metroplan orlando
A REGIONAL TRANSPORTATION PARTNERSHIP

MetroPlan Orlando CAV Readiness Study

Task 1 Memorandum

CAV Industry Best Practices Review

May 30, 2019

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1 Introduction

This technical memorandum provides a review of the current state of the connected and automated vehicle (CAV) industry in the MetroPlan Orlando Planning area, the state of Florida, and nationwide. This includes an overview of current CAV planning exercises and pilot deployments to identify lessons learned and best practices, while highlighting key elements that may be relevant to the Central Florida region and its unique characteristics.

The document contains the following sections:

- Section 2 defines relevant and current definitions, terminology, and standards related to CAV
- Section 3 reviews the supporting infrastructure required to enable a CAV system, including vehicle-based equipment, data and applications, and a communications network
- Section 4 identifies valuable data elements that can be acquired through and/or support a CAV ecosystem
- Section 5 summarizes current and past CAV pilots and planning efforts nationwide
- Section 6 assesses national research efforts
- Section 7 concludes the document and presents next steps

Performing best practice reviews is a common component of Intelligent Transportation Systems (ITS) and CAV master planning efforts conducted by state, regional, and local planning agencies around the country. This document seeks to expand on what has been done elsewhere with a specific focus on basing findings in reality for the specific environment and constraints of the Central Florida region. Identifying best practices and their local relevance can be used to support a full assessment of the Central Florida region's readiness for CAV.

2 Definitions, Terminology, and Standards

This section provides an overview of CAV industry terms and standards, to support a consistent understanding of subsequent sections throughout this memorandum and overall project. Many terms in the CAV realm are often used interchangeably, but actually have different meanings. These distinctions and a desire for consistency have resulted in the following recommended definitions for common industry terms[1]:

- An **automated vehicle** (AV) is a vehicle with some aspect of a safety-critical function controlled by something other than direct input by a human driver. Vehicles that provide safety warnings to drivers (such as a forward collision warning), but do not perform a control function are not considered automated since there is no control implemented, even if the technology necessary to provide that warning includes a degree of automation. To be considered automated, the vehicle must use information obtained via sensors to make its own judgements and actions in a driving environment.

- A **connected vehicle** (CV) is a vehicle that is equipped with some sort of wireless communication device that allows it to share information with other vehicles and objects on the roadway. CVs can be automated, but AVs are not necessarily connected.

While automated vehicles are expected to improve vehicle safety by limiting the impact of human error, only with connectivity can the potential safety benefits of fully automated driving systems be realized, as vehicles can then gain context beyond what a regular driver would know or be able to perceive visually. Similarly, while connectivity can enable alerts and warnings to a driver-operated vehicle, deploying these messages on an automated vehicle can streamline the links between information, decision making, and action. The overlap and differences between these two technology types, as well as ITS, is presented in Figure 1. The following subsections provide additional information on the three types of technologies and other related topics.

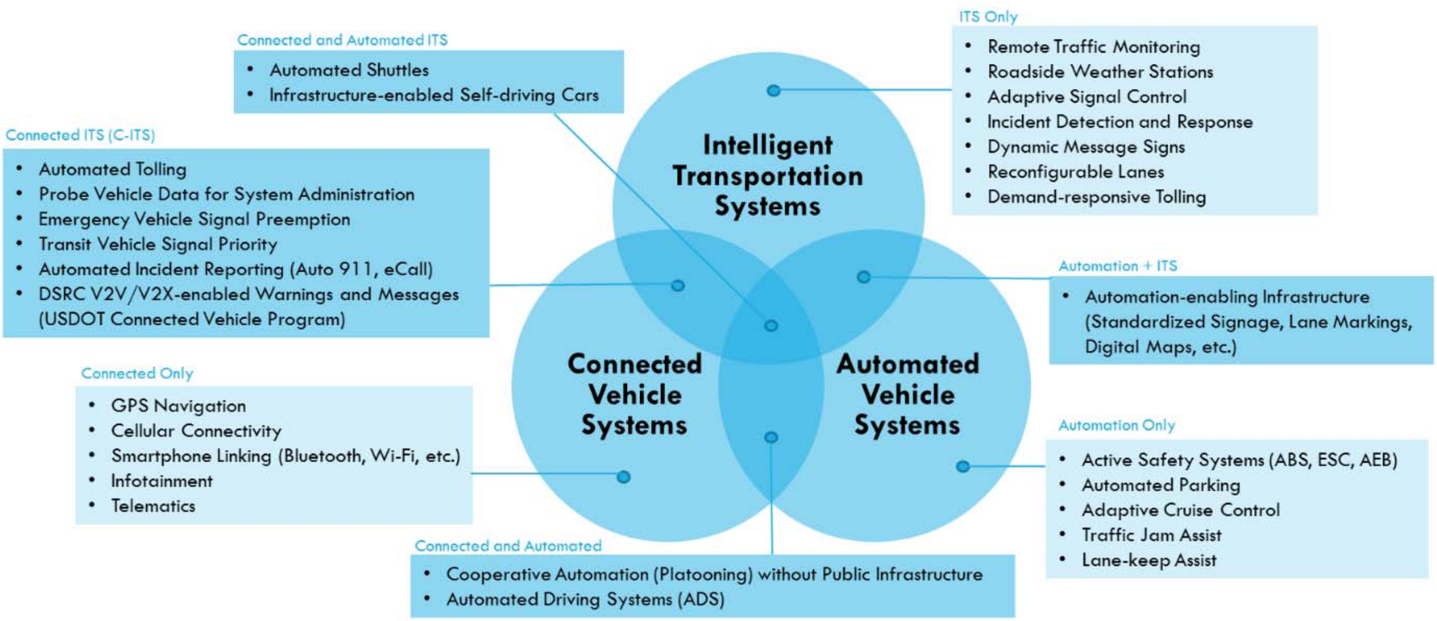

Figure 1: Categories of Advanced Transportation Technologies
Source: Public Sector Consultants and Center for Automotive Research for the Greater Ann Arbor Region Prosperity Initiative, "Planning for Connected and Automated Vehicles", March 2017, https://www.cargroup.org/wp-content/uploads/2017/03/Planning-for-Connected-and-Automated-Vehicles-Report.pdf.

2.1 Automated Vehicles

Automated vehicle (AV) technologies enable vehicles to detect their surroundings using a variety of on-board sensors, often using radar (radio waves), LiDAR (light pulses), cameras (images), and ultrasonic sensors (sound waves) or a combination of multiple sensor types. By merging these information sources, as well as others such as global positioning system (GPS) data and dead-reckoning location information, an advanced control system on a vehicle is able to interpret the data to detect obstacles, identify optimal navigation paths, and interpret traffic control devices such as traffic signals, traffic control signs, and pavement markings.

Many private companies have explored varying approaches to integrating the data from these types of sensors and using this information to create decision trees for a vehicle system, However, there are still many specific operational scenarios that have yet to be fully explored, the artificial intelligence algorithms are not standard across the industry, and even some of the specific data configurations and standards have not yet been developed. For example, some companies use semantic segmentation to detect objects, as shown in the first image in Figure 2, which classifies pixels by object type. This allows the vehicle system to differentiate a sign from a person, so it can move into either determining the message the sign is trying to convey or analyzing the potential path of the pedestrian. Other companies bind the location of objects to a box, as demonstrated in the second image in Figure 2, so they can track an object as the vehicle (and possibly the object) moves.

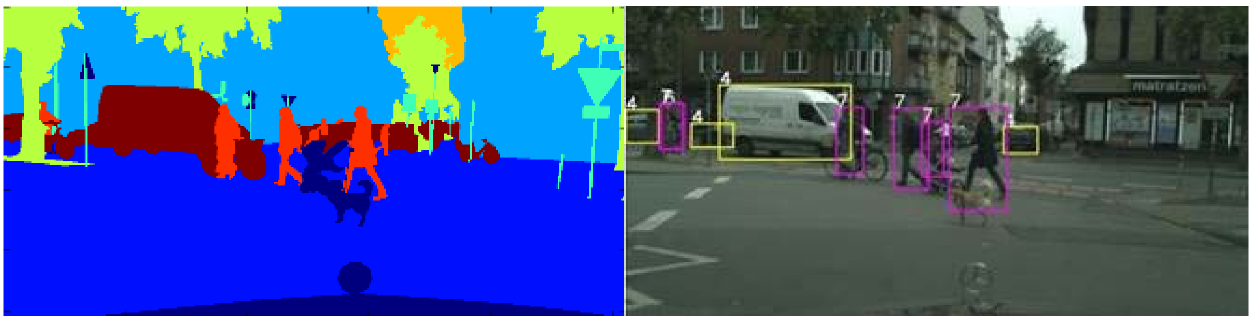

Figure 2: How an Automated Vehicle Senses Objects
Source: Shapiro, Danny, "Eyes on the Road: How Autonomous Cars Understand What They're Seeing", January 5, 2016, https://blogs.nvidia.com/blog/2016/01/05/eyes-on-the-road-how-autonomous-cars-understand-what-theyre-seeing/.

SAE International, a standards-setting industry association of automotive experts and technologists, has developed a scale of driving automation ranging from Level 0 to Level 5 – Level 0 indicates that the vehicle uses no automation of any kind, while Levels 1-4 have varying levels of abilities that can assist drivers on very specific tasks. The highest automation level, Level 5, indicates that the vehicle can perform all tasks under all conditions (Level 5). This SAE driving automation scale is shown in Figure 3.

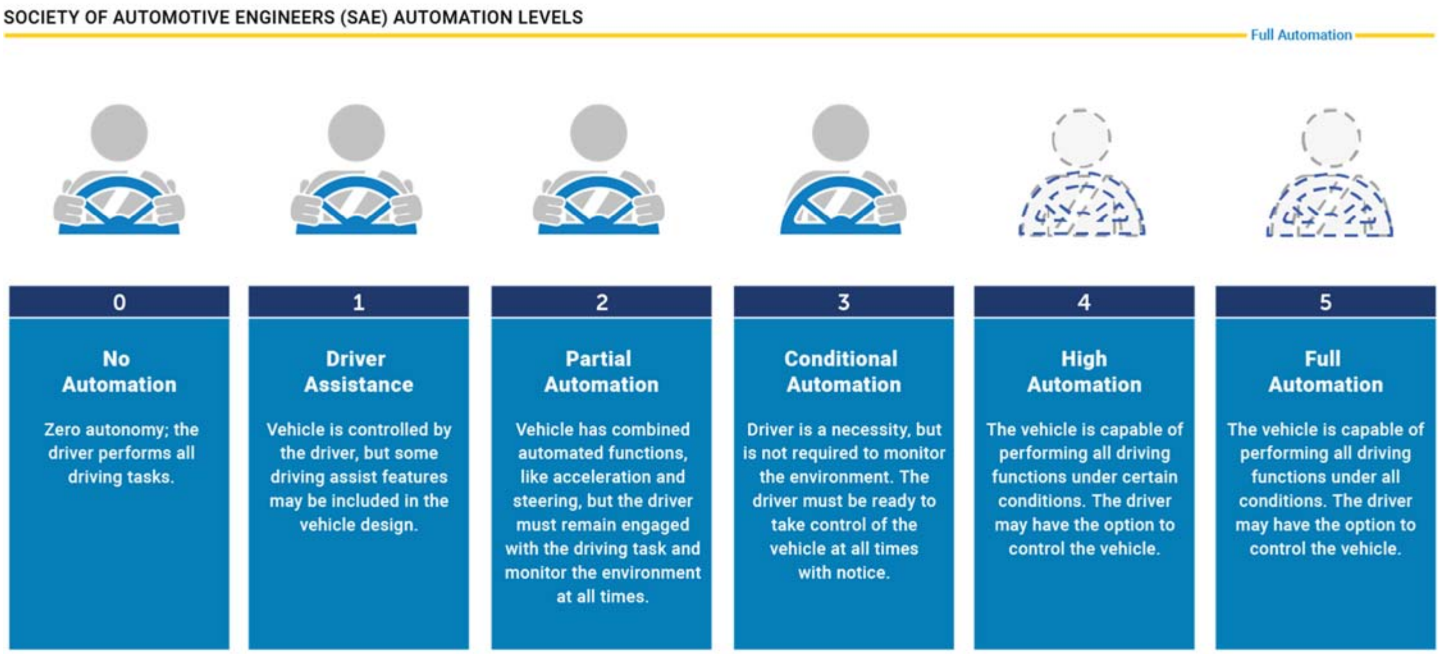

Figure 3: SAE Automation Levels
Source: US DOT, "Automated Vehicles for Safety", https://www.nhtsa.gov/technology-innovation/automated-vehicles-safety.

Levels 1-3 describe types of AV technology that have been introduced before vehicles are entirely self-driving, and many of these types are already available today. For example, Advanced Driver Assistance System (ADAS) components such as lane keeping, parking assist, emergency braking, and adaptive cruise control have been introduced on new vehicles to assist drivers without completely taking over the driving task. Level 1-3 vehicles may be fully automated within a certain operational design domain (ODD), or defined geographic conditions, such as roadway types and weather limits.[2] A driver may be required to remain onboard the vehicle and monitor its operation, to ensure it is operating safely and is not outside its ODD. In the future, Highly Automated Vehicles (HAVs), or Levels 4 to 5, will have multiple ADAS components and on-board sensors that can analyze multiple types of sensory data to distinguish between vehicles, bicycles, pedestrians, and obstacles, and with advanced connectivity (as described below), will be able to operate a vehicle on most or all types of roadway networks.

2.2 Connected Vehicles

Connected vehicle (CV) technologies enable various types of vehicles, roadway infrastructure, mobile devices, and other objects to communicate quickly to share vital information. CV technologies enable vehicles to communicate with infrastructure (vehicle-to-infrastructure, or V2I), between vehicles (vehicle-to-vehicle, or V2V), and with other objects on the roadway such as bicycles, pedestrians, or obstacles (vehicle-to-everything, or V2X).[3] Figure 4 provides a schematic of these communication interactions, as well as some of the systems and centers that could be used to enable them.

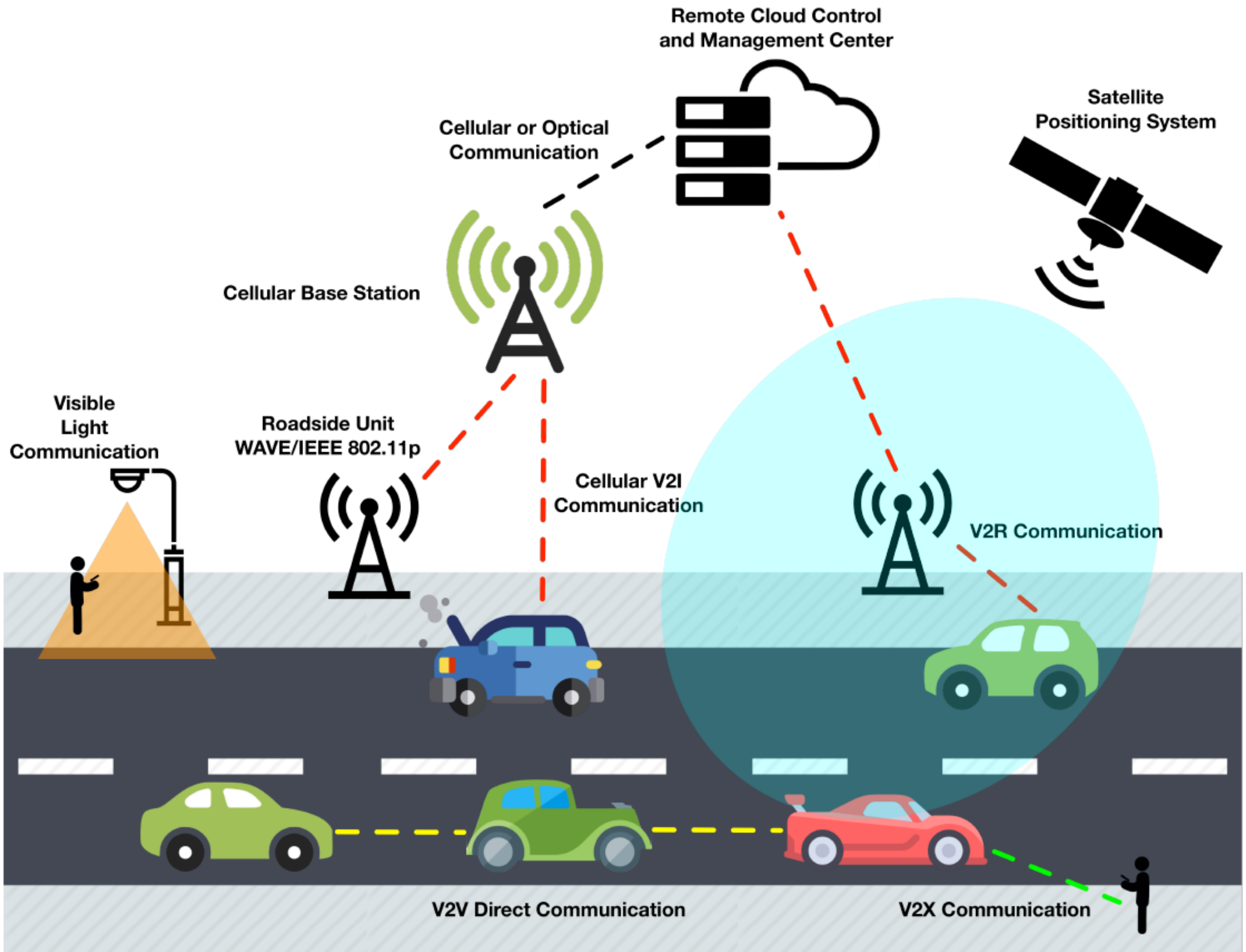

Figure 4: Drawing of V2I, V2V, and V2X Communications
Source: Fabio Arena and Giovanni Pau, An Overview of Vehicular Communications, January 24, 2019.

There are many potential mediums by which connectivity will be enabled. Satellite, cellular, Wi-Fi and other short-range communications all represent methods by which vehicles today are already connected, and the vehicles of tomorrow will become increasingly connected.

Dedicated Short Range Communications (DSRC) is one such medium, a WiFi-based short range method that has been developed for high-speed low-latency situations to specifically enable safety applications. While additional cellular-based communication methods are also being developed, many pilot projects have commenced across the country to better understand the uses and impacts of connected vehicles and infrastructure in transportation networks. The primary purpose of these pilot projects is to create test beds in a real-world environment that can provide insights for future deployments. Using this approach, public agencies can be earlier adopters of CV technology, which will also allow them to experience the technology first-hand and ensure it is compatible with their needs. This approach also provides the ability for public agencies to support and test proof-of-concept solutions. For example, a Security Credential Management System (SCMS) has been tested to help ensure that CVs operate in a safe and secure manner that protects the privacy of users.[4]

2.3 ITS and ITS Architecture

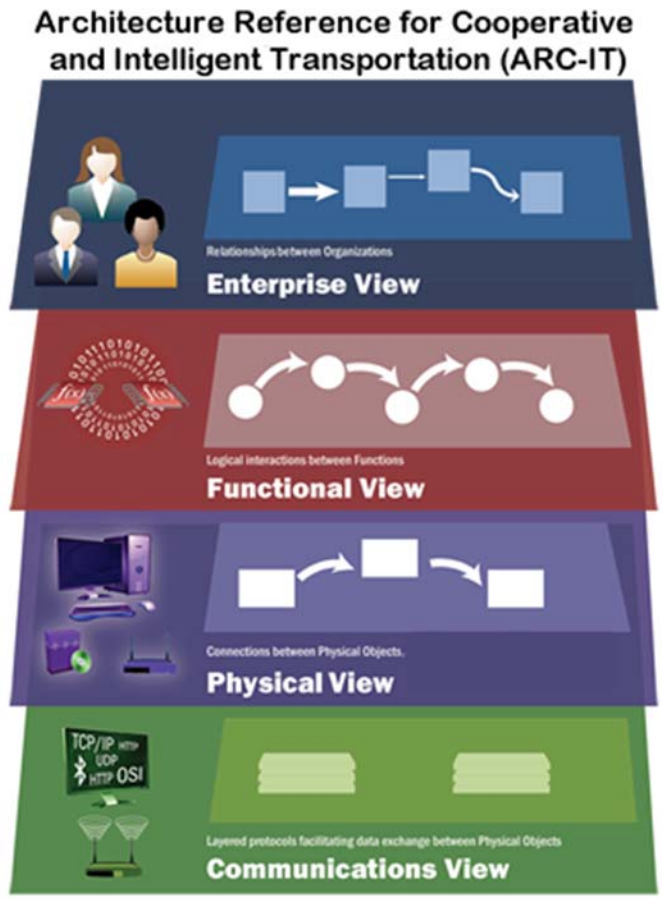

Figure 5: ARC-IT Reference Diagram
Source: US DOT, "Architecture Reference for Cooperative and Intelligent Transportation", https://local.iteris.com/arc-it/.

ITS integrates advanced information and communication technologies into transportation and traffic management systems to improve safety and mobility by leveraging technology to better utilize physical infrastructure. While ITS concepts and tools are not new, they are becoming consistently more refined and powerful, and state-of-the-art deployments have demonstrated additional capabilities that were not possible even just a few years ago. Because the impact of some ITS tools is dependent on human behavioral response, their effectiveness is expected to improve as more components of the transportation system become more automated, most notably with the continued introduction of CAV technology onto roadways.

The United States Department of Transportation (US DOT) has developed a national ITS Architecture to help define a consistent framework to guide the planning and deployment of ITS, as well as CV technology.[5] This architecture is intended to be adaptable and evolutionary, allowing agencies to collaborate and identify systems that could best help meet their needs and challenges. To support this, there is a tool called the Architecture Reference for Cooperative and Intelligent Transportation (ARC-IT). The ARC-IT tool, illustrated in Figure 5, provides a common framework to agencies for planning, defining, and integrating ITS. It is an established, industry-standard product that reflects the contributions of a broad cross-section of the ITS community. ARC-IT merges, unifies, and enhances National ITS Architecture and Connected Vehicle Reference Implementation Architecture (CVRIA), as it was previously known. ARC-IT presents Service Packages, previously known as "applications" in CVRIA, which are groups of physical objects and the communications between them that are tailored to fit, separately or in combination, real world transportation problems and needs.

2.4 Why CAVs?

The most promising benefit of CAV technology is the potential impact on safety. With the critical reason for approximately 94 percent of vehicle crashes attributed to driver actions, there is ample opportunity to improve safety by eliminating the impact of driver error.[6] While CAVs will have their own weaknesses such as potential vulnerability to hacking, they will not drive impaired, remove their focus from the driving task, or intentionally disobey the rules of the road. However, a major safety challenge for CAVs will be interacting with vehicles that are not also automated (and connected), and there is likely to remain a combination of these vehicle types on roadways for the foreseeable future.

In addition, while it is possible that CAVs will simply replace existing vehicles one-for-one, it is likely that this paradigm shift in how vehicles are operated will come in parallel with other paradigm shifts in how transportation is provided, funded, and consumed. CAVs provide the opportunity to efficiently operate new business models and improve the movement of people and products. For example, it may become more streamlined and attractive for people to share vehicle ownership and/or individual rides in right-sized vehicles, for vehicles to be utilized at a higher rate, or for less high-value real estate to need to be made available for parking.

Shared mobility options in dense urban areas, such as ridesourcing, microtransit, and traditional transit, will likely be enhanced by CAVs due to improvements in vehicle balancing (of empty vehicles) and reduced costs of operation. Other CAV applications will enhance the safety of all vehicles, including transit and freight vehicles of all sizes, by transmitting additional information on roadway conditions and the behavior of other vehicles that is not easily perceptible today. While these innovations will likely be introduced by private entities, public agencies can also take advantage of their benefits. From a congestion management perspective, the traveler experience could ideally be made virtually seamless across modes, as vehicles become capable of automatically tracking connection times and coordination with first-mile/last-mile solutions, removing this inconvenience and responsibility from passengers and providing a convenient travel option for more origins and destinations. This would allow travelers to be matched to the most efficient mode for each stage of their trip, which may occasionally be a single occupancy vehicle (SOV), but could often be a shared vehicle. Pricing strategies could also be included in this model, to provide travelers with even more options depending on the urgency and importance of their trip. There are a variety of technologies that could collaborate to help enable this shared CAV future. However, improvements in shared mobility may not result in a net reduction in vehicle miles traveled (VMT), as lower travel costs provided by CAVs could have the potential to induce additional travel demand. The exact effect is unknown at this time, and could also progress through different evolutionary stages as societal changes and technology offerings impact mobility trends both positively and negatively.

Potential economic and societal benefits to agencies include enhanced data collection and information sharing that could lead to more efficient operations, both by distributing travelers across alternate routes and modes in real-time and through enhanced maintenance, such as improved deployment of road crews during inclement weather and other incidents. However, data collectors will need to consider privacy concerns. The reduced costs of collisions, including those of lost productivity, medical treatment, congestion, and property damage, are expected to provide benefits to society as a whole. Secondary impacts could impact the insurance industry, as improved road safety triggers changes to vehicle insurance policies and premiums.

As with any new technology, early adoption will likely not benefit all people equally at first. Early CAVs are and will likely remain expensive and, thus, inaccessible to the average consumer. Many companies are emerging with automated rideshare and microtransit models for initial implementation, providing a service rather than the sale of these vehicles directly to drivers. This model has the potential to increase the general population's accessibility to CAV technology but, since the entities are generally still private companies, service provided may not be distributed fairly as it will only be offered on corridors on which it is most profitable. Many private platforms may also not be fully accessible for people with disabilities or those without a smartphone, at least at first. This discourages use by passengers with mobility or cognitive challenges, as well as passengers who do not own a credit card or smartphone. It will be important for public agencies to ensure CAV deployments, especially ones they are sponsoring, equitably and safely serve all their citizens. Best practices to meet this challenge are already being demonstrated with non-automated new mobility services, and include subsidizing access for qualifying users; performing outreach in key communities and using performance-based community engagement metrics to validate success; offering alternative access modes such as telephone or text booking options and physical kiosks; and switching public transit payment systems from card-based to account-based systems, which could allow users to transfer transit subsidies to other services that become available and can provide them with more mobility options on a familiar platform.[7]

3 Infrastructure Elements

To enable CAV applications, vehicles are outfitted with on-board equipment (OBE) that allows them to communicate wirelessly. The wireless network over which CVs communicate must be fast, reliable, secure, private, and interoperable (across applications and user types). As mentioned previously, there are several mediums that could provide the required quality of connectivity, including satellite radio, commercially available cellular, and DSRC. While these units and networks are available today, application feasibility and functionality is still limited by the low number of deployed units and concerns about interoperability between them (as the communications protocols are not yet fully standardized and certified between manufacturers).

To enable V2I communications, intersections and other roadway segments are equipped with roadside equipment (RSE) that can send and receive messages with OBEs to communicate information (illustrated in Figure 6 on the next page).

For example, an intersection could provide a vehicle with information about its physical geometry (MAP message) and current signal phase and timing (SPaT message). Similarly, OBEs could communicate information on the vehicle's current location, speed, heading, acceleration, and other attributes to the RSE. These messages can help the traffic controller determine whether the combination of these conditions may result in an unsafe situation, or if interventions could be made to improve safety or mobility.

Figure 6: Drawing of Roadside Unit Communicating with Various Vehicles
Source: US DOT Intelligent Transportation Systems Joint Program Office, "Vehicle-to-Infrastructure Resources", https://www.its.dot.gov/v2i/index.htm.

V2V communications are most commonly in the form of basic safety messages (BSM) that constantly share core data elements on a vehicle's current position, heading, speed, size, acceleration, and subsystem status with other vehicles. BSMs can enable many safety and mobility applications, such as forward collision warnings and cooperative adaptive cruise control. V2X communications can help enable safety and mobility applications, in particular to warn of and help prevent collisions with vulnerable road users such as bicyclists and pedestrians. Vehicle-to-pedestrian communications, sometimes referred to as V2P, may be enhanced by connectivity with smartphones and other mobile devices.

In the long term, CAVs are intended to operate on roads without any specialized infrastructure. However, current vehicle capabilities are limited, so some infrastructure adjustments can be helpful to ensure safe operations for early tests and pilot deployments.

Most CAV providers will conduct a site visit before deployment in order to ensure an environment is suitable for their vehicle, if solicited, or to find an environment they believe would create a favorable testing environment, if unsolicited. For example, challenges operating on multi-lane roads in mixed traffic, such as changing lanes and making unprotected left turns, have not yet been fully resolved, and many vehicle vendors are not comfortable operating on roads or routes with these types of obstacles. In addition, vehicles need to be able to consistently obtain a signal for localization purposes, so obstacles such as tall grass and tree cover can also present an issue. CAV vehicles can have reduced functionality in inclement weather, and are vulnerable to power failures unless an uninterruptable power source is installed with the equipment.

4 Data Elements

A CAV ecosystem will only be complete if key data sets are collected and distributed securely and in support of the correct applications. This section evaluates the necessary data elements essential to a CAV system and what an agency should consider when determining how to manage these large amounts of data.

4.1 Value of Data

Generally, drivers obtain information on the roadway primarily through sight, supplemented by familiarity with either the exact road they are currently on or with standardization among roads across the country. However, there are many conditions on the roadway that are not easily perceptible, either to a driver or to a CAV system, that could be enhanced by different types of data sharing. CV technology in particular can help improve safety by providing warnings directly to drivers and by improving the reliability of any information that can be shared on traffic and roadway conditions. For example, a CV system could send an in-vehicle message to a driver or vehicle system to warn them they are approaching an active school zone, a tight curve with a low speed limit, or a traffic backup due to a crash or other incident.

Vehicles themselves can also collect data, such as geolocated spots on the roadway with poor pavement or aggregated vehicle speed information to determine current roadway speeds (as many trip planning applications already do via smartphones).

While some newer vehicle models and smartphone-based applications are already collecting and sharing this data today, many vehicles currently on the roads are not capable of sending and receiving these messages, and for the foreseeable future, the fleet is expected to remain mixed between vehicles equipped with CV features and those that are not equipped. As a result, transportation design standards focused on human drivers must remain the minimum level provided, but enhancements can be included such as providing the information via both connected capabilities and continuing more traditional means such as dynamic roadway signage. Additionally, depending on the availability of data, validation of the recommended message from a back office or traffic management center may be necessary.

Of particular importance from an infrastructure owner/driver's perspective is environmental and weather data. Approximately 22 percent of vehicle crashes on U.S. roadways are weather-related.[8] Weather such as fog and rain can reduce visibility and pavement friction, making it harder for drivers to sense and respond to roadway hazards, and affecting the safe operating parameters of a roadway. Heavy winds can have similar impacts, especially in conjunction with other weather conditions. Weather impacts can be very localized and magnified by other high-risk behaviors such as speeding, as well as other roadway conditions such as poor pavement and tight curves. However, deploying technology on both the infrastructure and vehicle sides can allow data to be matched with vehicle performance data to provide information to drivers and CAV systems on possible hazardous situations.

This could potentially reduce the frequency of weather-related crashes, as well as the severity of crashes that do occur.

Many state departments of transportation already collect weather-related data, primarily to support maintenance crews. For example, the Michigan Department of Transportation (MDOT) currently has a large amount of road weather data gathered from Environmental Sensor Stations (ESS) and from a number of other fixed sources including National Weather Service (NWS) locations. In fact, ESS data is available publicly due to the proven reliability of this automatically collected data over time.

Another distribution point for roadway data is at traffic signals. Information on current signal status and time remaining until the next phase change, known as Signal Phase and Timing (SPaT) data, can open the door to critical safety applications in vehicles with the potential to significantly reduce and/or eliminate crashes at intersections. However, many traffic signals across the country use outdated technology, and may need to be updated before they can be connected to a wireless communication system.

Newer vehicle models on the road today are beginning to demonstrate the potential uses of data collected from CVs. Figure 7 shows the basic data-generating devices and flows that may be available in newer vehicles. While the data these devices generate are usually intended for a primary, safety-critical purpose, they could also be used for secondary purposes such as dynamic roadway pricing or transportation planning.

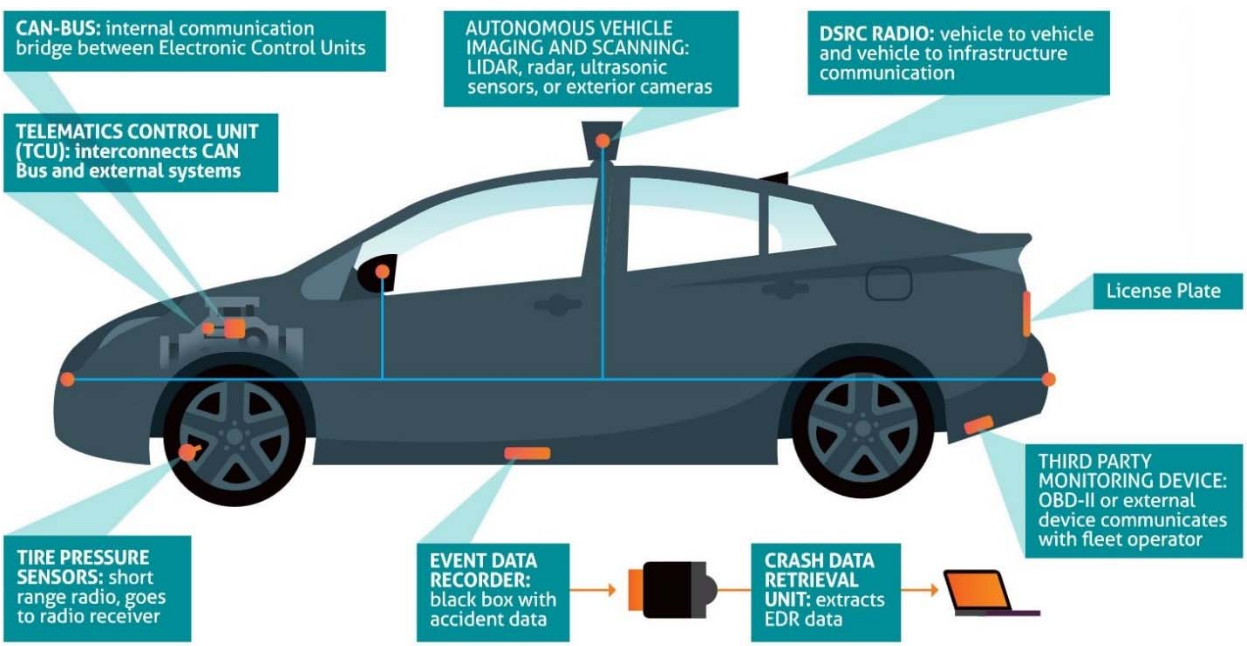

Figure 7: Schematic of Data from Connected Vehicles
Source: Future of Privacy Forum, "Data and the Connected Car", https://fpf.org/2017/06/27/future-privacy-forum-releases-infographic-mapping-data-connected-car-advance-ftc-nhtsa-workshop/.

Another type of valuable data is that collected by private mobility and CAV technology companies. Such data is used in many different forms, such as for real-time operations and in order to assess current performance and identify areas of future development. This data would be valuable to public agencies as they strive to assess the current capabilities of CAV systems and under what conditions they should be permitted to operate on public roadways. However, many of these private mobility companies are in direct competition with each other, and are therefore sensitive to sharing data they may see as proprietary in a public setting. Many vendors are more willing to share data when they are contracted to provide a service (and receiving payment or other special permissions) and under a non-disclosure agreement, but they are unlikely to share all data even under these conditions.

4.2 Data Management

Many state and other public agencies have existing programs to manage ITS and traffic planning data. While most are starting to discuss the benefits and challenges with integrating the wealth of CAV data that may soon be available, very few have specific plans or a timeline to add CAV data to their data management platforms. Rather, most agencies are just beginning to explore how CAV data could be used to help their agency answer questions and solve problems for both real-time operations and archived planning purposes.

During this planning process, it is recommended that agencies engage with each other to discuss similar experiences they may have gone through or currently are going through (or with vendors, to discuss whether they could offer additional capabilities or ideas). Due to the popularity of CAV research and testing, it is likely that another agency has already implemented a similar product, or even that a local university may be able to support research during the specific stage where the agency is.

Early on, agencies need to consider what data can and should be made publicly available, and what data should only be shared on an individual user basis. In Minnesota, MnDOT's traffic management software, IRIS, is a publicly distributable source. Because of this, they do not retain a full picture of who is using their data, but they do have a sense of the many ways in which users apply their data. For example, Metro Transit, in Minneapolis, used the IRIS data to create a tool to provide comparative bus travel times, while many other applications have been published by consulting firms, research groups, and others. This approach allows MnDOT to learn from a larger group of people what potential applications the data they collect could be used for. In addition, developing open-source platforms, or that can be easily integrated, allow flexibility to add in future capabilities.

Because of the wealth of data that CAVs are expected to collect and be able to provide, there may be a need for agencies to redevelop their data governance, distribution, and retention policies. The Florida Department of Transportation (FDOT) has particularly stringent data retention requirements – depending on the type of data, raw data may need to be saved for many years.[9] This creates a significant data storage need which may have been feasible to meet in the past, but could become more challenging as higher volumes of data begin to be collected automatically.

4.3 Smart City Data

Many cities worldwide have begun exploring the possibilities to integrate technology into their transportation and infrastructure systems in an effort to become a "Smart City". These high-tech improvements allow cities to integrate both traditional service information and advanced communication technologies into their systems to improve efficiency and better manage their services and assets. A major component of a Smart City is the wealth of data that can be collected and shared with citizens and other stakeholders. Because of this, it is worth exploring the relationship between CAVs and Smart Cities in terms of data and data management.

Smart City data can be used to understand how a city works in real-time, which can help prioritize investment, both physical and technological, in order to more efficiently identify improvements that best support the overall network and society within the city. Smart Cities also work to introduce new and emerging technologies into their systems, including integrating electric, automated, and/or connected vehicles into public vehicle fleets, as well as enhancing their operations and maintenance activities with smart sensors and smart infrastructure.

5 National CAV Pilots and Planning Efforts

Several CAV planning exercises and pilot deployments are underway across the nation. This section provides a few case studies of the types of CAV pilots that have been popular, highlighting relevant lessons learned and how these projects can help advance the state of the practice in Central Florida. This includes both national examples and key pilot programs that are underway within Florida.

5.1 Policy and Planning

The impacts of CAVs across modes will be heavily dependent on the policies that municipalities and other local maintaining agencies pursue, as well as their impacts on driver and passenger behavior. These policies include operational decisions, such as providing signal priority or preemption to certain high-occupancy (buses and trains) or high-priority (emergency vehicles) modes. Signal priority, which entails modifying normal signal operation by extending a green signal or shortening a red signal within pre-determined limits, is generally used to help transit vehicles maintain schedule adherence and to improve travel times by transit, while mitigating disruptions to other traffic. Signal preemption, an interruption/override of the normal signal operation to accommodate a vehicle regardless of the impact on other traffic, is only appropriate in more safety-critical situations, such as to improve emergency vehicle response times and the safety of emergency vehicles at intersections, or in some cases to support safer and more efficient rail operations on shared rights-of-way.

The policies agencies must consider also include regulatory decisions, such as parking requirements, vehicle occupancy minimums/maximums, and restrictions on the use of curb space by vehicle type. CAVs provide an opportunity for agencies to reassess existing transportation policies and regulations, which may be outdated, and ensure that impacts to the broader transportation network are considered and taken into account.

An emerging challenge in the new mobility space is the interaction and relationship between public government agencies and private mobility companies, as is already being seen with ridesourcing, bikeshare, and scooter providers, and varying approaches to either seek permission or ask forgiveness to operate on public roadways. Going forward, public agencies will need to find a balance between embracing CAV innovation and maintaining an acceptable level of risk to the public. They also need to ensure that the technologies they allow to be implemented are available to all and do not benefit one group at the expense of another, as will be further discussed in Technical Memorandum #2.

5.2 Connected Vehicle Pilots

Many CV pilot projects have commenced throughout the country to better understand the implementation challenges and user benefits of connected vehicles and infrastructure in the transportation network. Major ongoing CV pilot projects at the national level include:

- Various initiatives by the Michigan Department of Transportation (MDOT)
    - Ann Arbor Connected Vehicle Test Environment
    - Southeast Michigan Connected Vehicle Environment
- US DOT Connected Vehicle Pilots
    - New York City (NYCDOT)
    - Tampa Hillsborough Expressway Authority (THEA)
    - Wyoming (WYDOT)
- Colorado Department of Transportation (CDOT) RoadX
- Minnesota Department of Transportation (MnDOT) Connected Corridor
- Smart Columbus Connected Vehicle Environment

The majority of these projects are funded, at least in part, by US DOT. The primary purpose of these types of pilot projects is to create a test bed in a real-world environment that can provide insights for future deployments. While these projects are limited in their real-world benefits by nature of their pilot implementation, lessons learned can help prepare sponsoring agencies for future shifts in the industry and spur ideas on more efficient future deployment strategies and potential uses of the new types of data that can be collected. Figure 8 provides a schematic of US DOT's overall approach to the CV Pilot Deployment Program.

Figure 8: US DOT Approach to the Connected Vehicle Pilot Deployment Program
Source: US DOT Intelligent Transportation Systems Joint Program Office, Connected Vehicles: Connected Vehicle Pilot Deployment Program, https://www.its.dot.gov/pilots/pilots_overview.htm.

Having pilot projects throughout the country allows the technology and applications to be tested under a variety of conditions and environments, including in both urban and rural areas, and in response to a variety of local needs, such as signal priority for snow plows in Minnesota.

One of three US DOT sponsored CV pilots is being conducted in Tampa, Florida, under the supervision of the Tampa Hillsborough Expressway Authority (THEA). This pilot is being conducted on a tolled highway facility, with a primary focus on improving safety and mobility by reducing congestion during the morning peak. Another major focus of this deployment is to explore agency data applications that can reinforce these benefits and provide the agency with additional data from its customers, captured from multiple sources including vehicles, mobile devices, and infrastructure.

As part of the pilot, THEA has equipped 10 buses, 10 streetcars and the cars of 1,000+ individual volunteers with CV technology to "*make downtown Tampa a safer, smarter place to walk, ride and drive*." Nearly a dozen CV applications are currently being tested on various roadways, using both V2V and V2I communication technology to improve safety and traffic conditions in downtown Tampa. The locations of these applications are shown in Figure 9 on the next page. The foundation of most federally-sponsored pilots is the deployment of DSRC roadside units in the desired deployment area, and OBE on the desired fleet. Other systems, such as pedestrian detection systems or smartphone applications, may be included depending on the needs of the project.

Figure 9: Downtown Tampa Deployment Plan
Source: US DOT Office of the Assistant Secretary for Research and Technology, "Connected Vehicle Pilot Deployment Program: Tampa (THEA) Pilot Update at the System Design Milestone", https://www.its.dot.gov/pilots/pdf/CVP_THEASystemDesignWebinar.pdf.

A simple way for a region or municipality to launch a CV pilot is by outfitting an agency's maintenance fleet, private partner fleets, or other publicly owned vehicles such as transit vehicles, to create a critical mass of vehicles on the roadway that enables somewhat frequent interactions between CVs to occur. This approach is being used in the NYC DOT pilot, which includes equipping transit vehicles and other large privately-owned fleets such as taxis and UPS trucks with aftermarket safety devices and OBE that converts a regular vehicle into a connected vehicle.[10]

Other pilots, such as the Smart Columbus CV Environment, include outfitting a combination of publicly and privately-owned vehicles.[11] In this case, the target is to outfit approximately 1,000 public vehicles, including transit, emergency, and other city-owned vehicles, and to recruit 2,000 additional private vehicle owners to voluntarily have their vehicles equipped. All 3,000 vehicles will be outfitted with aftermarket DSRC units and in-vehicle signage that will allow communications between vehicles in the outfitted fleet and with infrastructure in the deployment area.

Alternatively, rather than requiring vehicles to be equipped with CV technology, the first phase of the Smart 70 Project, an initiative of CDOT's RoadX program, will allow interested participants to simply install a smartphone navigation application with text-to-voice alerts about road conditions. Future phases will add additional sources of information to support this application.

The CV environments deployed in these pilot projects each contain a subset of the CV applications that have been identified by the US DOT.[12] Application types include communications between vehicles (V2V), communications between vehicles and infrastructure (V2I), methods for collecting data for internal agency use, and applications that can enhance mobility in the transportation network.

While many of these projects are funded by federal programs, some have been funded locally. MDOT has partnered with the University of Michigan and a number of local automobile and technology companies to provide support for their projects and to share input and results. For example, the Ann Arbor Connected Vehicle Test Environment, building off a project launched in 2012, uses federal, state, and university funds, however, a long-term goal of this project is to transition from government funding to a more sustainable long-term funding solution.

Smart Columbus also received many matching funds and donated equipment from local sponsors as well as national companies after winning the US DOT Smart Cities Challenge. At the state level, CDOT set aside $20 million from its 2016 operating budget to launch RoadX. This program was designed to leverage partnerships with public and private innovators; for example, the Smart 70 Project is conducted in partnership with HERE, a mapping data and GPS navigation software company.

5.3 Automated Shuttle Deployments

Personal automobiles available to consumers today include systems up to Level 2 that automate specific tasks such as highway driving (using adaptive cruise control and lane keeping assist) and parallel parking. Hazard warning and intervention systems such as blind spot detection and forward collision warning with automated braking have also been implemented.

However, there are also several pilot deployments focused on higher levels of automation but at low speeds that have or could be undertaken by local and regional governments, such as regional agencies or MPOs, rather than private vehicle owners. Many private companies have begun testing, marketing, and piloting low-speed automated shuttles that can operate in specific conditions but without traditional vehicle controls (such a steering wheel and foot pedals).

A sampling of vehicle vendors that have deployed in the United States to date are shown in Figure 10. Automated shuttles operate on pre-defined, fixed routes in controlled environments, thus minimizing many remaining technical and operational challenges and enabling the vehicles to operate with minimal human intervention. However, in deployments to date, a human “safety operator” has still been on board to interact with passengers and take over vehicle control if necessary.

Automated shuttles are generally considered Level 3 or 4 on the SAE scale, depending on the vehicle vendor and the capabilities they have demonstrated to date. These vehicles generally have a capacity of 6 to 20 passengers, operate at low-speeds on surface streets rather than freeways, and most are electric, which is efficient at these speeds.

There are many opportunities for agencies to deploy automated shuttles to supplement or replace existing transit service. Generally, these vehicles are ideal for short-distance service, where they can be used to tackle the first/last-mile problem. Deployments to date have generally also been showcase opportunities, for an agency or organization to show they are innovative and supportive of AV technology.

Figure 10: Automated Shuttles from Various Vendors
Sources: https://easymile.com/, https://localmotors.com/, https://maymobility.com/, https://navya.tech/en/, https://www.optimusride.com/

Automated shuttles have also been opportunities for data capture to help guide future developments. For example, a one-year automated shuttle pilot in Las Vegas was sponsored by AAA, who was interested in seeing how people perceive AVs and whether their perceptions may change if they are directly exposed to the technology. This shuttle was deployed in an area of the city that attracts many tourists, and approximately half of the passengers were from outside the state of Nevada, which allowed AAA to reach a broader audience and not just the local public.

Automated shuttles can also be used for campus circulation, at a university, employment center, office park, or airport. For example, two shuttles owned by Mcity in Ann Arbor, Michigan are being used to supplement the University of Michigan's existing bus transit service that circulates students and others around campus. In another pilot by the Denver Regional Transportation District (RTD), the shuttle connects a commuter rail station to a busy employment park. Deploying these vehicles locally also provides an opportunity to educate the local public on emerging technologies. A transit agency or organization who pilots these technologies early on will be better able to adapt to future innovations, because both internal agency processes and the public will be better prepared for and accepting of AV technology.

Table 1, on the next page, provides an overview of current players in the automated shuttle industry and some of their most significant current and past deployments. As of August 2018, there have been a total of 260 demonstrations and deployments of low-speed automated shuttles in North America, Europe, Asia, Oceania, and Africa.[13] While comprehensive, this list is not necessarily exhaustive, and new products could come to market and new deployments could be launched at any time.

Table 1: Current and Past Automated Shuttle Deployments

Company	Characteristics	Current and Past U.S. Deployments
EasyMile	• French company • U.S. headquarters in Denver • Vehicle capacity is 12 passengers (6 seated) • First to include a ramp for accessibility	• Arlington, Texas • Denver, Colorado • Gainesville, Florida • Jacksonville, Florida • San Ramon, California
Local Motors	• U.S. company, headquartered in Phoenix • Vehicle capacity is 12 passengers (9 seated) • Partnered with the technology group Robotic Research to improve AV technology	• National Harbor, Maryland • Greenville, South Carolina
May Mobility	• U.S. company, headquartered in Ann Arbor, Michigan • Vehicle capacity is 6 passengers (all seated) • Vehicle is a modified Polaris GEM	• Detroit, Michigan • Columbus, Ohio
Navya	• French company • U.S. headquarters in Saline, Michigan • Vehicle capacity is 15 passengers (11 seated)	• Ann Arbor, Michigan • Jacksonville, Florida • Las Vegas, Nevada • Lake Nona, Florida
Optimus Ride	• U.S. company, headquartered in Boston • Vehicle capacity is 4 or 6 passengers (all seated) • Vehicle is a modified Polaris GEM	• Boston, Massachusetts

Lessons learned from some of the early automated shuttle deployments include the need for services deployed as transit systems to comply with applicable industry regulations and standards, even in cases where due to the funding source compliance may not technically be required. For example, most automated shuttle vehicles are not ADA-accessible, though they may have some accessible features, and this has been an issue. In addition, due to the high costs of CAV-enabling technology, automated shuttles are not inexpensive. As with most investments in new technology, they require significant upfront costs, with the benefit of overall cost-savings not seen during deployment or perhaps even within the lifetime of a product. Many pilots to date have therefore been leases rather than purchases of the vehicles.

5.4 Efforts in Florida

In addition to the US DOT funded THEA pilot discussed previously, there are additional local efforts to deploy connected vehicle technology within Central Florida and across the state. The CV Pilot on SR 434 in Seminole County, for example, involves upgrading six (6) signalized intersections shown in Figure 11, by installing roadside units allowing for V2I communications and the collection of automated traffic signal performance metrics. The main applications include the

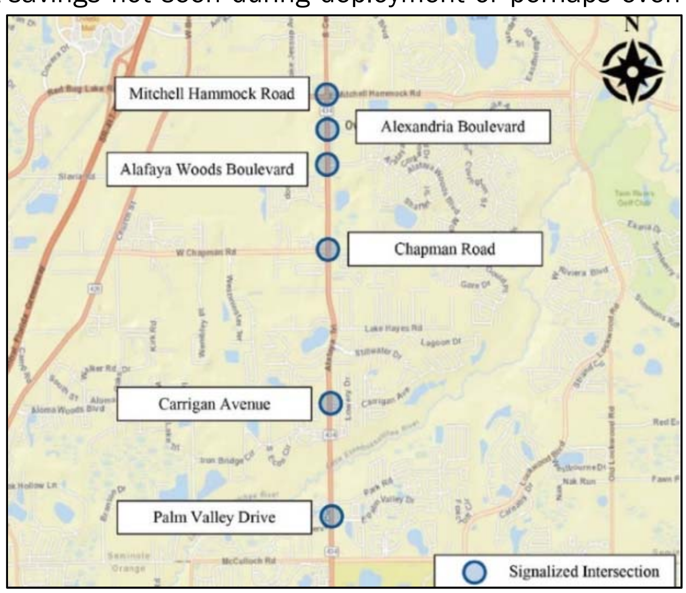

Figure 11: Installation Locations for SR 434 Deployment

Source: Open Street Map

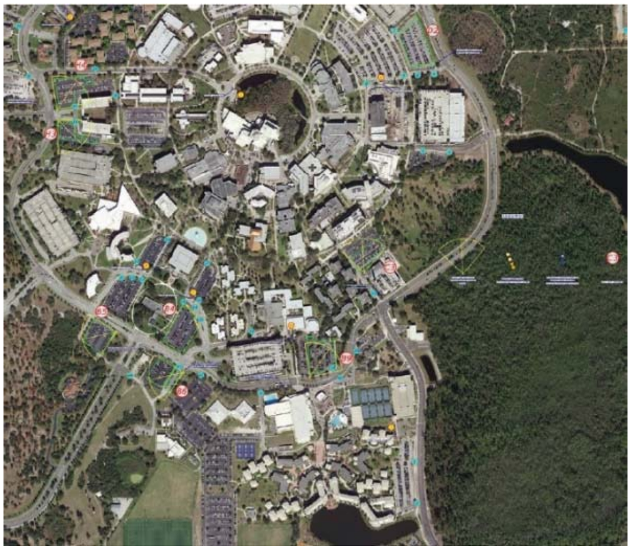

Figure 12: Aerial Image of Pedestrian/Safe Project
Source: Google Maps

transmission of SPaT data to enable emergency vehicle preemption and transit signal priority (TSP). Future CV applications along SR 434 within the test corridor could include congestion warnings, approaching emergency vehicles, and other traveler information.

Another local project is FDOT District Five Pedestrian/Safe Greenway deployment at the University of Central Florida, shown in Figure 12. The first portion of this project involves the implementation of a pedestrian and bicycle collision avoidance system that uses CV technologies to reduce the occurrence of pedestrian and bicycle crashes. The second portion of the project involves increasing throughput capacity and reducing congestion by optimizing traffic signal operations with the implementation of technologies and improving the multimodal movement of people and goods. This will optimize existing traffic operations, in terms of flow rate and safety, for all multimodal traffic during peak time and special events.

On the automated shuttle side, the Florida cities of Gainesville, Babcock Ranch, Orlando (Lake Nona), and Jacksonville have all deployed shuttles on local roads or testing facilities to meet various transportation use cases. In Gainesville, a three-year pilot program is being pursued near the University of Florida campus with a fleet of four (4) automated shuttles to provide fare-free rides from campus to downtown Gainesville. Just south of Tampa, the Babcock Ranch automated shuttle pilot is part of a Smart City initiative with the longer-term goal of providing on-demand service with vehicles of varying sizes to create a transportation ecosystem which, alongside hourly and daily car rental options, is as convenient as owning a personal vehicle. A similar initiative is underway in the Orlando suburb of Lake Nona, with Navya automated shuttles being deployed to enhance a developing network of transportation options in this planned community.

The Jacksonville Transportation Authority (JTA) vision is to transform the existing Jacksonville Skyway elevated automated people mover system into what is known as the U²C System: an expansion of the elevated downtown network into an urban circulator system with transitions to the street level to expand the reach of the system. This transformation will require a technological solution that is able to operate on both the elevated guideway and at-grade public roadways, likely AVs supported by modifications to the guideway that provide a more similar environment to the at-grade roadways (including the removal of the monorail beam).

This full program vision is currently being supported by early deployment stages; in December 2017, the U²C AV Test and Learn track was launched as an "outdoor classroom" to test and evaluate multiple vehicles and their associated technologies from the AV shuttle industry. This has enabled local stakeholders to gain critical information for the development of the U²C program and for other future applications of autonomous transit vehicles as part of its overall public transportation system.

6 National Research Efforts

At the national level, there are dozens of research projects planned or underway that identify critical issues associated with CAVs that state and local transportation agencies will face, conducting research to address those issues, and conducting related technology transfer and information-exchange activities.

A significant portion of the research is being led the National Cooperative Highway Research Program (NCHRP), run by the Transportation Research Board of the National Academies (TRB), and sponsored by the member departments of AASHTO (i.e. individual state DOTs), in cooperation with the Federal Highway Administration (FHWA). NCHRP addresses issues integral to the state DOTs and transportation professionals at all levels of government and the private sector. Contractors conduct individual projects with oversight provided by volunteer panels of expert stakeholders.

6.1 Impacts of CAVs on State and Local Transportation Agencies

One research program of great importance to this study is *NCHRP 20-102 – Impacts of Connected Vehicles and Automated Vehicles on State and Local Transportation Agencies.* The objectives of this research program include identifying critical issues associated with CVs and AVs that state and local transportation agencies and AASHTO will face; conducting research to address those issues; and conducting related technology transfer and information exchange activities. There are four "teams" of consultants and academics working on the following tasks under this program:

Completed Tasks

- 20-102(01) Policy & Planning to Internalize Societal Impacts of CV/AV Systems into Market Decisions
- 20-102(02) Impacts of Regulations and Policies on CV/AV Technology in Transit Operations
- 20-102(03) Challenges to CV and AV Application in Truck Freight Operations
- 20-102(06) Road Markings for Machine Vision
- 20-102(07) Implications of Automation for Motor Vehicle Codes
- 20-102(08) Dedicating Lanes for Priority or Exclusive Use by CVs and AVs
- 20-102(09) Introduction of CV/AV Impacts into Regional Transportation Planning and Modeling

Tasks in Progress

- 20-102(10) Cybersecurity Implications of CV/AV Technologies
- 20-102(11) Mobility-on-Demand and ADS: A Framework for Public-Sector Assessment
- 20-102(12) Business Models to Facilitate Deployment of CV Infrastructure
- 20-102(15) Understanding the Impacts of the Physical Highway Infrastructure Caused By the Increased Prevalence of Advanced Vehicle Technologies
- 20-102(18) Data for Planning Analysis of the Mobility and Reliability Impacts of CAVs
- 20-102(19) Update AASHTO's CAV Research Roadmap

Future Tasks

- 20-102(05) Strategic Communications Plan for NCHRP Project 20-102
- 20-102(13) Planning Data Needs and Collection Techniques for CV/AV Applications
- 20-102(14) Data Management Strategies for CV/AV Applications for Operations
- 20-102(16) Preparing TIM Responders for Connected Vehicles and Automated Vehicles
- 20-102(17) Deployment Guidance for CV Applications in the OSADP
- 20-102(20) Workforce Capability Strategies for State and Local Agencies
- 20-102(21) Infrastructure Modifications to improve the Operational Domain of AVs
- 20-102(23) Potential Impacts of HAV/SM on Traveler Behavior
- 20-102(24) Infrastructure Enablers for CAVs and Shared Mobility

Additional tasks are being formulated at TRB conferences and committees throughout the year, providing the 20-102 organizing panel with updated input to constantly changing research needs. The results of these tasks will provide fundamental guidance and input to state and local DOT's as they continue operating in this fast-evolving space.

Beyond the NCHRP 20-102 program, a project under the NCHRP 20-24 program (Administration of Highway and Transportation Agencies) is underway to help infrastructure owner/operators understand the level to which they intend to equip their roadways for the impending rollout of CAVs. NCHRP 20-24(112) focuses on developing a consensus Connected Road Classification System that will be useful to state and local DOTs and MPOs that are planning or implementing CAV-compatible infrastructure. The project is based on the premise that an important decision facing each infrastructure owner/operator is the level to which they intend to equip their roadways for the impending rollout of CAVs. Recognizing this, the Colorado Department of Transportation (CDOT) has proposed a road classification system with six levels that relate to the roadway's ability to support CAVs. The intent of this NCHRP research project is to build on CDOT's efforts to develop a uniform classification system. This will help agencies designate their roadways based on the degree and level of readiness to accommodate CAVs and plan their deployment of needed infrastructure.

6.2 Other National Research

US DOT has been working on important deployment-oriented research through their CV Pilot program for several years now. The CV pilot deployment programs are expected to integrate CV research concepts into practical and effective elements, enhancing existing operational capabilities. On September 1, 2015, US DOT awarded three cooperative agreements—collectively worth more than $45 million—to initiate a design/build/test phase in three sites: with New York City DOT in New York City, THEA in Tampa, and Wyoming DOT in Wyoming. All three pilot programs have progressed through development and are currently in varying states of operation and evaluation.

Other critical US DOT-sponsored research on cooperative automated transportation includes projects that evaluate enabling technologies, emphasize safety assurance, address need in transportation operational performance, and focus on policy and planning needs created as a result of this rapidly evolving space.

While automakers and device manufacturers will dictate availability of vehicular equipment, transportation agencies will deploy and operate roadside infrastructure and incorporate CV technologies into infrastructure applications (e.g., traffic signal control). In response to this environment, a group of state and local transportation agencies and FHWA created a pooled fund study (PFS) - the Program to Support the Development and Deployment of Connected Vehicle Applications - to conduct the work necessary for infrastructure providers to play a leading role in advancing CV systems.

The CV PFS has completed projects ranging from technical and economic research to ground-breaking design and development of a software and hardware system that services multiple modes of transportation, including general vehicles, transit, emergency vehicles, freight fleets and pedestrians. This multimodal intelligent traffic signal system (MMITSS) is the next generation of traffic signal systems that provide a comprehensive traffic information framework to service all modes of transportation, including general vehicles, transit, emergency vehicles, freight fleets, and pedestrians and bicyclists in a CV environment.

6.3 AMPO CAV Working Group

In early 2017, the Association of Metropolitan Planning Organizations (AMPO) assembled a Connected and Autonomous Vehicles Technical Working Group to "identify how to best leverage the benefits of CAV development and deployment." The effort began with four national meetings over a year and a national symposium in March 2018, and recently concluded with the release of a national framework.

White Paper #1 – April 2017

In April 2017, the AMPO CAV Working Group held their first meeting in Arlington, Texas, to kick-off the Working Group by identifying current policy, practice, and activities at MPOs related to CAV, as well as challenges, needs, opportunities, and next steps. The Working Group identified several challenges that MetroPlan Orlando has identified in other locations, including deployment timeline, safety/security implications, capacity/congestion implications, and impacts on mobility and mode options. Other challenges identified by this meeting included data management, the implications to funding and the operation, structures, roles, and responsibilities of transportation agencies, stakeholder coordination, information sharing, and the role of the MPO in building technical, institutional, and policy capacity. As a result of the discussion, the Working Group developed three primary recommendations for MPOs centered around training and technical assistance, information exchange, and regulations and guidance. At the conclusion of the first meeting, the group focused their efforts on developing recommendations on an information sharing template with which other regional agencies could use to collaborate on information sharing.

White Paper #2 – July 2017

In July 2017, the AMPO CAV Working Group held their second meeting in Cincinnati, Ohio, focusing on coordination with other regional transportation agencies and risk management in their metropolitan areas. This meeting strongly highlighted the need for early and frequent coordination between State DOTs, MPOs, and other transportation agencies, to increase awareness of CAV related activities, build synergy, reduce redundancy, and efficiently use and leverage limited resources for CAV projects. Coordination between MPOs and the freight industry was also highlighted since the application of CAV in freight industry has several applications to increase freight capacity and reduce congestion. The Working Group identified several questions/identified risks (safety, environmental justice/equity, stakeholder expectations, data sharing, and incorporation into the current planning process and decision making) for further exploration, and a desire to learn more about societal adaption to past technologies and the factors that led to their widespread implementation. The Working Group concluded with the identification of actions that transportation agencies can take now to prepare for CAV technologies, many focused on self-assessments to identify their strengths, weaknesses, and areas that need focus within agencies.

White Paper #3 – November 2017

In November 2017, the AMPO CAV Working Group held their third meeting in Washington, D.C., focusing on the federal perspective and coordination/collaboration with transportation stakeholders, associations, and organizations. Several topics discussed overlapped with topics identified at the previous meetings, but several discussions were new, including a significant discussion about CAV deployment on infrastructure stresses and loadings, particularly on bridges or ramps, and the potential need for design practice modification to adjust for additional reinforcement. Another significant discussion focused on considering the full range of emerging technologies (Smart Cities, electrification, shared carpooling, and crowdsourcing) while discouraging the bundling of CAV technologies for discussion, since their needs, benefits, impacts, and deployment scenarios/timelines are likely to be quite different. The Working Group also discussed the impacts of CAV deployment on the MAP-21/FAST Act performance measure requirements for MPOs and identified the need for federal support, potentially including new policies/regulations, guidance for planning/investment decisions, and guidance on the effective use of funding/investment. Ultimately, the Working Group identified three strategies to address the uncertainty in deployment and implementation:

- Make investment decisions that support the future transportation system with or without CAV deployment.
- Make investment decisions that support and guide the transportation system to the desired future.
- Identify specific elements to help guide incorporation of CAV deployment into transportation processes and stakeholder involvement.

White Paper #4 – March 2018

In March 2018, the AMPO CAV Working Group held their fourth and final meeting in Orlando, Florida, to focus on next steps in planning for CAV deployment and how to establish effective partnerships (between public and private sectors) and coordination practices between them. The meeting focused primarily on examples of CAV research and deployment in the Central Florida region, namely the City of Orlando Smart Cities, the Central Florida AV Proving Ground, the AV Mobility Initiative with FDOT, MetroPlan Orlando, and LYNX, the SR 434 AV Pilot Project, the I-75 FRAME project, the SunTrax AV Test Bed, and Florida Turnpike Enterprise test/pilot projects currently underway. The meeting also focused heavily on the roles of MPOs as innovators in C/AV technology and transportation planning, since over 75 percent of the nation's population lives within the boundaries of an MPO. Some of the strategies identified as part of this Working Group meeting include:

- Do not prematurely select a preferred technology
- Expand MPO staff skills in emerging technologies
- Explore the future in incremental transitions

The meeting also focused on the relationships between the public/private sectors, and the ways to establish effective partnerships and coordination practices between them, citing regular coordination meetings as a strong way to keep everyone informed on the status of CAVs in the region and best practices nationwide. As critical questions and theories on the impacts of CAV are discussed, it is essential for MPOs, transit agencies, and the private sector to continue to meet to discuss evolving trends surrounding and affecting the deployment of CAV technologies. The meeting concluded by identifying partnerships between transportation agencies and the private sector, namely, some essential needs related to data sharing, data quality and security, and privacy concerns that could be aggregated in a national repository.

National Framework – April 2019

The most recent publication from the AMPO CAV Working Group was their National Framework for Regional Vehicle Connectivity and Automation Planning document, unveiled during a public webinar in late April 2019. The frame "is intended to assist MPOs as they explore the implications of vehicle connectivity and automation for the transportation system, its users, and the concept of mobility." Recognizing this will be a "working document," there are many recommendations that can be viewed as initial steps, in response to what is a fast-evolving issue.

The framework is a culmination of the previous four white papers, bringing together two years' worth of dialogue and doing their best to capture in an easy-to-digest format the many impact areas, opportunities, challenges, and considerations for the planning process. The document is presented by key impact area, including the following issues of importance to MPOs:

- Safety
- Security
- Operations
- Mobility & Mode Choice
- Freight
- Transportation Demand
- Infrastructure Requirements
- Funding & Financing
- New Service Markets
- Equity
- Data Collection & Housing
- Public Acceptance
- Land Use
- Air Quality/Conformity
- Engagement
- Employment

A number of additional resources are being made available in parallel to the release of the national framework, to provide support for MPOs as they wrestle with institutional readiness, policies, and investment decisions that are often long-term in vision against a backdrop of rapidly changing technology.

6.4 Bringing Research to Florida

As noted, one of the three US DOT sponsored CV Pilots is being conducted in Tampa, under the supervision of THEA. The Central Florida region is also home to SunTrax, a soon-to-be-operational 475-

acre state-of-the-art facility dedicated to the research, development and testing of emerging transportation technologies in a safe and controlled environment, owned and operated by Florida's Turnpike Enterprise (FTE). When fully operational, SunTrax will provide numerous testing spaces to aid in the study of tolling technology, lane marking, intelligent transportation systems and CAVs. The SunTrax facility is located adjacent to Florida Polytechnic University, a long-standing partner to Florida's Turnpike. Other key academic partners in the partnership include the University of Central Florida (UCF), and FAMU-FSU College of Engineering.

SunTrax is part of the larger Central Florida Automated Vehicle Partnership (CFAVP). The partnership offers a comprehensive approach to the research, development and deployment of emerging mobility solutions across Central Florida by providing the three necessary components — simulation at the University partners, closed testing at SunTrax, and eventually open-road deployments on public roads. FDOT, also a member of CFAVP, has several CV pilot deployments underway throughout the state, to help them justify proposals or amendments to policy, design and engineering standards. Data that illustrates the use of AVs on public roadways is extremely important because these type of data sets for real-world conditions are scarce.

7 Conclusions

Nationwide, there is growing interest and excitement in CAVs, as there is when any new technology is emerging, but it is important to understand that there are still many challenges that must be overcome before CAVs can have widespread use on shared public roadways. While the technology is improving rapidly, the timeline for CAV introduction and adoption is still to be determined, and will be impacted not just by the readiness of the technology but also by the readiness of the regulatory environment and the receptiveness of overall public sentiment. MetroPlan Orlando has the opportunity to learn from and teach other regions and agencies during this transitional era, building planning expertise that goes beyond technology development and assessment.

Based on lessons learned, it is clear that one challenge with early CAV deployments and other projects is the need to balance projects that are feasible, projects that respond to a local need, and projects that demonstrate that an agency or region is innovative. In reflecting on the current needs at MetroPlan Orlando, as well as on the wide range of existing and emerging technologies with applications to the region, there are several short- and longer-term opportunities to introduce CAV technologies into future investments. Both the short- and longer-term opportunities are ripe for discussion now, so that MetroPlan Orlando can remain on the forefront of innovation as a more connected and automated future approaches. Based on the Central Florida region's specific areas of interest, these opportunities can be further explored and detailed to inform the decision-making process and match local needs and capabilities with emerging industry trends.

The next steps of the CAV Readiness Study will be guided by interviews with maintaining agencies across the three counties – Orange, Seminole, and Osceola counties – and public involvement to better understand where the region currently stands in the context of the current state of the industry, as well as where key stakeholders want to see CAV testing and deployment best practices implemented in a local context. This process will result in recommendations for leaders to evaluate in terms of developing short- to mid-term concepts and plans for CAV preparedness.

8 Acronyms

The following is a list of acronyms used through this memorandum.

Acronym	Definition
AASHTO	American Association of State Highway and Transportation Officials
ADAS	Advanced Driver Assistance System
AMPO	Association of Metropolitan Planning Organizations
ARC-IT	Architecture Reference for Cooperative and Intelligent Transportation
AV	Automated Vehicle
BSM	Basic Safety Message
CAV	Connected and Automated Vehicle
CDOT	Colorado Department of Transportation
CFAVP	Central Florida Automated Vehicle Partnership
CV	Connected Vehicle
CVRIA	Connected Vehicle Reference Implementation Architecture
DSRC	Dedicated Short Range Communications
ESS	Environmental Sensor Stations
FAMU-FSU	Florida A&M University and Florida State University
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
FTE	Florida's Turnpike Enterprise
GPS	Global Positioning System
HAV	Highly Automated Vehicle
ITS	Intelligent Transportation System
JTA	Jacksonville Transportation Authority
MDOT	Michigan Department of Transportation
MMITSS	Multi-Modal Intelligent Traffic Signal System
MnDOT	Minnesota Department of Transportation
NCHRP	National Cooperative Highway Research Program
NWS	National Weather Service
NYCDOT	New York City Department of Transportation
PFS	Pooled Fund Study
RSE	Roadside Equipment
RTD	Regional Transportation District
SCMS	Security Credential Management System
SOV	Single Occupancy Vehicle
SPaT	Single Phase and Timing
THEA	Tampa Hillsborough Expressway Authority
TRB	Transportation Research Board
TSP	Transit Signal Priority
OBE	On-Board Equipment
ODD	Operational Design Domain
UCF	University of Central Florida
US DOT	United States Department of Transportation
VMT	Vehicle Miles Traveled
V2I	Vehicle-to-Infrastructure

Acronym	Definition
V2P	Vehicle-to-Pedestrian
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-Everything
WYDOT	Wyoming Department of Transportation

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