ride AVs become popular, the demand for on-site parking may be reduced at multi-family residential developments, as well as in residential and employment areas with shopping, services, and transit options in the general area (but beyond convenient walking distance).

Eliminating parking minimums allows the market to determine the most efficient allocation of on-site parking.[30] Decoupling the cost of on-site parking from the cost of a unit in a multi-family residential building provides a cost incentive for tenants to forgo owning a vehicle and take advantage of other mobility options instead, including shared-ride AVs.[31] Development codes might need to require more space allocated for micromobility modes or delivery boxes, while zoning codes might need to be modified to allow for the reuse or redevelopment of existing parking facilities.[32]

Drop-Off and Pick-Up Zone Design Considerations



Source: Kittelson & Associates, Inc.

Increasing use of AVs could also change parking design standards, with more space allocated near building entrances to passenger pick-up and drop-off and short-term loading and unloading activities. The width of on-site parking spaces could be reduced, as there might not be a need for passenger access at the parking stall (the vehicle could drive itself to and from the pick-up or loading area). Parking structures could be transformed into remote parking facilities storing a greater number of vehicles and designed for only limited human activity (e.g., to perform maintenance).[33]

NOISE AND LIGHT POLLUTION

Some AV technologies have the potential to create new sources of noise and light pollution that do not exist today. For example, agencies might consider regulating the allowed noise level of unmanned aerial vehicles when operating over noise-sensitive land uses, or the times of day when automated delivery activities can occur.[34]

Similarly, the lights Texas requires for safe nighttime operation of automated sidewalk delivery robots might create light pollution issues for ground-floor residential units. Those issues, if they were to develop, could be addressed in a variety of ways, including site design requirements addressing the issue (e.g., location of delivery boxes, screening), time-of-day usage restrictions, or changes to state law allowing automated sidewalk delivery robots to use the (much lower) light levels permitted for human-controlled mobile delivery devices when the automated device is not operating on a roadway shoulder.

BUILDING CODES

Building codes may need to be revised to provide sufficient electrical, water, fire suppression, HVAC, and communications infrastructure within a structure to support new technologies, as well as sufficient structural support for different kinds of loading.[35] For example, structured parking for electric AVs built into a residential building could have different needs related to electricity (for charging the EVs), fire suppression (to address battery-related fires), communication (to allow updates to AVs' operating systems and databases while parked), structural loads (vehicles parked closer together), and emergency egress (access limited to maintenance staff).

Building and development codes may also need to incorporate flexibility to allow multiple AV-supportive uses within the same structure.[36] For example, downtown office buildings are being repurposed as data centers capable of supporting V2X applications. These buildings are also attractive to technology start-up firms, due to the availability of reliable backup power, high-speed communications infrastructure, cooling systems, and scalable data storage and computing power.[37]

OVERLAY ZONING

Overlay zones can be established as a way to tailor AV-related development requirements to one or more characteristics (e.g., density) of the underlying zone, without having to rewrite the entire zoning code. For example, land use requirements that prioritize micromobility modes and discourage single-occupant vehicle trip-making could be established for an overlay zone applying to areas with high population density.[38]

Operations

AGENCY-SPONSORED PILOTS

When an agency is fully or partially funding transportation services, it has a significant degree of control over how the service is provided, including polices related to:[39]

- Service areas, service hours, and maximum wait times
- Fare policy, including payment options and fare discounts
- Vehicle accessibility requirements for persons with disabilities
- Information accessibility for persons with limited English proficiency
- Methods for ordering a ride
- Hiring and labor practices (e.g., family wages, local resident preference)
- Data reporting

Agencies using federal grants to help fund a pilot project must, among other things, comply with Title VI of the Civil Rights Act, which prohibits discrimination on the ground of race, color, or national origin, as well as federal executive orders on environmental justice designed "to prevent minority communities and low-income communities from being subject to disproportionately high and adverse environmental effects."[40]

Transportation service providers are also required to comply with the Americans with Disabilities Act, which prohibits discrimination on the basis of disability. Not all the vehicles used in a demand-response transportation service operated by a public entity are required to be accessible to persons with disabilities, as long as the system in its entirety provides an equivalent level of service to persons with disabilities as it does to other individuals. An "equivalent level of service" considers response time, fares, service coverage area, hours and days of service, trip restrictions or priorities based on trip purpose, information and reservations service availability, and service availability constraints.[41]

GENERAL OPERATIONS

As discussed earlier, Texas law states that "a political subdivision of this state or a state agency may not impose a franchise or other regulation related to the operation of an automated motor vehicle or automated driving system."[42] As a result, while local agencies in Texas can develop aspirational policies regarding AV operation on roadways within their jurisdiction and can enter into voluntary agreements with AV service providers, they cannot regulate AV service providers (e.g., limiting the number of service operators or number of vehicles).

Local agencies that are pre-empted from regulating AV operations can choose to implement their policies by subsidizing trips that would otherwise not be served in a free market (e.g., subsidizing fares for low-income individuals, subsidizing an operator's trips outside its standard service area). The Building Partnerships section provides examples of ways that agencies and AV companies can voluntarily partner, as well as examples of different operating models for transportation services. One important potential partnership is data exchange, as discussed in detail in the Sharing Data section.

Private entities operating taxi-like services are not required to provide accessible vehicles when the only vehicles in their fleet are automobiles. However, other types of vehicles (e.g., minivans, vans, buses) are required to be accessible, unless the operator has another way to provide equivalent accessible service to riders with disabilities.[43] When an AV service within a jurisdiction offers only automobiles, an agency could consider purchasing accessible AVs (assuming they existed at the time) and making them available to the private operator as means of providing AV service to persons with disabilities. A public agency isn't required to supplement a private operator's fleet to make it accessible. However, a public agency could choose to do so in support of its policies and goals. If an agency chose to do so, then the provisions of 49 CFR Part 37 that apply to public entities would then apply to the service, even though a private entity would be operating the service. As a result, the public agency would need to ensure an "equivalent level of service" is provided, just as if the public agency itself provided the service. In addition, some persons with disabilities would require assistance boarding the vehicle and securing their mobility device, which would require the presence of an attendant on board the AV. Given the current tendency of AVs to brake hard in unexpected situations, which could be painful for some persons with disabilities, and the need for an attendant, a better solution in the short term might be to provide accessible service using human-driven vehicles.

AGENCY OPERATIONS

Agencies can direct policies toward their own internal operations as a means of making sure that AV-related issues are considered and addressed by all relevant city departments. Potential departmental and regional partners are discussed in the Building Partnerships section. In addition, many of the policy topics discussed in this section are ones that would be implemented by city departments (e.g., planning, public works, community development) through regulation or standards.

Policies can also be directed toward community outreach to provide opportunities to educate the public about AVs, regularly communicate the status of AV deployment in the community, and gather input about proposed agency policies and regulations.[44] Urbanism Next provides guidance on best practices for public engagement related to AVs.[45]

Equity

Equity policies are essential to ensure traditionally underserved communities are not ignored by new mobility technologieshat potential negative impacts of AV technologies are not disproportionately borne by those communities, and that workers who lose their jobs as a result of automation have opportunities to be retrained and employed. This section is organized according to the main equity policy categories defined by The Greenlining Institute and shown in below.[46]

Source: The Greenlining Institute (2019). Autonomous Vehicle Heaven or Hell? Creating a Transportation Revolution that Benefits All.

The Greenlining Institute's Mobility Equity Framework Goals

1

INCREASE ACCESS TO MOBILITY

1. Affordability
2. Accessibiity
3. Efficiency
4. Reliability
5. Safety

2

REDUCE AIR POLLUTION

1. Clean Air and Positive Health Benefits
2. Redution in Greenhouse Gases
3. Reduction in Vehicle Miles Traveled

3

ENHANCE ECONOMIC OPPORTUNITY

1. Connectivity to Places of Employment, Education, Services, & Recreation
2. Transportation-Related Employent Opportunities
3. Fair Labor Practices
4. Inclusive Local Business Economic Ativity

Source: The Greenlining Institute (2019). Autonomous Vehicle Heaven or Hell? Creating a Transportation Revolution that Benefits All.

ACCESS TO MOBILITY

Service Coverage Area

In a free market, private operators might choose to serve the densest, safest, and most profitable portions of a community, which are typically areas that already have the best mobility options. Depending on an agency's ability to regulate AV services, the agency can require or encourage service provision both to traditionally underserved communities and to community members' destinations (e.g., jobs; education; government, health, and food services; recreation).[47, 48, 49] These policies may follow similar approaches to those many cities implemented for e-scooter fleets, requiring them to be distributed and re-balanced to serve all zones in the deployment area.[50]

Active Transportation Infrastructure

Improving walking and biking infrastructure is important for providing a variety of safe mobility options and avoiding the need to have to pay to use AVs to safely make trips that could have otherwise been made on foot or by bike. Walking and biking are also the primary access modes for most public transit trips. Agency policies can prioritize infrastructure improvements, including upgrades to meet ADA standards, in traditionally underserved communities and anywhere within the walk- and bikeshed of transit stops. As discussed in the Public Works policy section, an agency can also update its street design standards to prioritize non-auto traffic and manage traffic speeds to encourage a safer walking and biking environment.[51, 52, 53, 54]

Information Access

Potential users of AV services may have limited English proficiency. Polices can require or encourage providing information about how to use the service in other common languages spoken in the community, and providing information in multiple formats (e.g., print, web, app) to avoid technological barriers to obtaining information. Policies can also direct education and outreach efforts to target specific communities that may not respond to passive forms of information provision.[55, 56, 57]

Reservations and Payments

Policies can require or encourage providing multiple means of making reservations and paying for AV services. SB 2205 prohibits local agencies from requiring options or regulating operations of AVs, but agencies can encourage AV operators to provide accessible payment options. Some users may be unbanked or underbanked (including children and youth) and not have access to credit or debit cards. Providing cash, direct-debit, and/or SMS-based (e.g., payment through the phone bill) options for ride credit expands the number of people with access to AV services. Similarly, providing phone-based options (e.g., call center, text) for ordering service minimizes technological barriers for those who do not have a smartphone, or have difficulty using one.[58, 59, 60, 61]

Pricing

Transportation costs are often a significant portion of low-income households' expenses: "the poorest 20% of Americans spend 40.2 percent of their income on transportation."[62] Policies can support fare-subsidy programs for low-income households to reduce this burden. These policies can be crafted in a way that supports the use of public transit where it is the most efficient option. In addition, policies supporting improvements to active transportation infrastructure help promote the usage of the cheapest, healthiest mobility options.[63, 64, 65]

Pricing can also be used as a policy tool to discourage transportation modes (e.g., single- or no-occupant passenger vehicles) that work against an agency's goals (e.g., congestion, climate, pollution) and as a means for generating revenue to subsidize and encourage greater use of preferred modes. A local agency's ability to charge particular fees or taxes may be pre-empted at the state level, but potential revenue sources include parking fees for using the curbside or municipal lots, and per-trip fees assessed on shared-ride services.[66]

Data Usage and Data Privacy

As discussed later in the Data Sharing section, the data generated by AV vehicles and services can support a variety of agency planning functions, including assessing the equitable distribution of AV services. Policies can be developed to require or encourage data-sharing activities. Policies are also needed to control the use of personally identifiable data that can be collected by AV vehicles or services, such as an individual's trip patterns.[67], [68], [69]

Other Access-Related Topics

Other topics that can be considered as subjects for policymaking include the following:

- Ensuring that AV-supportive infrastructure investments and maintenance activities (e.g., refreshing pavement markings, installing roadside communications equipment) are distributed equitably, allowing AVs to operate in all portions of a community.[70]
- Ensuring AV services are accessible to persons with disabilities, even when not specifically required by the ADA, and that services can accommodate a person's goods (e.g., groceries) and mobility aids.[71]

PUBLIC HEALTH

Lower-income neighborhoods often experience higher rates of public health–related issues, including air and noise pollution, unsafe walking and bicycling networks, and crime. Policies to encourage the use of cleaner transportation modes, to improve transportation safety for all modes, to provide access to curb-to-curb AV services (particularly at night), and to provide access to health-, food-, and recreation-related destinations, for example, will also provide public health benefits for all who live in the community. Policies can also direct emergency evacuation planning and the potential use of AVs to evacuate a community's residents.[72], [73]

ECONOMIC OPPORTUNITY

One of the biggest challenges with a transition to AVs will be how to address the large number of persons who may directly (e.g., bus drivers, truckers, mail carriers, taxi and TNC drivers) or indirectly (e.g., auto shop workers trained on gasoline motors) lose their jobs as a result of automation. Many of these people will be members of disadvantaged communities.[74] The Workforce Training section provides guidance on retraining these workers.

Policies can support job retraining. For example, a transit agency could make a policy to offer bus drivers training for other roles within the agency, such as a transit planner or a vehicle maintenance worker. Public agencies could also provide hiring preferences for persons who have lost jobs to automation and have been, or are being, retrained for new roles.[75]

Agencies sponsoring pilot projects, as well as agencies with the ability to regulate AV services within their community, can implement policies that support employee job quality, such as access to health benefits and family wages. Agencies can also give preferences to local businesses when contracting or purchasing AV-related services as a means of supporting the local economy. Finally, mobility-related policies can also support economic opportunity for community residents by supporting the provision of safe, reliable, inexpensive transportation to jobsites for community residents.[76], [77] Balancing potentially competing uses will require significant outreach and education efforts

Public Works

STREET DESIGN

An agency's street design standards can help support many of an agency's goals, including those related to safety, economic development, mobility, and the environment. The introduction of AVs onto public streets can provide an impetus for agencies to consider how their street standards may need to evolve.

In a future where nearly all of the vehicle fleet is automated, AVs are expected to be able to operate in narrower lanes and CVs are expected to be able to travel in closely spaced platoons, increasing the capacity of an individual travel lane.[78] Both of these factors can support reducing the amount of street width allocated to personal vehicles (on the next page).

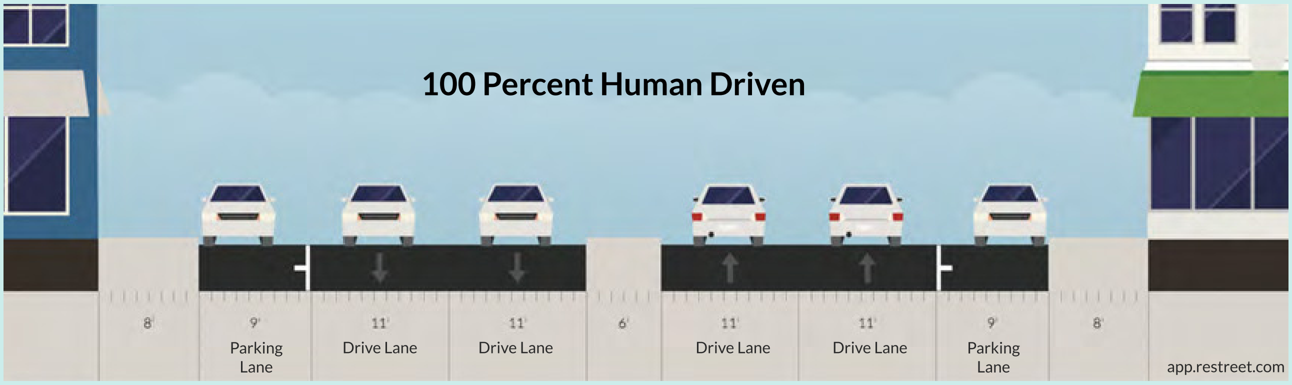
Agencies may have other motivations for reallocating street space. For example, although AVs may be able to use travel lanes more efficiently, they also introduce the potential for additional vehicle travel, particularly zero-occupant travel. Transit vehicles will continue to be the mode with by far the highest person-moving potential per lane. Agencies may also wish to reallocate street space to create protected bicycle networks, to create more sidewalk space to support the economic activity of adjacent businesses, to provide space for landscaping or water retention features, or to provide more passenger and delivery pick-up and drop-off sites, among other possible uses.

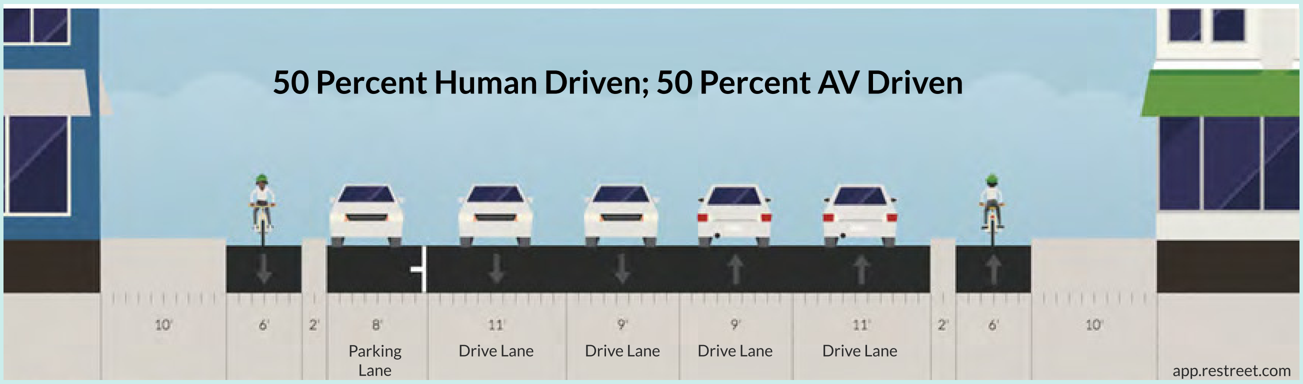
Balancing these potentially competing uses will require significant outreach and education efforts, but these efforts are necessary for making sure AVs and other travel modes are accommodated in ways consistent with community goals.[79] NCHRP Project 15-78, in progress at the time of writing, is developing a guidebook and decision-making framework on reallocating the street right-of-way.[80]

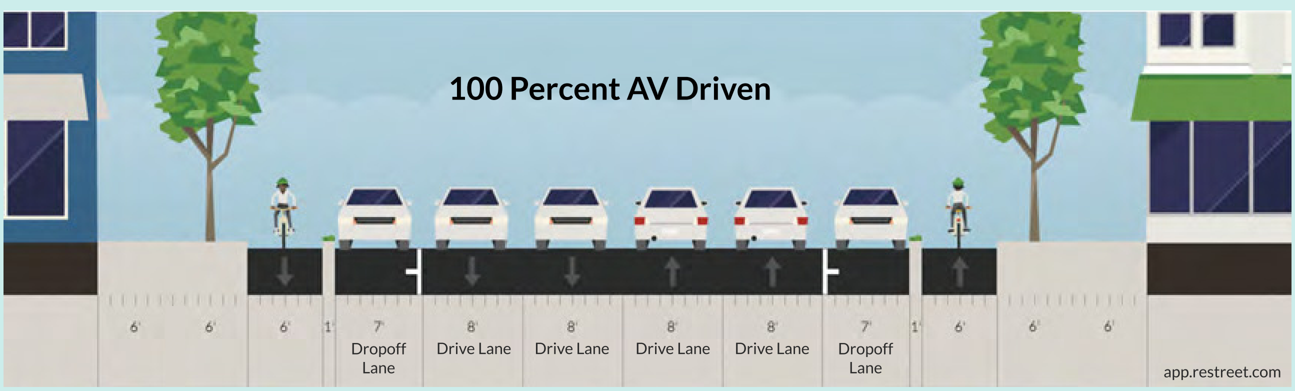
Other street design issues associated with AVs that a local agency may need to address include:[81]

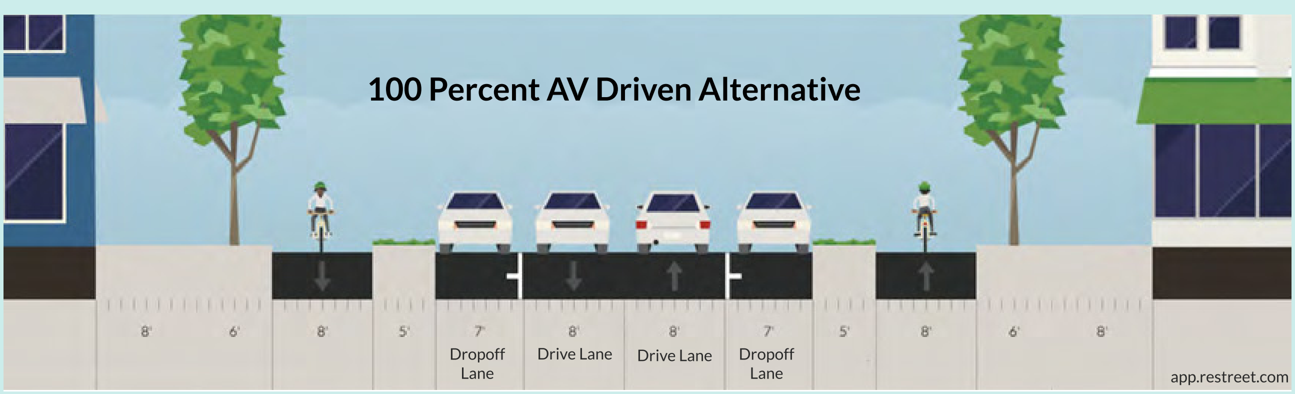
- Checking whether design loads for pavement and bridges are sufficient for trends such as truck platooning.
- Checking whether vertical and horizontal clearances are sufficient for vehicles equipped with a variety of sensors on the roof.
- Checking whether signing and striping standards and maintenance practices support the safe operation of AVs.

Potential Streetscape Transformations









American Planning Association, PAS Report 592

CURB MANAGEMENT

Changes in Curbside Usage Patterns

Increased use of AVs and micromobility modes will both increase the demand to use curbside space and potentially shift the demand from curbside parking to other users, including passenger and delivery pick-up and drop-off. In addition, policies on reallocating the street right-of-way may generate the need to reserve space for preferred modes, such as transit or bicycles. Agencies will need to consider whether their existing curbside zones are adequate to support anticipated demand patterns.[82] Agencies should identify funding and establish goals for reallocating curbspace, considering user experience and the agency perspective.

NACTO recommends prioritizing "uses and modes that serve the most people in the most sustainable fashion," along with the delivery needs of adjacent land uses. NACTO also recommends that local agencies inventory curbside uses and regulations and collect data about how the curbside is used. This information is invaluable for supporting decisions to change curbside uses and creates agency-owned and -maintained data sources that can be used in data-sharing negotiations with AV operators.[83] Currently available data collection methods include manual field observations, video data collection, and citation data, as well as real-time and archived data from existing parking payment systems or parking space sensors. Use a data-driven approach, including multimodal data, to make decisions on changing curbspace management practices and to select the appropriate tools, such as in-ground sensors, cameras, license plate readers, or other strategies.

Real-time Parking Availability

The technologies to provide real-time parking availability and pricing information include mobile apps, websites, and on-street signs. Apps such as ParkMobile, which is operational in the Dallas area, also facilitate a variety of mobile payment options. Agencies and private parking operators could choose to invest in the needed technology to collect real-time parking data and then make the data available to software and CV developers. This information could be used to efficiently guide drivers (human or automated) to available parking in a desired price range and parking duration in the vicinity of a desired destination. The information would also be a useful local agency bargaining point when developing data-sharing agreements.

Demand-Based Pricing and Time Limits

Establishing pricing and time limits for parking and curb usage based on demand can help distribute demand more evenly for parking, reducing situations where vehicles are circling blocks with no parking available, even though multiple parking spaces are available on other nearby blocks. Raising prices for premium spots near popular destinations at peak times and setting time limits can also encourage more turnover of spots.[84] Prices, time limits, and allowed uses could change dynamically based on the time of day to best serve the demand for the curb (such as goods loading/unloading zone in the early mornings, passenger loading zone in evenings, and long-term parking overnight).[85] These strategies have been deployed by many cities, but determining prices, time limits, and allowed uses is an iterative process informed by constant evaluation and adjustment and the local context.

Use a data-driven approach, including multimodal data, to make decisions on changing curbspace management practices

Consistent Enforcement

Enforcement is essential to managing the curbside and minimizing vehicles blocking facilities for people walking and biking. Automated enforcement technologies, whether by pole-mounted license plate readers or vehicle-mounted cameras, have proven effective and unbiased in application.[86] The City of Dallas uses automated license plate readers for parking enforcement and a 2016 Downtown Parking Study in Plano recommended modernizing the city's handwritten system to be digital.[87], [88] It is important to coordinate with enforcement and educate officers on new practices.

Parking Governance

In the NCTCOG region, parking regulations and enforcement are typically managed by local governments such as local departments of transportation, public works, or the police department. In many cases, different divisions or departments within these local governments set parking policies, enforce policies, and handle the adjudication. Other governance strategies include parking benefit or management districts, which are public or private management entities that manage parking spaces within a specific boundary and reinvest the parking revenues into improvements. It is important to identify potential parking stakeholders, including the DOT, other agencies, businesses, policymakers, and the public, and develop a clear communication plan among the players.

Additional Sources of Information

NCTCOG has developed best-practice guidelines for parking and curbside management.[89] Another source of information is ITE, which provides guidance on curbside management in general.[90] NCHRP Project 20-102(26), in progress at the time of writing, is producing a guidebook on dynamically managing the curbside (e.g., by changing allowed uses by time of day, by adjusting pricing to reflect time-of-day demand).[91]

INFRASTRUCTURE

Planning for Technological Change

Technology changes quickly, and agencies should expect to need to upgrade their technology more frequently than they may be accustomed to. Because of the cost involved with maintaining and upgrading technology at a large scale, local agencies should carefully consider how investments in technology or technology support will meet immediate needs and/or support the introduction of new technologies. Importantly, agencies should keep in mind that technology is a means of achieving a goal, rather than being the goal itself. Consequently, agencies should plan for applications of technology, rather than specific technologies, which may change over time.

Because of the current uncertainty around when AVs will become commercially available and what technology standards the industry will settle on, it is not recommended that agencies rush to install technology today in preparation for an AV future. Instead, agencies should consider:

- What agency-owned technology and infrastructure might be needed to support existing or desired AV pilot projects?
- What can the agency begin doing to become ready to support technology needed for future AV deployments?

Infrastructure to Support Pilot Projects

The specific agency infrastructure needed to support a pilot project will depend on the specifics of the project. Related policies can express the agency's commitment to obtaining and/or reliably operating and maintaining the infrastructure.

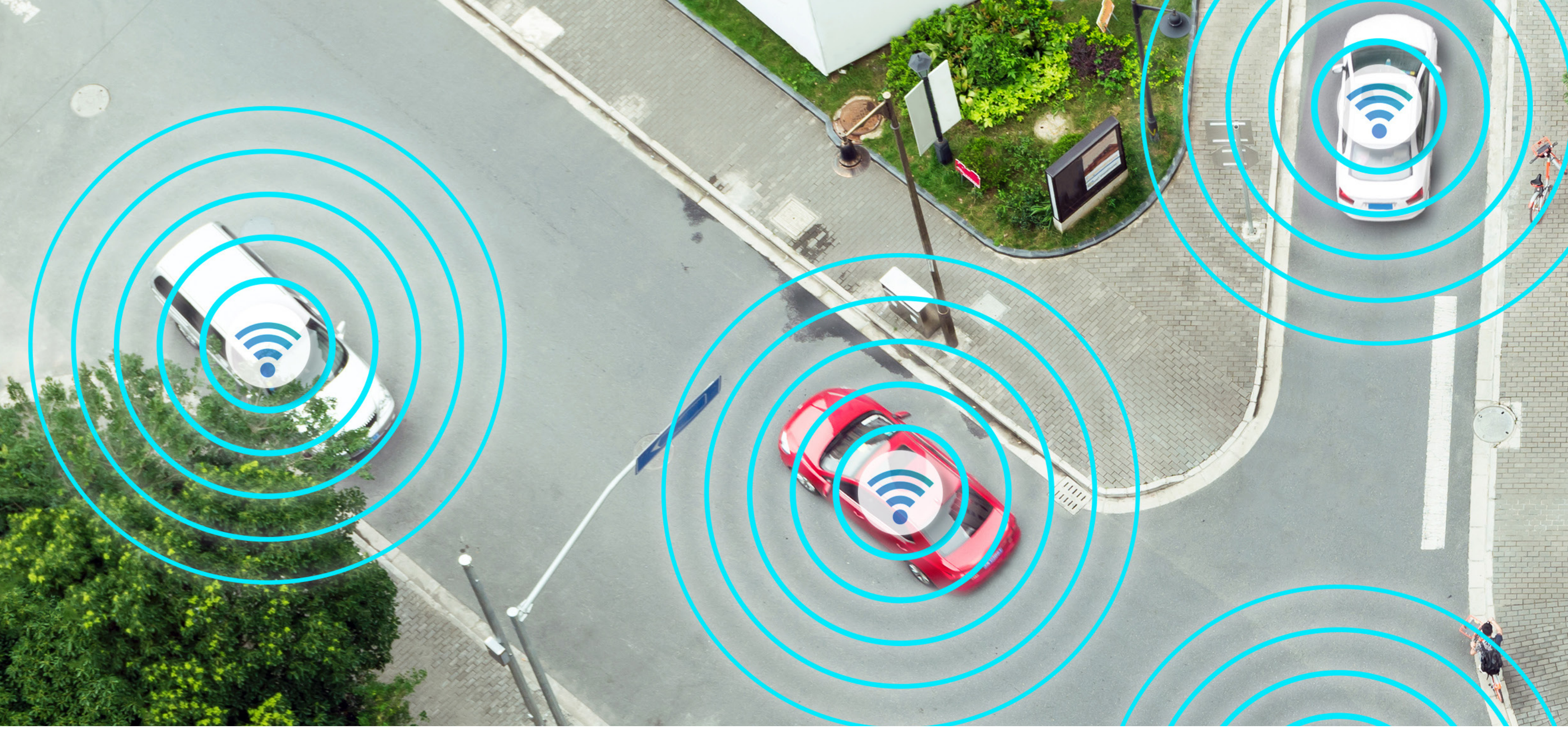
For example:

- A policy to make agency-owned EV-charging stations available to AV companies operating within the agency's jurisdiction.
- A policy to regularly maintain vegetation along a path or roadway used by AVs in a pilot project, if the AV's control system may be easily confused by waving branches or vegetation that grows over the edge of a path.
- A policy to regularly inspect and, as needed, refresh lane markings used by AVs to maintain their lane position.
- One or more policies that support cooperation with a local transit agency to provide transit signal priority; for example, supporting the installation of related equipment in traffic signal controllers, prioritizing bus operations at traffic signals, or prioritizing staff time required periodically to adjust signal timing to optimize the provision of signal priority.

Infrastructure to Support Future Technology Needs

Agencies can also use policy to prepare themselves for future technology needs. For example:

- Winter Haven, Florida implemented a "dig once" broadband policy in 2004, where the city installs conduit and fiber whenever feasible as part of other infrastructure projects. Fiber bandwidth can be leased to private companies and is also available to support the city's own technology applications.[92]
- Counties could use fee incentives to encourage private telecommunications companies to expand high-speed Internet infrastructure into rural portions of the county.[93]
- Chicago changed its municipal code in 2020 to prepare its infrastructure to support the projected growth in EVs. The changes expand the scope of the new developments that must install EV charging facilities, increase the percentage of total parking spaces that property owners must designate for EVs, and specify that EV-designated parking spaces must be equipped with an electrical plug.[94]
- Agencies could develop a policy that major roadway projects include sufficient right-of-way to install conduit for communications technology. In rural areas with spotty or no cellular coverage, the policy might address providing right-of-way and reducing challenges to obtaining development permits or access permits for cell towers.[95]



Public Transit

As mentioned earlier, in an AV future, transit vehicles will continue to be the most efficient way to transport large numbers of people per a given width of roadway space. However, public transit will face a number of challenges that could be addressed through policy:

- People may be willing to travel farther if the car is doing the driving. If true, this effect could lead to more sprawl, but it could also lead to revitalization of rural communities, depending on land-use policies.[96] Transit agencies could adapt by developing more intercommunity and park-and-ride-based express routes, which could become more financially feasible if operated by automated buses. Commuting by bus would lose its current advantage over human-driven vehicles of being able to use one's commuting time productively in other ways. However, partner agency policies prioritizing buses and other shared-ride vehicles on congested roadways, assessing roadway usage fees based on vehicle miles traveled, and reducing parking supplies (thus increasing costs) could help provide time and cost savings for travel by transit.
- People may be more likely to use shared-ride AVs for its convenience.[97] However, shared-ride AVs may be more likely to compete with walking and biking trips for short trips, while more and longer automobile trips will tend to increase roadway congestion. Shared-ride AVs could also support transit by providing first-/last-mile access to transit, increasing the pool of potential riders served by a transit route and avoiding the need for transit agencies to provide unproductive service into low-density areas. Transit agencies could develop policies encouraging partnerships with shared-ride AV services for transit access and one-shop fare payment. Partner agency policies could prioritize transit vehicle movement on city streets and charge fees for shared-ride trips based on whether they compete with or complement transit service.
- People may feel less secure traveling with strangers in an automated bus without an attendant.[98] However, there is also a safety-in-numbers effect. Automated rail transit systems have operated safely in many cities and airports without staff on board, relying instead on video surveillance and emergency call devices. Agency policies could require these and similar security

measures on automated buses and smaller shared-ride AVs.

- Public transit agencies are often significant employers in a community and provide good-paying jobs that would be lost if automated.[99] As discussed above in the Equity policy subsection, agency policies to provide retraining and give hiring priority to persons who have lost their jobs to automation could help counteract this issue.

There are also potential opportunities for transit agencies in an AV future. Lower operating costs as a result of automation could be reinvested in the form of increased service levels. For example, policies could prioritize adding service at off-peak times.[100] Because personal AVs could provide improved mobility options for seniors and persons with disabilities, the demand for costly ADA paratransit service could be reduced, with automated accessible transit vehicles (some still requiring an attendant, for example to secure mobility devices) used for those without access to a personal AV.[101] In addition, buses traveling on predictable, mappable, fixed routes could become an early urban AV use case, giving transit a head start on deployment over shared-ride AVs that would need to operate everywhere in an urban environment.[102]

Transportation Planning

An agency's transportation plan(s) describe how the agency will provide, manage, and/or support transportation infrastructure and services in a way that supports the agency's broader goals. These plans also express or reference the agency's transportation-related policies. As such, it is important that the assumptions used in developing the plans reflect the potential effects of AV technology. These assumptions include potential changes in where growth occurs and changes in travel demand pattern, due to AV usage, telecommuting, changes in transportation costs, etc. Scenario planning techniques can be applied to test different combinations of assumptions to identify which transportation projects and services are most likely to be needed.[103]

Data Sharing

As discussed later in the Sharing Data section, AV-related data can support agency functions in a number of ways:

- Monitoring compliance with agency regulations, policies, and/or contracts.
- Evaluating the performance of AV projects.
- Supporting an agency's planning, operations, and decision-making functions.

Given its usefulness, most sources recommend that agencies actively pursue obtaining data from AV operators. Where permitted by state law, local agencies can develop policies requiring data reporting as a condition of operation. In other states, such as Texas, local agencies can establish voluntary data-sharing agreements; the Sharing Data section provides guidance on how to do so. For example, policies that establish an agency's willingness to share its data with AV operators who are willing to share their data with the agency can be a starting point for negotiating a data-sharing agreement.

Given that individual travel patterns can be identified from AV origin–destination data, agencies may need to review and update their data management and privacy policies to ensure that personally identifiable data "are protected and managed appropriately."[104]

Safety

Although a local agency's ability to regulate AV safety may be superseded at the federal or state levels, local agencies can promote improved safety through policies that:

- Lower urban speed limits to levels appropriate to the roadway context and that consider the safety of persons walking, biking, and scooting along and across the roadway.[105] Whereas human drivers may be prone to violating speed limits, AVs can be expected to respect designated limits.
- Require (where allowed by state law) or encourage the prompt reporting of crashes involving AVs within the agency's jurisdiction, and regular reporting of the number of times a human operator had taken control of an AV and the reasons why.
- Encourage data sharing that provides real-time notification of AV crashes and hard-braking events to traffic management centers, to allow appropriate responders to be dispatched to the scene.
- Require that video surveillance, location monitoring, the ability to request emergency help, and a process for providing help when requested be provided on shared-ride AVs operating within a jurisdiction.

Pricing

Trends toward AVs and EVs, along with potential increases in the use of shared mobility modes, will have significant effects on transportation funding at all levels of government. In particular:

- Greater use of EVs and fuel-efficient vehicles will reduce revenue from fuel and motor oil taxes.
- AVs can be programmed to comply with all traffic laws, reducing revenue from traffic fines.
- Increased use of shared vehicles could reduce the demand for on- and off-street parking and thereby reduce parking revenue.
- Increased use of shared vehicles could reduce vehicle registration fee revenue and sales tax revenue from the sales of new vehicles.
- AVs could lead to persons living farther away from central cities and could generate zero-occupant vehicle trips (e.g., returning home empty after dropping someone off at work), both of which could result in increased toll road demand and revenue.

- To the extent that AVs and other societal changes decrease demand for transit service, transit fare revenue would decrease; however, transit costs could also decrease as a result of adopting automation.

Local entities should identify their current revenue sources, collect data to understand trends and potential vulnerabilities in a shared, electric, and automated future, and examine potential alternative revenue streams to fill transportation funding gaps, some of which may be limited by state and local policies. These potential streams include:

- Curbside pricing mechanisms
- Replacing on-street parking with publicly owned remote parking facilities for AVs
- EV charging fees
- Charges for real-time access to agency data
- Congestion charges for dense urban centers
- Public–private partnerships for new, upgraded, or expanded transportation infrastructure
- Increasing development impact fees
- Increasing non-transportation taxes and fees
- Increasing local registration fees

Another potential strategy is usage-based fees, which would be led at the state level, but could be supported by local agencies. Vehicle Miles Traveled (VMT) fees are road user charges based on the number of miles traveled by a vehicle. VMT fees may be applied to all vehicles or may be applied in different ways to certain vehicle types (like trucks) or to certain operating conditions (like an AV or rideshare vehicle not carrying any passengers). VMT fees are being explored in several states to address the issue of declining revenue from fuel taxes as fuel economy increases. They are marketed as a simple switch from a "pay-per-gallon" to a "pay-per-mile" option that follows a "user pays" principle for infrastructure funding. This allows the state to receive revenue from hybrid and electric vehicles that contribute less or no gas taxes but still cause wear and tear on the road.

The primary motivation of VMT fees is to serve as a replacement for declining gas tax revenues. VMT fees should be coupled with land use policies that make shorter trips more feasible and are likely to be just one additional piece of the puzzle to replace declining gas tax revenue. For some, VMT charges raise privacy concerns if the government can track where the vehicle went. Instead, charging by the hour when the vehicle was used might help alleviate privacy concerns about knowing where the vehicle went. At the state level, VMT fees could also be collected annually at the time of vehicle registration by reporting odometer readings.

As an example, Oregon's OReGO program has inspired other states to explore VMT fees as a revenue-neutral substitute for the gas tax. The program covers electric vehicle drivers as well. In California, the Road Charge Pilot Program was launched in 2016 and ran for nine months, with over 5,000 vehicles across the state participating. The pilot program was enabled by Senate Bill 1077 passed by the California State Legislature in 2014 and administered by the California Department of Transportation (Caltrans). Like in Oregon, the fee was set at 1.8 cents per mile to be revenue neutral compared to a gas tax (the rate was established by taking a five-year average of the gas tax and dividing by average miles per gallon of the statewide fleet).

> VMT fees may help address the issue of declining revenue from fuel taxes as fuel economy increases.

Procurement, Contracting, and Regulation

PROCUREMENT

The National League of Cities recommends that cities "assess their current procurement policies and look specifically at whether these policies might inadvertently erect any roadblocks to purchasing the technology and smart infrastructure necessary to support AV deployment." This assessment can include policies related to unsolicited proposals (e.g., for an AV pilot) and contractual requirements that could inadvertently exclude new technology companies or public–private partnerships.[106]

Local agencies can also assess their procurement processes to identify where they can become faster, less bureaucratic, and more flexible. Urbanism Next provides several examples of state and local approaches to innovating the procurement of technology services.[107]

As discussed in the Workforce Training section, some cities have issued requests for information (RFIs) for AV pilots. This approach both informs the agency about the latest technologies and approaches to addressing the agency's needs (as stated in the RFI) and provides transparency and fairness in the procurement process.[108]

CONTRACTING

Agencies that are sponsoring AV pilots can build reporting, accountability mechanisms, and incentives into the contract.[109] The contract language needs to be clear enough to be enforceable,[110] but provide sufficient flexibility to "allow the agency to adjust as needed to account for lessons learned during program implementation."[111]

REGULATION

As discussed above in the Agency Regulatory Powers subsection, local agencies in Texas, as well as agencies in states with similar local pre-emption laws, are limited in their power to regulate AVs operating on public roadways. Elsewhere, some agencies have found regulation to be a useful tool for avoiding negative outcomes and promoting city objectives when new mobility services are being deployed.

The best example of negative outcomes is some cities' experiences with e-scooters, where many companies entered the market and flooded city streets with far more scooters than needed to serve the demand. Outcomes included scooters blocking sidewalks, significant scooter vandalism, unprofitable experiences for vendors, and a poor image of e-scooters and city leadership in the eyes of the public.

Operating or business permits are a tool that agencies can use to ensure fair access to the market, while avoiding negative outcomes. These permits can specify, for example, operating requirements (e.g., maximum number of vehicles, service area, fare payment options), equity-based requirements, reporting requirements, mechanisms for responding to customer or citizen complaints, and fees or taxes (e.g., per-trip fees). The permits can provide incentives (e.g., more vehicles allowed) when specified outcomes have been met and specify penalties if the terms of the permit are not met.[112]

Accountability mechanisms are essential for fair competition between AV operators. However, enforcing regulations takes staff time and agencies should consider which regulations are really important for achieving desired outcomes, versus being merely nice to have.[113] Agencies can use revenue generated from permitted AV operations to cover the cost of staff time needed to enforce regulations. For example, Seattle allocated some of its (non-AV) bikeshare revenue to pay for the cost of bikeshare parking enforcement.[114]

Climate and Health

Policies discussed previously that support the development of AV and related technologies, while limiting their undesired effects, can also have positive effects on achieving an agency's climate- and health-related goals. For example, as discussed in the AV Applications section, AVs are expected to also be EVs. As a result, agency policies that support the adoption of AVs will also support goals related to reducing vehicle emissions. Similarly, policies designed to minimize vehicle miles traveled (e.g., land use policies, pricing policies, policies supporting the use of shared-ride modes) will also reduce environmental impacts (e.g., energy usage, tire wear) and health impacts (e.g., noise pollution). Policies that deprioritize the use of the right-of-way by single- or zero-occupant vehicles, which encourage the use of active transportation modes, and that improve public safety also work to improve public health.

EXAMPLES

The following documents give examples of AV-related policy development processes, policy language, regulations, and/or design standards:

- **Preparation and self-assessment:** National League of Cities, *Autonomous Vehicles: A Policy Preparation Guide*;[115] *NCHRP Report 924: Foreseeing the Impact of Transformational Technologies on Land Use and Transportation*;[116] *NCHRP Report 952: Guidebook for Managing Data from Emerging Technologies for Transportation*[117]
- **Connecting policies to goals:** National Institute for Transportation and Communities (NITC), *Matching the Speed of Technology with the Speed of Local Government: Developing Codes and Policies Related to the Possible Impacts of New Mobility on Cities*;[118] *NCHRP Report 845: Strategies to Advance Automated and Connected Vehicles*[119]
- **Parking:** NITC;[120] American Planning Association (APA), *Planning for Autonomous Mobility*[121]
- **Equity:** Greenlining, *Autonomous Vehicle Heaven or Hell? Creating a Transportation Revolution that Benefits All*;[122] *Urbanism Next, A Framework for Shaping the Deployment of Autonomous Vehicles and Advancing Equity Outcomes*[123]
- **Street Design:** NACTO, *Blueprint for Autonomous Urbanism, 2nd Edition*[124]
- **Curb Management:** NACTO;[125] NCTCOG, *Parking Toolbox*;[126] ITE, *Curbside Management Practitioners Guide*[127]
- **Public Transit:** NACTO,[128] APA[129]
- **Data Sharing:** NACTO[130]
- **Procurement:** National League of Cities, *Autonomous Vehicles: A Policy Preparation Guide*;[131] *Urbanism Next, A Framework for Shaping the Deployment of Autonomous Vehicles and Advancing Equity Outcomes*[132]
- **Case Studies:** Connect Arlington;[133] National League of Cities, *Autonomous Vehicle Pilots Across America*;[134] *Urbanism Next, Perfecting Policy with Pilots: New Mobility and AV Urban Delivery Pilot Project Assessment*[135]

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04 BUILDING PARTNERSHIPS

This section provides guidance on developing partnerships, engaging stakeholders, and getting a seat at the table. It also describes potential changes to the way an agency conducts business that may become necessary when AVs are being deployed.

A local agency may seek to partner with an AV vendor to address a local need, or an AV service provider may now or in the future seek to establish operations within an agency's jurisdiction. In either case, a partnership is key to achieving outcomes that are compatible with an agency's goals and objectives.

Partnerships are not only between an agency and an AV vendor or service provider. It is also important to involve the decision-makers, policymakers, and local communities who help shape outcomes and who are affected by the outcomes of policies and decisions. Additional partnerships may be required, depending on the use case. For example:1, 2

- Partnerships are usually required within agencies, for example, to identify policy changes that might be required to accommodate a new AV technology, to identify data needs and opportunities for data exchange, and to identify needed upgrades to their in-house technologies.
- Projects involving EVs may include utility provider, vehicle manufacturer, and/or private developer partnerships, depending on the project specifics.
- Transportation services that require access to the street curb may require partnerships with emergency services agencies, transit providers, business interests, and public and private micromobility providers.
- Agencies seeking to attract technology companies may need to consider their housing supply and costs and transportation services (which affects location choice). Pursuing this goal could involve partnerships with private developers and transit providers, as well as with agency policy-making staff and decision-makers.
- The deployment of new technologies brings workforce development opportunities to install and maintain equipment and to collect and analyze data. This topic is discussed in detail in Section 7.

KNOWLEDGE AND EXPERIENCE IS CONTINUALLY EVOLVING

AV vendors and service providers know a lot about their own technology, but often not much about local agency policies and processes. Conversely, local agencies have considerable experience with regulating land development and commercial services, but often lack staff expertise in technology-related matters.[3] Consequently, both parties have a lot to learn from each other. Furthermore, because AV technology and experience with that technology is continually evolving, the process of developing agency knowledge about AVs must also be continual.

Some agencies deliberately seek to be at the forefront of AV deployments. Benefits of this approach include hands-on experience with AV technology's abilities and challenges, learning how the public reacts to the presence of AVs, and developing a reputation as an innovative, business-friendly location.[4]

Other agencies would prefer to let others take the risks first before committing to AV projects of their own. This approach allows an agency to apply the experiences of others to a hopefully smooth AV deployment in the future, one with more predictable outcomes. Nevertheless, because Texas law allows self-driving cars on the state's roads and driveways if they follow traffic laws and have recording devices and insurance,[5] it is important for local agencies in Texas to prepare now for the presence of AVs, even though they may not have any plans for AV pilot projects of their own.

The impacts of AV technology on the transportation system and on land use and travel patterns will be significant. The impacts of many new technologies are currently unknown, with many technologies still in the research and development stage. Until the technologies are in the hands of the general public in real-world use, and until the sustainable price point of the new technologies or services is known, the long-term, real-world impacts will be unknown. Planning agencies such as NCTCOG need to consider multiple potential future scenarios and frequently measure system performance to monitor trends and learn how these new technologies are impacting North Central Texas communities and roads.

WHAT MAKES A GOOD PARTNER?

Characteristics of a good partnership between an AV provider and a local agency include those listed in the table below.

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[6]
Nimbleness	Adopt less-formal approaches to working with AV providers funding their own pilots,[7] empower agency staff to adjust regulations and fees within limits to adapt to evolving knowledge and technologies[8]	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

In addition to the characteristics listed in the above table, other partners involved in an AV deployment (e.g., transit agency, local university, agency IT department) should contribute experience and/or expertise in areas where neither the local agency's planning or engineering staff nor the AV provider have expertise. When planning and engineering staff already have established relationships with these partners for other types of projects, it can be easier to get them to commit to participating in an AV deployment project.[9]

The degree to which partnerships are formalized can depend on who is funding the project and state regulations regarding AV operation. In case studies reported by the National League of Cities,10 cities that were interested in supporting AV development, but were not yet at the stage to sponsor their own pilot, often took on the role of facilitator. These cities worked internally to update their policies and processes to support AV development, and worked informally with AV companies operating, or considering operating, within their city. Boston, which had some ability to regulate AV operation on its streets, identified two desired pilot projects, chose AV providers willing to operate pilots at their own expense from a pool of applicants, and signed memoranda of understanding (MOUs) with the providers that provided a high degree of flexibility to respond to issues as they arose. Cities funding their own pilots generally issued formal requests for proposals (RFPs) and contracted with the selected AV vendor.

An operator may not have significant AV experience (and an AV vendor may not have significant experience as a transit operator). When interviewing AV providers, it is worthwhile to have a standard checklist that covers both AV-specific questions and general questions regarding operating experience. This need will become more urgent as deployments scale up to cover larger fleets (greater than 2–3 vehicles). Sample question agencies may want to include in their checklist when evaluating AV operators, include :

- Will the vendor require exemptions or waivers from NHTSA or other agencies to operate on public roadways?
- Will the vendor require any additional infrastructure or maintenance (e.g., trimming vegetation) to operate in the proposed service area?
- Can the vendor provide the following operating statistics from other relevant deployments:
    - Safety history (number of incidents, number of near misses)
    - Average travel speeds
    - Maximum posted speed of roadways used by the service
    - Total revenue hours operated
    - Total revenue miles operated
- Does the vendor require an on-board attendant?
- What are the storage, charging, and spare ratio requirements of the proposed solution?
- Does the vendor have an established risk management plan to address planning, implementation, and operation of the proposed solution?
- Does the vendor provide full operational services (e.g., scheduling, website or app updates, and on-board attendants)?
- What kind of communications equipment does the AV use (e.g., low-/mid-/high-band 5G cellular, dedicated short-range communications (DSRC), or something else)? Will limited infrastructure availability and/or technological issues with the communications band constrain the vehicle routing or service area?
- What data can the vendor share with a public agency on their operations?
- What are the insurance coverage requirements for the vendor?

The Preparing Infrastructure section later in the guidebook outlines questions local agencies can ask the AV vendors to understand what infrastructure readiness is needed to support the technology.

Use a standard checklist that covers both AV-specific questions and general questions

ENGAGING STAKEHOLDERS

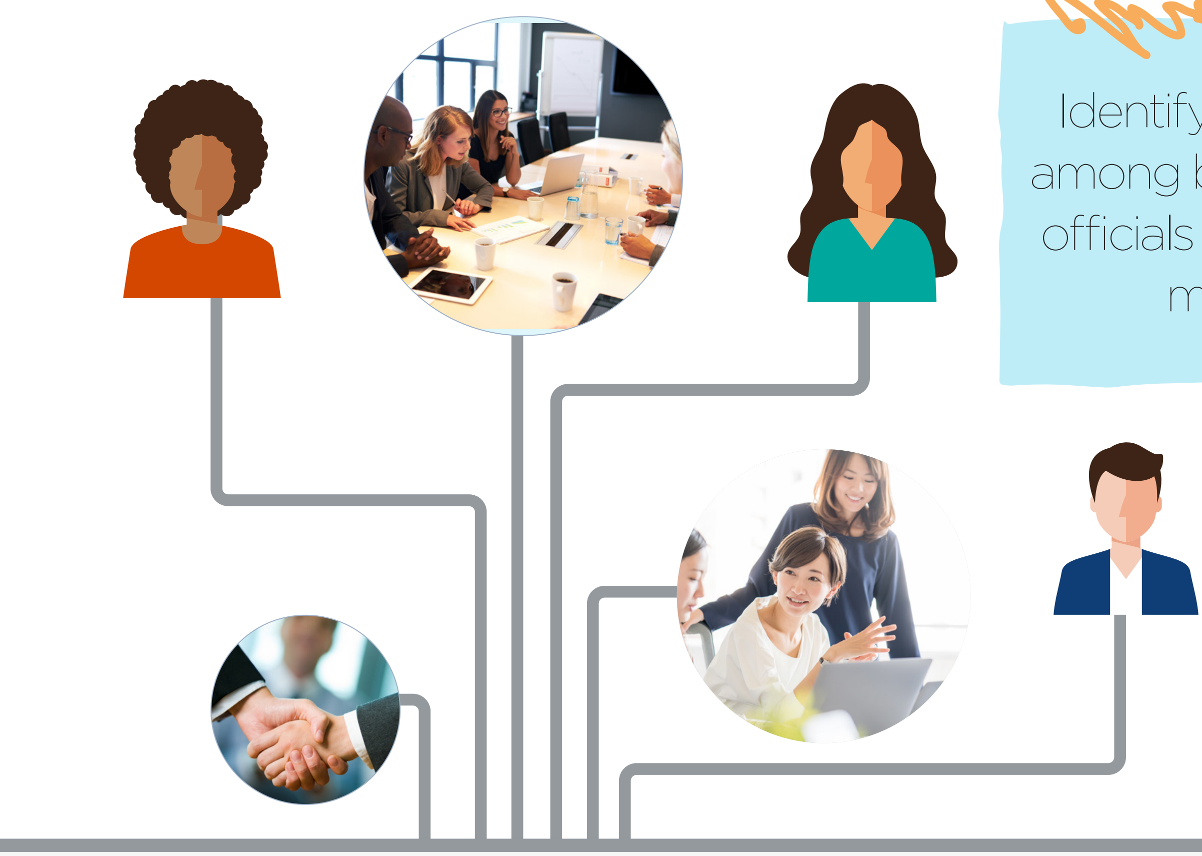
AV projects involve some different stakeholders than a typical planning project, such as AV vendors and technology companies, but many stay the same, and there is no need to reinvent the wheel. Importantly, many community stakeholders will not have a broad understanding of AVs or AV technology, how they might use AVs, or how they might interact with AVs. As a result, public agencies and AV vendors need to "[empower] community members with the information they need in order to make informed decisions."[11]

To introduce residents of Chandler, Arizona to AVs, Waymo held a weekend demonstration of AV technology that was attended by several thousand people and continued to follow up by bringing vehicles to community events. Pittsburgh, Pennsylvania established AV working groups incorporating a broad cross-section of city residents, city departments, and partner agencies. Arlington's first pilot involved a free autonomous shuttle to transport spectators between remote parking lots and the city's entertainment district, giving a variety of residents and visitors the opportunity to try AV technology first-hand.12

It is often not the case that if a city issues AV-supportive policies or proclamations, AV vendors will come. Many larger cities have had to hold round tables with industry representatives and issue requests for information (RFIs) to attract interest. Smaller cities could look to join or create a regional partnership to attract AV pilots and potential grant funding, and to coordinate policies and processes across city boundaries.13

GETTING A SEAT AT THE TABLE

As with many other types of new initiatives, it is essential to identify high-level champions early on who can generate internal and external support for an agency's AV activities. Given the potentially broad effects of AVs on both the community and agency operations, it is important to identify champions among both



Identify champions among both elected officials and agency management.

elected officials and agency management. The support of political leadership is necessary to obtain funding for the agency's AV activities and to identify issues important to elected officials that potentially can be addressed by AVs. The support of agency top and departmental management is crucial to prioritizing staff time and agency resources, avoiding silos within departments, and identifying departmental responsibilities.14

Once champions have been identified, next steps that agencies can consider to increase their chances of hosting an AV pilot include:

- Demonstrating a willingness to engage with AV partners by updating agency policies to support AV testing and deployment.
- Attending trade organization meetings and conferences to develop contacts.
- Hosting workshops or roundtables with industry representatives.
- Participating in regional efforts to attract AV pilots.
- Issuing requests for information (RFI) asking AV vendors for their approaches to addressing a transportation problem of interest to the community.
- Bringing money to the table to help subsidize AV testing.

CHANGING AGENCY PRACTICES

The combination of rapidly changing technology and potentially broad societal effects due to AVs means that agencies may need to develop new ways of doing business when working with AV projects. Some examples of practices that may need changing include:[15]

- Breaking down data silos that may have developed due to agency culture or technological reasons and updating data management practices.
- Encouraging cooperation among offices, such as through an AV working group or task force.
- Empowering staff to adjust fees and rules implementing regulations within defined limits, rather than requiring the agency's governing body to make these changes every time.
- Being proactive: anticipating potential needs as a result of AV deployments and planning for them, rather than reacting to the consequences afterwards.

NACTO's Blueprint for Autonomous Urbanism, 2nd edition, provides recommendations for specific actions that the following local agency offices and departments can take to prepare for AVs:16

- Mayor, city manager, and city council
- Transportation and public works departments
- Transit agency or department
- Taxi commission
- Parking authority
- Planning department
- IT department
- Employment and administrative services
- Sustainability, energy, and environmental offices
- Fleet services
- Police and fire departments
- Finance department

POTENTIAL OPERATIONS MODELS

Agencies have sponsored or encouraged pilot AV deployments for a number of reasons, including testing and assessing the viability of AV technology, gauging public interest, identifying potential use cases, to be at the forefront of new innovation, and to learn about what changes in agency policies and processes may be necessary.17 A variety of operations models have been applied to AV pilot projects, including the following:

- Do-it-yourself. The agency procures the technology and manages the day-to-day operations of deployment. In this approach, the agency has the greatest degree of control over the project and can access all the data generated by the pilot. However, agency staff have to learn about the technology and its quirks as they go, and take on jobs they might not have expected, such as trimming vegetation daily along the path used by an automated shuttle. Arlington's Milo shuttle pilot and some cities' bikeshare programs are examples of this approach.
- Plug-and-play. The agency identifies the pilot's goals and objectives and issues an RFP to obtain the services of an AV vendor whose technology can meet those objectives. The resulting agreement often incorporates a greater degree of flexibility than on typical services projects, as both the agency and the vendor learn from and adapt to actual operating experiences. The agency can build reporting and compliance requirements into the agreement. For example, Baltimore's micromobility pilot requires reporting from the vendors.
- Subsidy. The agency works with AV service providers already operating within the agency's jurisdiction to fund trips that meet agency objectives (e.g., equity, expanded access to transit) that might not otherwise be commercially viable. This model is currently applied between some transit agencies and traditional TNCs to improve first-/last-mile transit access, and it could also be applied to TNC services using AVs.
- Free market. The agency updates its policies and processes as needed to support the operation of AVs, but lets the market decide how and where (and if) to deploy AVs. Chandler, Arizona and Pittsburgh are examples of this approach. A variation on this approach is a regulated market, where a city or state sets conditions on how and where AVs operate (e.g., restrictions on the number of vehicles or where AVs are allowed to operate; insurance, backup operator, or reporting requirements), but permits any operator who meets those conditions. Portland, Oregon has been considering this approach.18 In Texas, Senate Bill 2205 (2017) specifies that "a political subdivision of this state or a state agency may not impose a franchise or other regulation related to the operation of an automated motor vehicle or automated driving system."19

Potential revenue sources for funding AV pilots were described in the Pricing subsection of the Developing Policies section.

DATA PROCESSING PARTNERSHIPS

As described in the next section, Sharing Data, AVs generate tremendously more data than small- and mid-sized cities may be used to handling, and introduce new privacy and data security concerns. Partnering with local academic institutions that have these capabilities can be a win-win approach, providing local agencies with the data storage and analysis they need to evaluate the effects of AV deployments, and opening new research and education opportunities for the academic institution.20 Another potential option for local agencies is to work with their MPO to develop these capabilities at a regional level and share the costs.

EXAMPLES

North Texas

In 2021 and 2022, NCTCOG awarded funding to a combined nine deployment proposals through the AV2.2 and AV2.3 programs. Proposals were submitted by cites, institutes of higher education, a transit agency, a private sector company, and a non-profit. Project objectives ranged from delivering food to needy communities, moving students around campus, creating first-mile/last-mile connections for hospital patients, and expanding infrastructure in support of autonomous freight. Details of the nine awarded AV2.2 and AV2.3 projects are provided in the Table on the next page.

The technologies that will be deployed and tested through these nine projects include:

- Automated Vehicle (AV) Shuttle
- AVs as Service Delivery Tools
- App-Based Ridesharing
- AV Trucking
- Automated Parking
- Curb Management
- Connected Vehicle (CV) communication
- CV Emergency Alerts
- CV Traffic Signals
- Broadband Access/Virtual Transport
- Neighborhood Delivery Bots
- Public Transit Buses
- Teleoperation

NCTCOG AV2.2/2.3 Funded Projects

Proposer	Title	Project Purpose	Partners
City of Arlington	AV RAPID Tech Expansion	Two-year continuation of Arlington RAPID automated ridehail service, which has been growing ridership (200+/day) and has a predominately low-income, transit-dependent ridership base. Adding teleoperation and emergency vehicle alert technology, which will help speed transition to fully driverless operation.	University of Texas Arlington, May Mobility (Toyota), Via
City of Fort Worth	Open-Access Autonomous Truckport	Increase the efficiency of Interstate 35W, which serves as one of the Metroplex's key lifelines and faces high levels of traffic congestion. Leverage the existing supply chain ecosystem within Alliance Texas to improve transportation efficiencies focused on drayage and long-haul movements.	Alliance Texas, Pilot Travel Centers LLC, and leading autonomous trucking developers spearheaded by Kodiak Robotics
City of Fort Worth	South / Southeast Fort Worth Projects	Three projects supporting City of Fort Worth Resolution 5028 12 2018 (Task Force on Race and Culture): Technology Application of Expanded ZIPZONE Transit Service in Zip Code 76104. Pilot Project on Design and Implementation of Equal Access to the Internet as a Travel Demand Management Tool: Southeast Fort Worth Lancaster and Rosedale. Western Application of Next Generation Traffic Signals: Emergency Vehicles and Transit Vehicles.	Multiple local and technology partners
City of Richardson	Infrastructure Upgrades and Senior AV Ride Services	Upgrade infrastructure at 10 locations to supplement AVs with crucial information, including vulnerable road user location information and traffic signal status, using Cellular Vehicle-to-Everything communication. Provide AV ride services for seniors and the underserved to/from various points of interest in the city, including Network of Communities Ministries, Richardson Public Library, City Hall/Civic Center, YMCA, First United Methodist Church, USPS, and Arapaho Center Station.	University of Texas at Dallas, private entities

Proposer	Title	Project Purpose	Partners
DART	Transit Bus Automated Vehicle Purchase and Deployment	Purchase and deploy in transit service four 40-foot SAE Level 4 automated transit buses. These buses will be placed into service on DART's Love Link route, which operates between the Inwood Road/Love Field Station and Love Field airport.	NCTCOG, City of Dallas, Love Field Airport
Dallas College	Dallas College Autonomous Vehicle Initiative	Deploy autonomous shuttles on and around campus to provide practical learning and internship opportunities for students engaged in the program. Provide better mobility options for students and visitors and explore how AV technology can achieve that goal.	Beep, Inc., May Mobility
DFW International Airport (DFWIA)	Self-Parking Vehicle / Curb Management / Parking Management Test Site	Develop an automated parking test bed to test Automated Parking using Low-Speed Vehicle Automation (LSVA), Supervisory Parking Management (SPM), and Active Curb Management (ACM).	NREL
City of McKinney and South Dallas	AV Wellness Wagons	Use vans outfitted to serve as telemedicine studios and deployed using teleoperation to provide health care services to underserved communities in McKinney (suburban, semi-rural environments) and South Dallas (urban environment). Food/medicine delivery.	Feonix, Invene, Halo, Children's Health, Spare, TTI, SMU, DART, Senior Center Resources and Public Transit, DCHHS, American Foundation for the Blind, Parkland, Superior Healthplan, Reach, Toyota, Ford, May Mobility, Autonomous Vehicle Alliance, Accessible Mobility Collaborative
Paul Quinn College (PQC)	Automated Delivery of Produce in the South Dallas Food Desert	Use automated and/or remote-controlled vehicles (bots) to deliver fresh produce from PQC's WE Over Me Farm to 250 pre-determined single-family homes and key locations in a defined service area.	City of Dallas and technology partners

Orlando

Orlando, Florida has established a "Smart and Sustainable City" initiative that seeks to "become the most environmentally friendly, socially inclusive, technology-enabled, and economically vibrant city in the southeast."21 In pursuit of these goals, Orlando received Smart Cities Council Readiness Challenge grants in 2017 and 2021, along with a Federal Highway Administration grant in 2017 as part of the Central Florida Autonomous Vehicle Partnership (CFAVP).

Partners in the CFAVP include state and regional roadway agencies (Florida DOT, Florida's Turnpike, and the Central Florida Expressway Authority), the Orlando region's transit agency, three universities, and the NASA Kennedy Space Center. The agency partners provide "a comprehensive multi-modal environment for research, development, testing, and deployment of emerging mobility technologies and solutions."22

Orlando has also partnered with the Florida DOT, University of Central Florida, General Motors, and the American Automobile Association in research and development work on in-vehicle navigation systems.23

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05 SHARING DATA

This section describes types of data useful to local agencies, AVs, and AV service providers; ways a local agency can obtain useful data without overwhelming its IT and analysis capabilities; and potential applications for AV-generated data. It also provides references to other sources providing guidance on improving an agency's data management and analysis capabilities.

Data are critical elements of transportation planning. Agencies are both *consumers* of data for making informed transportation policy decisions, and *collectors and managers* of data that are useful for internal agency functions and potentially valuable to AV service providers and individual connected vehicles.

The volume and detail of AV data, and the speed at which AV data can be provided, can be tremendously greater than what local agencies are used to working with. Connected vehicles already generate 25 MB per day per vehicle[1] in basic safety messages, the minimum amount of data regarding a vehicle's position, speed, heading, acceleration, size, and vehicle system status that a vehicle transmits, typically 10 times per second.[2] One source estimates that AVs will generate 4 TB of data per day as they move through a city,[3] excluding data associated with booking parking, travel, and other AV-related transactions.

Planners and engineers who are used to working with spreadsheets and relational databases to store and analyze data will quickly find that these techniques are inadequate to work with the amount and kind of raw data generated by AVs. Instead, big data approaches are required, involving not only new approaches to addressing the volume of data, but new analysis techniques to inform decision-making, and new attitudes toward data sharing to break down departmental data silos to use all of an agency's data in new and productive ways.[4] Finally, data security and personal privacy issues associated with AV data may need to be addressed in ways an agency has not had to deal with before.

WHAT DATA SHOULD YOU ASK FOR?

Types of Potentially Useful Data

The kinds of data potentially available from AV service providers will depend on the use case. In addition, not all of the data potentially available may be useful to an agency. Therefore, the types of data to request should generally fall into one the following categories:

- Data required to monitor compliance, as specified by permits, regulations, agreements, contracts, etc.
- Data required to evaluate the performance of an AV project. In this case, the data should match the agency's established goals and performance metrics for the project.
- Data that can support an agency's planning, operations, and decision-making.

The Monitoring Progress section provides examples of data that may be available from AV service providers, as well as data available from other sources that can be used to evaluate the broader effects of AV deployments.

Obtaining the Data

Just because AVs collect data that are potentially useful to agencies does not mean that agencies have ready access to the data. The companies collecting the data may not want to share it out of a fear that trade secrets or market share will be disclosed,5 because they believe they can generate revenue from the data, or simply because the staff time required to fulfill data requests is taken away from the company's core service.

In Texas, agencies are further limited by HB100, which specifies that municipalities can request data sharing from mobility providers (such as TNCs) and voluntarily enter into data sharing agreements but cannot pass specific regulations requiring data sharing.6 This law leaves the following options open to Texas municipalities:

- Persuading AV providers that providing the desired data is in the providers' long-term best interest and promising to respect the confidentiality of the data.7
- Entering into a voluntary agreement with an AV provider to obtain the desired data in exchange for agency data useful to the provider.
- Building data-sharing requirements into the funding agreement, for projects where the agency is contributing funding.
- Purchasing the data, if available.

Outside of Texas, public agencies in Chicago,8 Portland,9 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. Where state legislation permits, data-sharing requirements could also be incorporated into conditions of licenses or permit approvals issued by a local agency for AV services.10

PROCESSED DATA OR RAW DATA?

Advantages and Disadvantages of Processed Data

Using data processed by an AV provider or a regional data aggregator is likely the best option for local agencies with limited IT capabilities. Using processed data containing the desired performance metrics saves agency staff time to understand and analyze raw data. Processed data will also avoid privacy issues in many cases, as the raw data stay in the hands of the AV provider and the processed data typically are aggregated in some fashion.

Access to real-time summary data is preferred over weekly or monthly summary reports, particularly for pilot projects, as both the local agency and the AV provider can identify and respond more quickly to issues identified by the data (e.g., hard-braking events that occur repeatedly at the same location). Quickly addressing service quality and potential safety issues can go a long way toward ensuring a successful project and gaining support for follow-up projects. Presenting performance metrics in the form of real-time dashboards instead of spreadsheets can (1) help agency staff better visualize and understand the data, compared to spreadsheets, and (2) allow project results to be shared more readily as needed with a cross-section of agency staff, decision-makers, or even the public.

One disadvantage of processed data is that agency staff cannot readily verify that performance metrics are being calculated in an agreed-upon manner. If it becomes apparent as a project proceeds that alternative or additional performance metrics might be useful, it might take some time to incorporate these into the processed data. Finally, big data applications rely on access to a pool of raw data. Agencies applying big data have often found unexpected uses for the raw data after the initial application of the data has been completed; these uses would not be possible with processed data.11

Advantages and Disadvantages of Raw Data

Using raw data is likely the best option for local, regional, and state agencies with the necessary IT staff and technology capabilities to work with big data. The required capabilities, and guidance on obtaining those capabilities, are described in NCHRP Report 952.12

The big data approach to storing, processing, and analyzing data seeks "to combine and use these various data types to gain insights that were difficult or impossible to obtain prior to big data analytics."13 Larger agencies that have a number of existing datasets that they maintain or aggregate from other agencies can combine them with data generated by AVs to conduct new types of analysis. Big data techniques can also be used to classify incoming data, predict future data points on the basis of existing data points, and convert language as it is naturally written into a machine-readable form.14 Potential applications include predicting road conditions 15 minutes from now based on current and historical conditions, and converting online written reviews of an AV service into categories that go beyond a simple star rating.

Using standard data specifications for raw data can greatly help when integrating data sources from different agencies and operators. For example, the Mobility Data Specification (MDS) is a data specification to streamline micromobility data sharing across agencies and operators. First developed in Los Angeles in 2018, MDS is now widely adopted by cities across the country. The intent of MDS is to provide a standard data-sharing format to give cities valuable access to real-time data to better plan for micromobility and give private providers consistent data formats across different cities. In Dallas, the updated dockless vehicle ordinance states any operator "shall

comply with the MDS standard and cooperate with the city in the collection and analysis of aggregated data concerning its operations."15 Using open data standards can help agencies avoid being locked into proprietary technology and tools.16

Even when the amount of data being generated by an AV pilot project is relatively limited, working with the raw data requires that staff understand how each data element is defined, be able to identify and flag potential data errors, address personal privacy and data confidentiality issues, and have access to a system for storing, managing, and analyzing the data. Once these requirements are met, staff still need to have sufficient time available on a regular basis to update and process the data, perform analyses, and prepare summary reports.

POTENTIAL DEPARTMENTAL DATA APPLICATIONS

Transportation Planning

Mobility service providers can generate data about volume of travel, times of travel, and origin–destination patterns that have numerous transportation planning applications. Because this kind of data and its associated supplementary data are often capable of identifying individuals' trip patterns, potential privacy issues need to be addressed. NACTO describes several ways that privacy can be addressed while maintaining the usability of the data; for example, by aggregating point data to street-segment or area levels.17

Asset Inventories and Mapping

AV service providers often map a new service area before beginning service. The data collected varies by the type of service, but they could include things such as traffic control device locations, detailed roadway geometry, and speed limits (for AVs),18 or sidewalk widths, sidewalk obstacles, and curb cut and crosswalk locations (for sidewalk delivery robots). This information could be useful to an agency, for example, in updating its asset inventories or creating one if such inventories do not already exist.19

Roadway Maintenance

Data collected by AVs while on the road could also benefit an agency's roadway maintenance staff. For example, road sections where the striping quality has degraded to the point that an AV has trouble navigating could be identified and passed along to the agency to address. However, other types of maintenance items of interest to agencies may not be mapped by AV providers; for example, pothole locations.20

Parking Policy

Parking data can be used to better understand where, when, and how long AVs and micromobility vehicles park.[21] The results of this analysis could then be used to support curbside management decisions or changes in policies about required amounts of on- or off-street parking.

Traffic Safety

In the future, real-time data about AV hard-braking events or crashes could be used by a traffic management center to identify a roadway incident as it occurs and to dispatch appropriate response vehicles. In the near-term, hard-braking events are more likely indicators of a situation that an AV vehicle was unable to cope with, but they could still be useful to agencies in evaluating the success of an AV pilot or in evaluating changes over time in AV passenger satisfaction.

Intelligent Transportation Systems

V2X technologies allow for data sharing between vehicles, transportation infrastructure, and other road users. These data can be used to optimize personal and regional travel, as well as generate traffic operations data that can inform capital planning and programming decisions. Much of the data generated by V2X systems are not publicly available and must be obtained by subscriptions to third-party solutions such as HERE or INRIX (who, in turn, are partnered with the original equipment manufacturers selling the vehicles). In the North Central Texas Region, Dallas Fort Worth has defined a Regional ITS Architecture22 to guide future deployment and to develop a roadmap for multi-agency systems integration.

Traffic Monitoring

Indiana uses connected vehicle data to monitor slowdowns on Interstate highways, hard-braking events, and traffic signal performance. The Los Angeles Metro23 supports real-time data sharing between freeway, traffic, transit, and emergency service agencies to improve the management of the Los Angeles County transportation system.

Information Technology

The investments that agencies make in building IT capabilities and staff expertise around data management to support AV applications can also be used to support other agency functions as big-data applications become more widespread in the future. Agencies should consider how to develop a data management framework that allows them to partner with others to collect, maintain, and analyze data (or consider joining existing regional partnerships, especially if such partnerships include participation from key transportation partners.) Local agencies can look for opportunities to recruit local entrepreneurs and academic institutions to create new uses for agency-generated data, as this may result in useful consumer applications of agency data while supporting local economic development.

WHAT DATA ARE VALUABLE TO INDUSTRY?

Data collected and maintained by transportation agencies can be valuable to AV developers and service providers and can be used as a bargaining chip when trying to obtain data collected by these entities. Examples of data that the industry can use include:

- Roadway mapping and inventory data. Accurate and complete inventories of roadway locations and dimensions, speed limits, traffic control devices, public EV charging locations, etc. can give AV vendors a head start on their mapping efforts when entering a new market.
- Curbside management data. Information about where, when, and for how long parking, stopping, and loading are permitted along sections of a street, along with data on historic utilization patterns, can help TNCs and delivery companies using connected vehicles to plan more-efficient routes to their destinations and identify alternate locations when the first-choice location turns out to be occupied when the vehicle arrives. These data, coordinated through NCTCOG, could continue to build on NCTCOG's Regional Parking Database.[24]
- Roadway characteristic changes. Information about work zones, short- and long-term road closures, changes in curbside use, speed limits, etc. help AV developers and operators operate their vehicles within their specified operating domain, avoid traffic delays, and comply with current traffic regulations.
- Real-time sensor data. Agencies could provide AV developers and operators with access to their real-time sensor data to help them optimize AV travel paths. As sensors continue to become lower-cost and connected, more data could become available to share. For example, in the future, sensors could provide data on which parking spaces, loading zones, and EV charging stations are currently available. Agencies could also partner with AV developers to install counters and sensors at strategic locations within roadway right-of-way.[25]

EXAMPLES

The Waze for Cities data program is a two-way data sharing partnership between local governments, the Waze database, and travelers. Information can be shared about slow-downs, crashes, construction, road closures, and special event traffic management. Sharing planed road closures and construction zones with automated vehicles will help pre-trip navigation planning .

NCTCOG was the first MPO and Fort Worth the first city in Texas to join the Waze for Cities program. It may be noteworthy that NCTCOG provided challenge grants that helped a number of cities join the Waze for Cities program. It has also partnered with NCT-911 and others to get the Waze roadway incident data stream into 911 centers throughout the region.

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06 PREPARING INFRASTRUCTURE

This section describes potential infrastructure needs in each of these areas, along with broader discussions of the challenges AVs presently face with operating within a designated operational design domain (ODD) and with relying on base maps.

The Developing Policies section introduced short- and longer-term technology, infrastructure, and maintenance needs that might be needed to support AV operations:

- Agency-owned technology and infrastructure needed to support existing or desired AV pilot projects.
- Agency-owned infrastructure upgrades to support the technology needed for future AV deployments.

OPERATIONAL DESIGN DOMAIN CHALLENGES

Importance of the Operational Design Domain

SAE International defines the ODD as "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."[1] For example, the ODD for an automated shuttle might consist of a specific defined route, with turns made only at traffic signals, speed limited to 25 mph or less, and operation only during daylight hours.

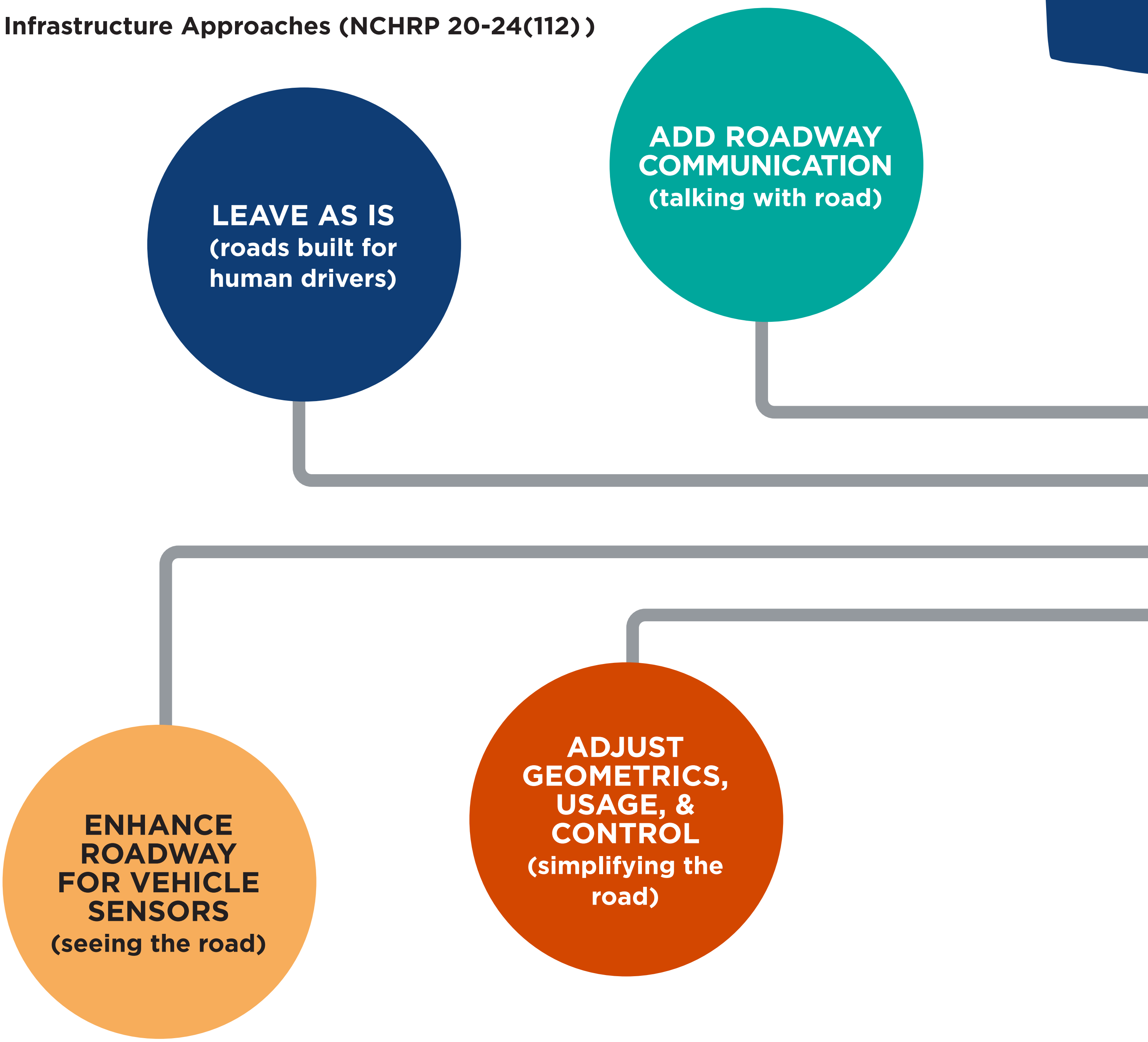
Prescribing a vehicle's ODD and adhering to it while in operation is essential for safe operation. Providing and maintaining the infrastructure supporting the ODD is essential for reliable operation. This section focuses on the latter condition, as an AV's automated driving system will require human intervention and/or bring the vehicle to a safe stop if it finds itself operating outside its ODD.

Manufacturers have said they cannot assume all infrastructure will be the same quality or standardized from one municipality to the next (such as pavement condition or traffic signal control communications). Therefore, they are developing automated driving systems that aren't dependent on good-quality or standardized infrastructure. In the near term, however, many AV pilots will need to rely at least in part on the existence of particular types of infrastructure (such as pavement markings and regulatory signs). In the longer term, agency-owned infrastructure could help provide redundancy to an automated driving system's database of road conditions and regulations.

Infrastructure Considerations for AV Pilots

Technology is constantly evolving, and different AVs will have different infrastructure needs. This subsection provides some common issues to consider when assessing infrastructure condition, deficiencies, and maintenance needs for an AV pilot. Specific projects may have additional infrastructure needs not listed here. The National Cooperative Highway Research Program (NCHRP) 20-24(112) Connected Roadway Classification System (CRCS) project developed a framework that can be used to classify infrastructure readiness for connected and automated vehicle deployments.[2] To prepare infrastructure for connected and automated vehicles, the study identified four broad approaches that local agencies may have at least partial control of.

Infrastructure Approaches (NCHRP 20-24(112))



Roadway Infrastructure

- Will the AV rely on regulatory signs to operate and/or rely on a database? If signs, are the necessary signs present and readily visible, do they need to be mounted in a specific height range, and can the AV reliably decipher the signs? If a database, what will be the process for updating the database if conditions change (e.g., road construction)? What will be the process for notifying the jurisdiction of missing or damaged signs and replacing them?
- How much wear can pavement markings experience before the AV can no longer identify them? What will be the process for inspecting and refreshing pavement markings within the area AVs operate in?

ROUTING CONSTRAINTS

Some existing infrastructure and land uses may constrain where the AVs used in a pilot project may operate. Considerations include:

- Minimum lane width needed by the AV (as narrow lane widths may decrease an AV's operating speed).
- Minimum pavement quality needed by the AV. What will be the process for inspecting and repairing or resurfacing roadways that fall below the minimum pavement quality?
- Steep gradients (power limitations).
- Ability of the automated driving system to assess gaps in vehicular and pedestrian traffic, such when making turns or entering roundabouts. Do left turns need to be made at signalized intersections with left-turn arrows (i.e., protected left turns)?
- Proximity to glass windows, bodies of water, or other reflective objects that could confuse vehicle cameras.
- Overgrown or wind-blown vegetation interfering with vehicle operation or confusing vehicle sensors.
- Tall buildings interfering with communications or GPS signals.
- Availability of a secure vehicle storage site along the route. For example, some EV shuttles have limited ranges and recharging speeds and cannot afford to deadhead to a distant garage the way fuel-powered transit vehicles can.
- Infrastructure needs for the vehicle storage site related to EV charging (e.g., charging speed, type of charging cable connector), data transfer, and vehicle maintenance.
- Pedestrian infrastructure needs for sidewalk delivery robots (e.g., curb ramps at intersections, even sidewalk surfaces, sidewalk effective width, need/ability to request a pedestrian phase at traffic signals).

COMMUNICATIONS INFRASTRUCTURE

- What kind of communications equipment does the AV use (e.g., low-/mid-/high-band 5G cellular, dedicated short-range communications (DSRC), and/or something else)? Will limited infrastructure availability and/or technological issues with the communications band (e.g., range, signal absorption) constrain the vehicle routing or service area?
- What kind of data need to be transferred to and from the vehicle (e.g., remote performance and location monitoring, maps and databases, operating system upgrades, security camera images), and how will this occur?
- Is traffic signal priority part of the pilot project? If so, how will the vehicle request priority? Are traffic signal controllers equipped to receive and process priority requests?
- How will temporary or permanent changes in roadway changes (e.g., road construction, adjacent building construction causing sidewalk or lane shifts or closures) be communicated to the AV operator?

DATA MANAGEMENT INFRASTRUCTURE

- What kinds of data will the agency be receiving and in what form? How will the data be stored, secured, and processed?

Infrastructure readiness extends beyond traditional transit and transportation system operations

Longer-term Infrastructure Considerations

Over the next 25 years, NCTCOG expects to see changes in vehicle automation, shared mobility, and electrification. As a result, infrastructure readiness extends beyond traditional transit and transportation system operations to EV charging infrastructure, active transportation networks, CV and AV support, data sharing and management, and resiliency.

At the same time, technology ages rapidly and can be expensive to install and periodically replace at a large scale. Therefore, it is recommended that agencies wait and see what technology will be needed to support AVs, once the initial testing phase of AVs is over and AVs have entered commercial production. However, it is not too early to begin thinking about possible future infrastructure needs, or to start preparing infrastructure that (1) supports the adoption of future technology and/or (2) also supports current non-AV goals and applications.

COMMUNICATIONS INFRASTRUCTURE

Investment is needed in communications infrastructure, such as fiberoptic cable and small cells that support wireless communications. Not only will this infrastructure support future CV deployment, but it can support existing needs as well. For example, policymakers describe a growing digital divide between rural and urban regions that could put geographic limits on technological, social, and economic opportunities in the future without the right investments in rural digital connectivity.[3] Infrastructure readiness and resilience improvements need to focus on the digital divide.

CV-supportive communications infrastructure that could be needed in the future includes DSRC radio equipment. It can also include "supporting infrastructure needed for deployment, such as backhaul communications, CV data analytics, and CV-equipped traffic signal controllers."[4]

TRAFFIC SIGNAL SYSTEMS

Advanced traffic signal systems could require upgrades to traffic signal infrastructure along arterial corridors and to centralized signal management systems, where they exist. Examples of needs and applications of potential upgrades include:

- Upgrades to signal controllers to support advanced signal timing features and to provide more data ports.
- Upgrades to signal controller cabinets to provide additional space for new equipment used for communication, signal priority request processing, and other features, and for heating/cooling equipment to provide a suitable operating temperature for the electronics.
- Upgrades to the number and type of detectors installed on intersection approaches to optimize signal timing in response to approaching platoons of AVs.
- Installation of V2I communications technology to support signal priority requests from CVs and to communicate signal phasing information to CVs, to allow CVs to approach the intersection in the most power- or fuel-efficient way.[5]

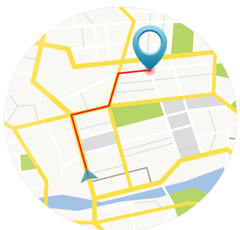
DEDICATED AV/CV LANES

As the fleet transitions to automation, dedicated lanes might be needed for special use, such as AV-only lanes, truck-only lanes for platooning, or separated and protected bike/e-scooter lanes. For safety, capacity-optimization, and/or technology-prioritization reasons, agencies could consider restricting certain roadways (e.g., freeways) to AVs or CVs only, once AVs become the dominant vehicle type in the regional, statewide, or national vehicular fleet.

MAPPING CHALLENGES

At present, mapping is not a standardized process, as different AV vendors use different software and processes to map a route. Before deployment, an AV vendor creates an initial map of a route or area. The route or area being mapped has to stay largely the same over time for this base map to function correctly; otherwise, the route will need to be re-mapped and uploaded to the vehicle. Road and other kinds of construction, new traffic signals, vegetation growth, etc. will impact AV operations relying on the base map.

These maps may include three-dimensional information about static objects and infrastructure, including the roadway itself. Maps may also include important navigation information, such as the number of lanes on a road segment and other lane characteristics (e.g., directionality, left turn, bus-only), speed limits, and the presence of traffic control devices or markings (e.g., stop signs, traffic signals, crosswalks, passenger loading zones).



EXAMPLES

The City of Arlington evaluated the lessons learned from a one-year mobility-on-demand AV pilot in a one-square-mile area of the city that included downtown Arlington and the UT-Arlington campus.[6]

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07 WORKFORCE TRAINING

Many aspects of AV technology and its applications will require workers with new skill sets. This section provides guidance in two areas of workforce training. First, improving local agency staff's expertise and capabilities with respect to AV technology. Second, preparing tomorrow's workforce with the skills needed by AV-related companies, whether those workers are just entering the workforce or have been displaced from their existing jobs by automation.

AGENCY STAFF TRAINING

Agency-Sponsored Training

As first discussed in the Policy Development section, before starting an AV pilot project of their own, agencies need to become familiar with AV technology, its current status, and its potential benefits and problems. Agencies also need to self-assess their technology-related staff and equipment resources and capabilities. Some questions to ask as part of this self-assessment include:[1]

- Are staff and management sufficiently aware of the agency's technology-related goals?
- Are staff sufficiently trained in anticipated new technologies to address planning and policy questions as they arise?
- Do staff have access to sufficient outside resources to deal with technology questions?
- Is a process in place to ensure that staff can regularly keep up with the latest technological developments?
- Does the agency have the necessary equipment to support desired types of AV pilot projects and are staff trained in the use of this equipment?

Operating a pilot project in-house requires a higher level of staff expertise than managing a project contracted to an outside vendor. However, staff expertise is still necessary when working with vendors, from designing the parameters of the pilot project, to developing an RFP and making an informed selection decision, and finally to monitoring the vendor's performance, working with the vendor to address issues as they arise, and evaluating the outcomes of the pilot. The Getting and Staying Smart subsection of the Policy Development section describes methods for building staff expertise and capability.

VENDOR SUPPORT

Agencies can also turn to AV vendors to help educate them on the state of AV technology and its potential application to supporting agency goals. For example, rather than specifying a specific approach or technology to apply to an AV pilot, a number of agencies are describing their values and desired project outcomes to potential vendors through requests for information (RFIs) and requests for proposals (RFPs). Potential vendors are then free to describe how their approach best satisfies the agency's needs. For example:[2]

- San Jose released an RFI requesting information about how an AV pilot could specifically address and resolve public transportation problems.
- Portland, Oregon released an RFI focused on pilots that could support the city's public transit system.
- Pittsburgh developed an RFP for public transportation pilots that could serve city priorities, address first-/last-mile gaps, and provide equitable access to vulnerable populations.

The RFI/RFP process provides transparency and fairness in the procurement process, and allows agencies to find out about the latest technologies and potential approaches to addressing the agency's needs (which may not necessarily involve advanced technology).[3] Portland found that because technology had changed so significantly over the course of a year, some projects they had been considering no longer seemed so useful.[4]

WORKFORCE DEVELOPMENT

Training Tomorrow's Workforce

A public meeting was held during the development of this guidebook to identify workforce development needs in the North Texas region to support automation technologies. Panelists included educators at the K-12, community college, and university levels, and NCTCOG staff involved with workforce development. Participants included public agency staff and officials, and members of the public. Based in part on the discussion that occurred during this meeting, this section identifies some of the challenges and opportunities involved with workforce development.

CHALLENGES

Workforce development challenges that were identified included:

- **Challenges with obtaining technology resources.** Educational districts and institutions must balance their desire to provide students with hands-on exposure to current technology with other educational needs, all within a fixed budget.
- **Challenges with evolving technology.** The technology that students will need to work with may not have been invented yet. The skills they will need continue to change and evolve.
- **Lack of peer examples or mentors.** The transportation workforce is primarily an aging, male workforce that students may not identify with. Students' priorities are often shaped by their parents, friends, or role models. Students with an interest in technology may be more interested in developing a YouTube channel or a smartphone app than in developing or working with AV technology.

OPPORTUNITIES

- **Partner with industry.** Identify industry's needs and expectations for their workforce and tailor training and education to fit those needs. Work with industry to develop internships that let students get job experience while pursuing an education, and apprenticeships that provide new trainees and graduates with a pathway to a career.
- **Develop transferable skills.** Don't focus too early on technology, as it will probably be obsolete by the time a student enters the job market. Develop transferable skills such as communication, as well as a basic grounding in STEM (Science, Technology, Engineering, and Mathematics) subjects that can be applied to many types of technology jobs. Expect that more specialized and continuing training will be needed on the job as specific technologies are developed or applied.
- **Demonstrate the range of job possibilities in the industry.** Student interests will vary, so job and career fairs can demonstrate a variety of job types (e.g., maintenance, operations, administration). Project-based learning teaches multiple skills during the accomplishment of a project and demonstrates to students that what they're learning has practical, job-related applications.
- **Start early.** For example, NCTCOG has developed lesson plans for K-12 educators on preparing students for emerging transportation technologies. Modules include:[5]
    - *English*: Same Message, Different Audience
    - *Social Studies:* Reviewing Transportation Policy
    - *Math:* Avoid the Crash!
    - *Science*: Pavement Markings and the Science of Retroreflectivity
    - *First Lego League (WeDo 2.0 Software):* Blind Spot Monitoring
- **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.

NCTCOG'S EFFORTS

NCTCOG is making major investments in emerging technologies through demonstration projects, focusing on projects not being served fully by the private sector. The agency is investing in workforce development activities at the community college level, has developed educational aids for K-12 students and teachers, and provides funding support at the university level through the North Texas Center for Mobility Technologies. NCTCOG is trying to connect emerging technology companies with faculty and students to help with skill- and career-building. For example, the agency worked with the City of Dallas to put together an economic incentive package with Ford Motor Company that includes commitments from Ford to help support workforce development. Finally, NCTCOG is partnering with two global engineering firms to create a mobile innovation zone.

RETRAINING WORKERS LOSING JOBS TO AUTOMATION

As discussed in the Equity subsection of the Developing Policies section, one of the biggest challenges with a transition to AVs will be how to address the large number of persons who may directly or indirectly lose their jobs as a result of automation. Automation in many industries is eliminating lower-skilled jobs, so there will be a need to upskill these workers so they can find medium- and high-skilled jobs. These types of jobs require formal training and education. [6]

Many people losing jobs to automation will be members of disadvantaged communities. However, these communities face multiple barriers to obtaining training and education. Policy interventions will be required at all levels of government, in partnership with the private sector, with regard to "assessing which jobs are at risk, which new occupations will be in demand, expanding the social safety net, initiating programs to close skills gaps, and ensuring jobs exist at the end of retraining pipelines."[7]

Potential local agency actions that support job retraining include:

- **Dedicating a portion of local revenue from AV operations to support local job retraining efforts.** Training could focus on higher-skilled jobs in the AV industry (e.g., maintenance, operations, monitoring, manufacturing, development, planning), skilled jobs in other emerging industries, and skilled jobs in industries less likely to be affected by automation (e.g., caregiving).[8]
- **Providing incentives to support the hiring of workers displaced by AVs.** These incentives could include contracting selection or regulatory preference for AV operators that agree to hire displaced workers, and tax or fee reductions for companies that hire displaced workers.[9]
- **Job preference within the agency for hiring workers displaced by AVs.** This preference would work similarly to other hiring preferences (e.g., for veterans).
- **Fund the retraining of an agency's workers being displaced.** For example, a transit agency could retrain some of its displaced bus drivers for existing roles within the agency (e.g., maintenance or planning), or for new roles that could be created if the agency transitions to a mobility-manager model.

A US Department of Transportation report[10] notes that the average age of truck and bus drivers is older than the workforce in general. Given the long typical useful lives for long-haul trucks (9 years) and full-size transit buses (12–14 years), converting an organization's fleet to automation will take many years once the technology becomes commercially available and the organization decides to adopt it. As a result, job reductions in these industries may be accommodated to a large extent through retirements, rather than worker displacement. However, these industries also tend to pay better than other professions requiring no more than a high-school diploma, meaning that those who are displaced may have a harder time finding a comparably paying position.

EXAMPLES

The Tampa-Hillsborough Expressway Authority (THEA) in Tampa, Florida was a participant in a USDOT CV pilot involving over 1,600 private vehicles and public transit buses and streetcars. The project required installing two radio antennas and a GPS antenna on vehicles' roofs, replacing the rear-view mirror with an electronic model that could display warnings, and installing a computer in vehicles' trunks. THEA partnered with Hillsborough Community College's Master Mechanic Program and the equipment vendor to perform the installations using the program's professional auto bays. The students in the program received a 6-month paid internship that also met a graduation requirement and obtained skills they can apply in the future at the auto dealerships they work at. The pilot benefitted from the experience of the master mechanic staff supervising the students, which reduced project risk, and from the labor cost savings by using paid student interns.[11]

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08 MONITORING PROGRESS

Without performance monitoring, an agency has no way to quantify the outcomes of specific AV pilots, nor the broader impacts of AV deployment on the community and region.

Pilot evaluations, in particular, are helpful for communicating project outcomes to the public and to decision-makers, for identifying lessons learned, and for building support for new or expanded AV deployments in the future. Despite these benefits, a national study of micromobility and AV pilots found that post-pilot evaluations were conducted for only 11% of 220 pilots that were studied. Investing resources in performance monitoring pays off for the agency in the form of better decision-making and better transparency.[1]

This section presents potential performance measures that agencies can use to

- Evaluate the performance of a specific AV pilot.
- Evaluate broader effects of AV pilots on the community and region.

Many other performance measures than those listed here can be used to evaluate AVs' effects on specific agency goals and objectives.

Other sources of performance measures include:

- FTA *Mobility Performance Metrics for Integrated Mobility and Beyond*[2]
- FHWA *Transportation Performance Management Guidebook*[3]
- EPA *Guide to Sustainable Performance Measures*[4]
- UC Davis *Measuring Land Use Performance: Policy, Plan, and Outcome*[5]
- *TCRP Report 88: Guide to Developing a Transit Performance-Measurement System*[6]
- State DOT performance measurement guidebooks

SELECTING PERFORMANCE MEASURES

Not all of these measures listed in this section need or should be included in an evaluation. Some measures may not relate to a project's goals and objectives, data may not be available to measure others, and staff time and resources will constrain how many measures can realistically be included. One possible approach to identifying performance measures is as follows:

- Identify potential performance measures that can help evaluate each project objective, using the performance measure lists and references in this section as starting points.
- Consider the data collection needs for each measure.
  - If data are not available, the measure will need to be dropped.
  - If data will need to be obtained from the AV operator, the measure is a candidate, but also identify whether alternative measures are available as backups if the data cannot be obtained.
  - If data are readily available, the measure is a candidate.
- Select one or more measures for each objective, balancing data availability and collection needs with how well the measure addresses the objective.
- For measures that require data from AV operators, build these data requests into the agency's AV regulations (where permitted by state law) or make them priorities when negotiating with AV operators.

Performance measures are useless when the data required by them are not readily available or are too difficult to collect. Too much data can also be an issue if it takes too much time to collect and analyze the data. It may be better to start smaller and expand the number of measures as the agency gains experience with AV pilots.[7]

EVALUATING AV PILOT PERFORMANCE

This subsection provides potential performance measures to address an AV pilot's performance from both the traveler or shipment receiver point of view ("quality of service") and the owner/operator point of view. These measures are derived primarily from FTA's *Mobility Performance Metrics for Integrated Mobility and Beyond,*[8] supplemented with additional measures from *TCRP Report 88: A Guidebook for Developing a Transit Performance-Measurement System,*[9] and measures identified through agency and expert interviews conducted during the development of this handbook.

Traveler-Focused Measures

Performance measures are available to help evaluate a traveler's experience before, during, and immediately after a trip. **Measures marked with** * require data from an AV provider. **Measures marked with** ** can be obtained from user surveys. Surveys can also ask about riders' demographics, origins and/or destinations, and trip purposes to allow more detailed analyses of survey results.[10]

PRE-TRIP MEASURES

- **Reservation convenience for trips requiring an advanced reservation**
    - Lead time (minimum advance notice required to reserve a trip)
    - Offset time* (difference between preferred and available departure/arrival time)
    - Excess wait time* (lateness) (difference between when the vehicle is scheduled to arrive and when it actually arrives)
    - Trip planning and booking experience**
- **Reservation convenience for on-demand trips**
    - Wait time* (time between when a trip is requested and when the vehicle is scheduled to arrive) (e.g., by trip, time, or geography)
    - Excess wait time*
    - Trip planning and booking experience**

- **Service availability**
  - Service coverage area (square miles)
  - Times of day/week when service is offered
- **Service reliability**
  - Number of different options/modes available (e.g., by trip, time, or geography)
  - Trips deferred or denied*
  - Connection redundancy (for trips requiring a transfer, time to the next travel option if the planned transfer is missed)
- **Price**
  - Median price
  - Price variability for a given trip or traveler*
  - Price is reasonable for the service provided**

TRIP EXPERIENCE MEASURES

- **Travel time**
  - Median travel time (e.g., by selected origin-destination(O-D) pairs or geography)*
  - Travel time variability (e.g., by trip/ traveler, O-D pair, or geography) *
- **Travel experience**
  - Perception of safety**
  - Perception of personal security**
  - Perception of ride quality**
  - Number/percentage of missed connections*

POST-TRIP MEASURES

- **Travel time**
  - Travel time prediction accuracy*,**
- **Price**
  - Median difference in price from the pre-trip estimate*,**
- **Overall experience**
  - Overall user satisfaction**
  - Likelihood to use again**
  - Likelihood to recommend to others**
  - Perception of data privacy**
  - Recommendations for improvements**
  - Mode would have used if service had not been available**

Delivery-Focused Measures

Most of the pre- and post-trip measures described above for passenger-based services also apply to delivery services. Persons ordering and receiving shipments are primarily interested in the ease of the ordering process, the lead time required to order a delivery, the cost for the delivery, and whether the delivery arrives when promised. As a result, the trip experience measures are less applicable, although travel time measures could still be considered. For services that deliver goods to a storage box for pick-up by the customer at a later time, additional measures could focus on that aspect of the delivery process.

Owner-/Operator-Focused Measures

The measures in this group are useful to both agencies and service operators for monitoring service and evaluating the outcomes of the pilot. **Measures marked with *** require data from an AV provider. **Measures marked with **** can be obtained from user or community surveys. Project evaluations can also incorporate project-level results from the traveler-focused measures listed above. Most of these measures can also be applied to delivery services by substituting “deliveries” for “rides” or “trips” in the measure description.

SERVICE MONITORING

- **Supply**
  - Maximum number of trips that can be served by the system (per hour/day)*
  - Median wait time*
  - Variability of wait time*
  - Median hours per day with surge pricing*
- **Usage**
  - Median number of planned trips by hour*
  - Median number of linked trips by hour (includes transfers)*
- **Safety and security**
  - Crash data (details)*
  - Hard braking events (location, time, date)*
  - Automated driving system disengagements (location, time, date, cause)*
  - Crimes (persons or property) (details)*
- **Customer satisfaction**
  - Number of complaints by category
  - Number of compliments by category

PROJECT OUTCOMES

- **Usage**
  - Number of linked trips by month, year*
  - Median trip length*
- **Supply**
  - Vehicle revenue miles operated by month, year*
  - Vehicle revenue hours operated by month, year*
- **Productivity**
  - Rides (linked trips) per vehicle revenue hour*
- **Cost**
  - Annual system subsidy
  - Total fare revenue*
  - Median fare*
  - Median operating cost per ride*
  - Average fare subsidy*
  - Operating cost per vehicle revenue hour*
  - Operating cost per vehicle revenue mile*
- **Safety and security**
  - Safety (crash rate per million vehicle miles or 100,000 trips)*
  - Security (crime rate per 100,000 trips)*

- **Equity**
    - $ of services directed to local businesses*
    - Local hiring activity*
    - Usage by census block/block group/tract or neighborhood*
    - Median monthly cost of transportation as percentage of median monthly household income by census tract*
- **Environmental**
    - Percent vehicle miles/hours operated without a passenger*
    - Trips shifted to electric vehicles**
    - Trips shifted to/from single-occupant vehicles**
    - Change in greenhouse gas/particulates emissions due to shifted trips**
- **Community perception**
    - Overall perception**
    - Helps improve congestion (agree/disagree)**
    - Helps improve traffic safety (agree/disagree)**
    - Helps improve community image (agree/disagree)**

EVALUATING AV EFFECTS ON THE COMMUNITY AND REGION

This subsection provides potential performance measures for use in a longer-term monitoring program to evaluate how AVs may be affecting the community and region. For these measures to be useful in decision-making, they need to be regularly measured and monitored (ideally annually), which may be a more frequent data-collection and -analysis schedule than an agency may be used to for transportation planning.[11]

The measures are derived primarily from *NCHRP Report 924: Foreseeing the Impact of Transformational Technologies on Land Use and Transportation*[12] and FTA's *Mobility Performance Metrics for Integrated Mobility and Beyond*,[13] supplemented with additional measures identified through agency and expert interviews conducted during the development of this handbook. These references also describe potential data sources for these measures.

A challenge with applying these measures is identifying how much of the change in a given measure is attributable to AVs and how much is attributable to other causes. Trend analysis and comparing areas with AV services to similar areas without AV services can help in this regard.

- **Job access**
    - Number of jobs and/or other destinations accessible in "X"/ "Y"/ "Z" minutes of specified geographies (e.g., census tract, TAZ)
    - Service coverage area
    - Median travel time (generally, for persons with disabilities, by geography)
    - Monthly cost of transportation as a share of census tract median monthly income
- **Growth**
    - Population (total, by geography)
    - Jobs (total, by geography)
    - Employed persons (total, by geography)
    - Tax receipts (sales, property, transient occupancy, other)
    - Licenses and permits
- **Land use**
    - Permits pulled
- **Early indicators of code and plan problems**
    - Complaints
    - Code enforcement requests
    - Conditional use permits
    - Zoning variance requests
    - Comprehensive plan amendments
- **Parking**
    - Curb/lot/loading zone parking utilization
    - Median price
    - Average parking duration
- **Travel demand**
    - Average daily ridership by travel mode
    - Average daily vehicle-miles traveled (VMT) by travel mode
    - Average daily passenger-miles traveled by travel mode
- **Safety**
    - Crash rate per million VMT by travel mode

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09 CONCLUSIONS

This guidebook equips agencies with tools to proactively plan for the impact of emerging transportation technologies. Most of the technology is still in the development and testing phase. There are many uncertainties about the long-term impact of some technologies and the ultimate use cases (e.g., will AVs be individually owned or used by fleets like robotaxis only). However, the early state of technology and uncertain impacts provides a window of opportunity.

Local agencies can start preparing now by incorporating emerging technology into the planning process, developing local policies, building partnerships, engaging stakeholders, preparing the workforce, developing performance metrics, and sharing data to build durable and nimble deployments. Agencies have an opportunity to plan ahead and proactively shape the development and adoption of emerging technologies to solve transportation challenges and meet public goals.

Assess Potential Use Cases and Business Models. The applications and business models of AV providers vary widely. Understanding the various AV use cases can help agencies assess the transportation challenges each use case might be best positioned to address. Use cases include but are not limited to:

- **Personal Mobility**
  - Automation
  - Communication (Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), Vehicle-to-Everything (V2X))
  - Ridehailing
  - Public Transit
  - Aerial Passenger Services
- **Freight**
  - Interstate and Regional Shipping
  - Intermodal Transfers
  - Business-to-Business Deliveries
  - Urban Freight Delivery
  - Rural Freight Delivery
- **Data Collection**
  - Crowdsourcing and data sharing
  - Vehicle-to-Everything (V2X)
  - Cloud, Fog, and Edge Computing
  - Data Analytics

Steps to Planning the Development and Adoption of Emerging Technologies

1. Assess Potential Use Cases and Business Models
2. Develop and Update Policie
3. Prepare
4. Self-assess
5. Take action
6. Monitor and adjust
7. Build Partnerships and Share Data
8. Prepare Infrastructure
9. Train the Workforce
10. Monitor Progress

Develop and Update Policies. Once familiar with AV technology, use cases, and potential benefits and challenges, agencies should be proactive in assessing policies to support the technology. Policies should connect to public goals to help emerging technologies address challenges facing the region and set expectations for the industry with a framework under which to operate.

Prepare. Become familiar with AV technologies and agency regulatory powers, develop the agency's vision for technology, and set technology-related goals.

Self-assess. Review the agency's staffing, resources, capabilities, organization, policies, and plans. Identify needs and courses of action. In this self-assessment, agencies should think holistically to prepare for the far-reaching impacts of AVs. Agencies should break down traditional silos by including a variety of stakeholders to assess policies. Policy considerations may include land use and development, operations, equity, public works, public transit, transportation planning, data sharing, safety, pricing, procurement, climate, and health.

Take action. Address the policy gaps identified in the self-assessment. Identify and/or develop funding sources to address resource gaps. Train staff, hire new staff, or partner with others with the necessary expertise to address capability gaps.

Monitor and adjust. Monitor progress toward achieving the agency's technology-related goals and adjust programs, plans, and actions as necessary to meet the goals. AV-related policies need to consider short-, medium-, and long-term conditions, and agencies will likely need to revisit these policies as future conditions change.

Build Partnerships and Share Data. Fostering partnerships is critical to understand and learn from different perspectives. Emerging technology is new and rapidly evolving, meaning everyone has a lot to learn from each other. AV vendors and service providers understand the technical aspects of their technology, but often not much about local agency policies, processes, and performance measures. Conversely, local agencies have considerable experience with regulating land development and commercial services, but often lack staff expertise in emerging technology-related matters. Successful partnerships often:

- Establish clear expectations with the problem to be addressed, goals, and desired outcomes.
- Take a long-term perspective to transportation planning and building relationships.
- Build trust by setting expectations for communications, performance reporting, and established agency processes.
- Adapt processes to evolving nature of technology and prepare to make adjustments to pilot deployments.
- Collaborate on providing mutually beneficial datasets to support AV operations or public agency functions.

Prepare Infrastructure. Different AV use cases will have varying infrastructure needs. Agencies can be proactive in identifying infrastructure improvements to support existing and future deployments, including roadway, communications, and data management infrastructure; routing constraint considerations; and traffic signal systems.

Train the Workforce. Agencies should start now to build internal agency capabilities and to train workers needed by the AV industry. Agencies and educators may partner with industry to understand needs and tailor training and education. Training and education should focus on transferrable skills that can apply to a variety of future conditions, rather than focusing on a specific technology that may change.

Monitor Progress. Technology is not a "silver bullet" to the transportation problems facing North Central Texas. There is work to be done to maximize the potential benefits of technology, while minimizing the potential externalities. Agencies should develop performance metrics to continually evaluate the impacts of technologies in the community and make adjustments as needed to achieve the desired benefits.

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