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Planning for Connected and Automated Vehicles

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INTRODUCTION

Connected and automated vehicle (CAV) technologies have the potential to change transportation on a global scale. These technologies could improve safety, significantly alter transportation costs, and change traffic patterns and congestion. As the home of the Motor City, stakeholders in Southeast Michigan are working to leverage the region's unparalleled automotive heritage to become the center of connected and automated vehicle technology development. This emerging industry could drive local job creation, talent retention, and economic development, and improve quality of life throughout the region.

Connected and automated vehicles, however, are not just an economic development opportunity. Their implementation poses significant questions for government entities about how to maximize the technology's benefits to social welfare, and at the same time, mitigate negative externalities. Government entities must carefully consider how the potentially substantial changes posed by CAV technology may dramatically change transportation, infrastructure, and land use.

Given the time horizon of CAV implementation and the lifespan of infrastructure, the time for these conversations is now. Although the anticipated timeframe for the full implementation of automated vehicles varies greatly and depends on a variety of factors, even partial implementation could have dramatic impacts on our transportation infrastructure and travel patterns (Litman 2017). Meanwhile, infrastructure investments made today may still be in use at the beginning of CAV implementation.

Consider a real-life example currently taking place in some Michigan communities—a local government is managing an increasingly dense downtown core. This government entity may decide to build a parking garage today, and in doing so, may choose to finance the debt over the next 30 years—until 2047.

By 2047, we could see partial implementation of automated vehicles. Such a scenario means that the revenue potential of the garage could be threatened, particularly if CAV technology significantly changes the demand for parking. This could have a dramatic impact on that community's ability to pay off the debt incurred while building the structure, sustain other critical public services, and manage a large stranded asset.

PROCESS

To aid stakeholders in the Greater Ann Arbor Region when considering these kinds of scenarios, Public Sector Consultants (PSC) and the Center for Automotive Research (CAR), along with guidance from the Michigan Municipal League, produced this report. Funded through a Regional Prosperity Initiative technical assistance grant, this report was guided by input from Michigan communities, including stakeholders from regional government, and academic and business leaders, who met to evaluate potential implications associated with the connected and automated vehicle technology.

Given that CAV technology is constantly changing, this report describes current knowledge of the field. PSC combined CAR's research with other recent work to develop a final set of conclusions and supplemented these findings with a series of recommendations.

DEFINING CONNECTED AND AUTOMATED VEHICLES

The term "connected and automated vehicle" can refer to a variety of vehicle technologies currently being implemented to improve travel. These technologies may work at the level of the vehicle, the transportation system, or both. Many types of connectivity and automation are feasible, as are many ways to combine them. For example, some vehicles could be connected without being automated, and possibly others could be automated without being connected (though increasingly, vehicles are connected one way or the other, even if only via a 4G LTE device inside the vehicle). Meanwhile, an automated vehicle could theoretically only rely on information from its sensors (camera, radar, etc.) to perceive the external environment, and human-operated vehicles can have connectivity applications (telematics, GPS, etc.). Further complicating these discussions, both connected and automated systems are often conflated with intelligent transportation systems (ITS). ITS may include connected and automated vehicle systems, but is a much broader concept involving a variety of advanced applications that go beyond vehicle systems. For example, connected and automated vehicle technologies may or may not be integrated into ITS, depending on the specific application.

As shown in Figure 1, approaches to CAV technology can be identified within three categories: intelligent transportation systems, automated vehicle systems, and connected vehicle systems.

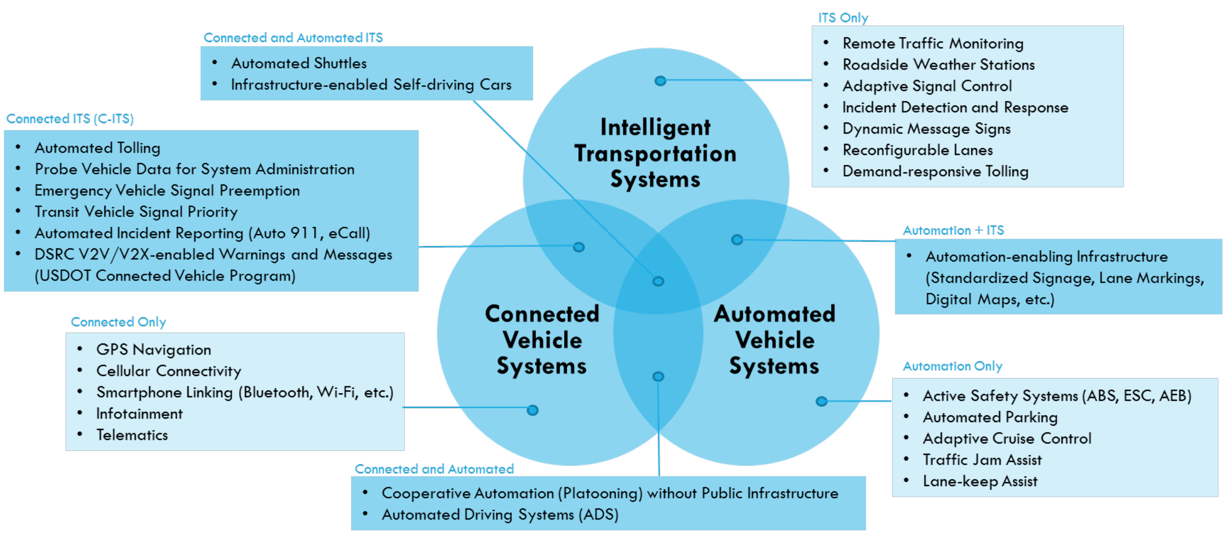


FIGURE 1: Advanced transportation technologies

- Intelligent transportation systems are formally defined by the United States Code of Federal Regulations as "electronics, communications, or information processing used to singly or in combination improve the efficiency or safety of a surface transportation system" (CFR, section 940.1). The distinguishing feature of ITS is a focus on the performance of the system as a whole, without regards to a particular actor. Therefore, ITS is typically implemented by a public or quasi-public organization.

    - Vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication systems are important elements of ITS. V2V systems describe wireless communication between vehicles, such as safety warnings and messages. V2I systems describe wireless communications between vehicles and the infrastructure, such as a system that connects a vehicle to cellular towers for navigation purposes.
- Connected vehicle systems enable the exchange of digital communication between a vehicle and the world. Some vehicles may only receive communication, others may only send data, and still others may both send and receive. Connected vehicle systems are considered digital in nature and do not include sensor-based systems (e.g., radar, Lidar) or analog systems (e.g., AM/FM, CB radio).
- Automated vehicle systems are electronic systems that influence the lateral and/or longitudinal motion of a vehicle. If this influence is sustained, this is referred to as a driving automation system. This definition does omit warning and alert systems that do not independently act upon driving control systems (powertrain and brakes).

As referenced above, a given situation involving advanced transportation technology can include one, two, or all three of these types of systems—for example, a connected and automated vehicle that is utilizing V2I information to choose a route and avoid traffic congestion. More examples of these definitions, as well as examples of commonly known applications, are shown in Figure 1. A more thorough description of connected and automated vehicle systems is provided in Appendix A.

LEVELS OF AUTOMATION

Many of the new vehicles on the market today include elements of automated vehicle systems, such as sensing technologies that help the driver monitor the vehicle's environment to proactively avoid crashes. Some of these automated systems can influence movement of the vehicle over sustained periods of time, fundamentally changing the role of the driver. The various levels of driving automation systems are defined and categorized by SAE International. Because there are countless variations of driving automation possible, including steering, parking, and speed control, several organizations have attempted to provide a formal taxonomy of these systems. The most universally recognized of these taxonomies is SAE J3016, a document entitled "Taxonomy and Definition of Terms Related to Driving Automation Systems for On-road Motor Vehicles".

SAE has determined that "it is not possible to describe or specify a complete test or set of tests which can be applied to a given automated driving system (ADS) feature to identify or verify its level of driving automation." Therefore, the SAE taxonomy describes the relationship between a human driver and an automated driving system as determined by the manufacturer.

The SAE levels of automation are frequently referred to by policymakers and industry insiders to achieve clarity and precision in discussions regarding automated vehicle systems. A summary table describing the levels of driving automation is provided below in Figure 2.

Level	Name	Narrative definition	DDT		DDT fallback	ODD
			Sustained lateral and longitudinal vehicle motion control	OEDR		
Driver* performs part or all of the *DDT						
0	No Driving Automation	The performance by the *driver* of the entire *DDT*, even when enhanced by *active safety systems*.	*Driver*	*Driver*	*Driver*	n/a
1	Driver Assistance	The *sustained* and *ODD*-specific execution by a *driving automation system* of either the *lateral* or the *longitudinal vehicle motion control* subtask of the DDT (but not both simultaneously) with the expectation that the *driver* performs the remainder of the *DDT*.	*Driver* and *System*	*Driver*	*Driver*	Limited
2	Partial Driving Automation	The *sustained* and *ODD*-specific execution by a *driving automation system* of both the *lateral* and *longitudinal vehicle motion control* subtasks of the *DDT* with the expectation that the *driver* completes the *OEDR* subtask and *supervises* the *driving automation system*.	***System***	*Driver*	*Driver*	Limited
***ADS* (“*System*”) performs the entire *DDT* (while engaged)**						
3	Conditional Driving Automation	The *sustained* and *ODD*-specific performance by an *ADS* of the entire DDT with the expectation that the *DDT fallback-ready user* is *receptive* to *ADS*-issued *requests to intervene*, as well as to *DDT performance-relevant system failures* in other *vehicle* systems, and will respond appropriately.	*System*	***System***	*Fallback-ready user (becomes the driver during fallback)*	Limited
4	High Driving Automation	The *sustained* and *ODD*-specific performance by an *ADS* of the entire *DDT* and *DDT fallback* without any expectation that a *user* will respond to a *request to intervene*.	*System*	*System*	***System***	Limited
5	Full Driving Automation	The *sustained* and unconditional (i.e., not *ODD*-specific) performance by an *ADS* of the entire *DDT* and *DDT fallback* without any expectation that a *user* will respond to a *request to intervene*.	*System*	*System*	*System*	**Unlimited**

FIGURE 2: SAE International J3016 Taxonomy and definitions for terms related to driving automation systems for on-road motor vehicles summary table

Glossary for Figure 2

DDT = dynamic driving task
OEDR = object and event detection and response
DDT Fallback = dynamic driving task fallback
ODD = operational design domain

Automated Driving Systems

Within the SAE taxonomy, the upper levels (three through five) are distinguished from lower levels by the fact that the automation system is performing the entire dynamic driving task. Levels three through five are exciting (and concerning) to policymakers because this implies that no human is controlling the motion of the vehicle in real time. Theoretically, automated driving systems could be much safer and more efficient than human drivers; however, deployment and adoption of ADS implies that long-established frameworks of driver regulation and liability must be amended.

As of the date that this report was published, there are only a handful of vehicles in operation around the world that are equipped with fully automated driving systems. These vehicles are generally low-speed, limited-range shuttles that operate in controlled environments with few conflicts.

Currently, many automakers and technology developers are working to bring road-ready, ADS-equipped vehicles to market for use on public roads in real-world conditions. Elon Musk, product architect for Tesla Inc., has suggested that their newer vehicles will have optional ADS capability sometime in 2017 (Stewart 2016). Volvo is also planning a limited pilot deployment of 100 ADS vehicles in 2017 (Davies 2015). Most other automakers have discussed a target of 2020 or later to introduce an ADS-equipped vehicle to market.

RECOMMENDATIONS

Although full deployment of CAVs remains years away, government officials, planners, and economic developers are wise to begin preparing for the potential impacts of this transformative technology. In 2015, one national study found that just 6 percent of planning documents consider the potential effects of automated driving (National League of Cities 2015). And a recent study of the nation's 25 largest metropolitan areas found that, despite planners' awareness of CAV technology, not a single region has yet to mention the new technology in a current regional transportation plan (Guerra 2015).

Based on the background research presented in this report, the following recommendations identify how regional partners can prepare now for the potential policy and land use implications of CAVs. Given the high degree of uncertainty around the timing, scale, and direction of CAV impact, many of these recommendations are oriented toward monitoring specific aspects of policy, planning, and investment—at least until more information can be gathered.

Where feasible, these recommendations identify an actor, with the aim of helping Region 9 stakeholders work with actors at multiple levels of government as well as with key partners (such as Prosperity Regions 6 and 10), share best practices at the local and regional levels, and advocate together for policy changes at the state level.

In the short to medium term, government entities should consider the following actions.

- **Navigate the changing legal landscape.** The existing rules of the road were developed over the course of the last 100 years and are based on the assumption that drivers are human beings. However, law enforcement and other government entities may soon need to adapt to a world where this is no longer true. Consider this scenario: how does law enforcement pull over a fully automated vehicle that has committed a traffic violation? Law enforcement and other agencies must refine the legal mechanisms around the driver as the central actor in driving.
- **Investigate how transit agencies can have a role in protecting public benefits.** With increasing use of shared modes of travel—including bike sharing, car-sharing, and ride-hailing services such as Uber and Lyft—research has shown that travelers that use these services are more likely to use public transit (APTA 2016). As CAV technology begins to overlap with shared modes of travel, public transit agencies will be critical to ensuring that the benefits of CAV technology are widely shared, and not just for those that can afford it. Public transit agencies should seize opportunities to improve mobility for all users of the transportation system, including people with disabilities. For example, agencies can begin work on this now by investigating opportunities for public-private partnerships between transit providers and ride-hailing services to improve connectivity and ensure accessibility to these transportation choices for a wide variety of consumers. And eventually, transit providers could use CAVs to extend and improve service.
- **Tackle zoning changes.** CAVs will likely result in significant changes to the built environment. To prepare for these potential changes, local governments should begin to examine their zoning requirements, including:
    - Parking requirements. Increased use of CAVs will likely lead to less need for parking, particularly in dense urban areas. Therefore, some local governments might benefit from reducing or eliminating minimum parking requirements.

    - Specifications for site design. Because CAVs will likely reshape road rights-of-way and access management, they will potentially have a large impact on site planning. Local governments should consider new streetscape design standards to maximize CAV efficiency. To manage traffic congestion and flow, high-traffic development projects should consider expanding or adding curb space for pick-up and drop-off areas or possible space for automated vehicles to create a queue.
    - Specifications for parking lots and garages. As highlighted later in this report, parking lots and garages could become less desirable, particularly in dense urban areas. Given the time frame for CAV implementation, local governments may want to encourage design specifications to ensure that new parking garages in dense areas can be retrofit to serve other purposes.
- **Change parking policy.** The potential for more efficient parking and reduced demand for parking space as CAV technology is implemented means that local governments should do more than just alter zoning regulations; they must also investigate policies and programs governing the location, form, price, and amount of parking. This includes monitoring how changes in vehicle ownership models and CAV adoption could impact parking revenue, particularly for municipalities that rely heavily on this revenue to support public services. Local governments may also need to develop specifications for parking design for self-driving cars and may need to examine redevelopment opportunities for parking lots in dense urban areas.
- **Protect nonmotorized users.** The implementation of CAV technology could provide opportunities to enhance the mobility and safety of nonmotorized users, including bicyclists and pedestrians. Future excess right-of-way created by space-efficient CAVs could, for example, allow for the creation of more complete streets and expanded nonmotorized networks. However, there are also potential drawbacks to nonmotorized users, such as fragmented nonmotorized networks created by CAV-only roadways. Planners and government agencies should examine both the potential benefits and drawbacks of CAVs to nonmotorized users and prioritize safety and mobility.
- **Track lane-keeping technology.** To date, automated vehicle technologies have been developed to rely on pavement markings and signage to help the vehicles stay in their lane and navigate roadways. However, shoddy infrastructure has proven to be a roadblock that has vexed engineers and added time and cost to the development of this technology. This is particularly an issue in Michigan, where poor markings are the result of limited road funding and weather challenges. As a result, some vehicle manufacturers are moving away from a reliance on pavement markings and signage for lane keeping. The direction in which this technology goes will have an impact on pavement marking policies and signage development and rehabilitation, both of which will cost road agencies more in maintenance costs. Therefore, road agencies should track how vehicle developers and manufacturers are handling CAV lane-keeping technology.
- **Contemplate funding changes.** CAVs will also have a major impact on how we fund transportation infrastructure. For example, if several individuals and families co-own a single CAV, who pays the vehicle registration fee, and how is it collected? Government agencies at all levels should participate in ongoing conversations at the state level about transportation funding reform, including mileage-based user fees, tolling, local options, and congestion pricing, as well as the evolution of the Comprehensive Transportation Fund, particularly as the relationship between CAVs and public transit becomes more clear.

- **Plan ahead.** Government agencies at all levels should begin taking steps to incorporate CAVs into planning documents. For example, metropolitan planning organizations should seek ways to take the impact of self-driving cars into account in long-range transportation plans. This could include work to seek creative ways to consider multiple potential outcomes of CAVs, such as one scenario where vehicle miles traveled (VMT) rises substantially, and another scenario where shared CAVs replace private automobiles. Eventually, road agencies will need to update travel demand models and roadway design manuals to take CAVs into account, and must develop policies for data collection and sharing, including map creation and policies governing open data and data exchange.
- **Consider communications infrastructure as transportation infrastructure.** Transportation agencies will also need to grapple with the communications infrastructure required by the connected portion of CAV technology. This includes identifying how agencies will ensure CAVs have timely, accurate information about construction, detours, and other road hazards. It also includes monitoring the evolution of intersection design and signalization infrastructure.

DETAILED IMPACTS

The next three sections describe the potential impacts of CAV technology on our infrastructure investment decisions, transportation systems, and land use patterns. The final section discusses the legal and regulatory aspects for policymakers to consider. These detailed impacts are outlined to inform the recommendations presented earlier in this report.

INFRASTRUCTURE IMPACTS

Companies and researchers are developing automated vehicle technologies that can function reliably on today's roads, despite the imperfections and specificities of this existing infrastructure. As a result, automated vehicles may not require significant infrastructure investments before they can be deployed on public roads. Maintaining and improving road infrastructure, however, could speed up deployment, avoid costlier technology needed to cope with road imperfections, and increase the reliability of automated vehicles. Policymakers will be asked to determine the amount governments should invest in modifying infrastructure to make operating automated vehicles easier, and how to prioritize that investment compared to other transportation needs.

Existing Infrastructure

Today's road and highway infrastructure has been designed to suit the needs of human drivers, which may not be optimal for vehicles driven by computers. Thus, the transition from human-driven to computer-driven vehicles might require changes to road markings, signage and signalization, lane width and road capacity, and access management, as well as the potential for new infrastructure.

Road Markings

Some automated vehicles rely on identifying road markings with the help of machine vision systems, such as radars and cameras. This is the case for many partially and fully automated vehicles in development, as well as some vehicles already on the market with assisted driving, such as vehicles offered by Tesla, Mercedes, Audi, and Volvo.

The Transportation Research Board currently is funding a research project to identify performance characteristics of pavement markings that could affect the ability of machine vision systems to recognize them (TRB 2017). The results of this research could prove useful to the American Association of State Highway and Transportation Officials (AASHTO) and SAE, along with automotive industry and infrastructure owners and operators, to scope guidelines and criteria for road markings and develop common standards. The target audience will be highway agencies that will prepare and maintain their systems for vehicles equipped with machine vision systems.

That said, many automakers understand that relying solely on lane markings to control automated driving is not a viable strategy. It is unrealistic to expect that all roads will have lane markings in perfect condition all the time. With the goal to produce a self-driving car capable of driving on any road anytime, automakers are exploring other ways to automate lane keeping, such as positioning with respect to the other vehicles, guard rails, and barriers, with input from several sensors and 3D maps.

Improving road markings could be beneficial to encourage early adoption and accelerate the potential safety benefits of these vehicles, but it is not obligatory in the long run. Communities that want to provide optimal conditions to automated vehicles will need to maintain road markings in good condition on their public roads, potentially increasing road maintenance costs. These improvements would prove useful for human-driven vehicles, cyclists, and pedestrians as well.

Signage and Signalization

V2I communication and high-definition 3D mapping may replace some of the functions currently performed by road signs and signals. Road indications could be transmitted to vehicles via dedicated short-range communication (DSRC)[1] or cellular communication. Pedestrians, cyclists, and human-driven vehicles will still need signs and signals, however, so removing them is not a viable option at present.

Traffic signs could be updated to enable V2I applications, as discussed later in this chapter. Some of these applications may help improve traffic flow and optimize speeds through intersections, thus reducing unnecessary braking and accelerating.

Road work zones represent another consideration for CAVs and signage. To limit error risks, construction workers could have wireless beacons that give automated vehicles instructions from a predetermined list. The same could apply for law enforcement and emergency workers.

Lane Width and Road Capacity

In some areas, the same amount of traffic could be accommodated on fewer road lanes as CAVs promise to increase road throughput and efficiency. V2V and V2I applications will allow for smoother traffic by optimizing speeds depending on traffic signal phase. Vehicles will be able to drive at closer following distances safely, therefore increasing throughput. Additional benefits may include fewer crashes, which today cause 25 percent of traffic congestion (FHWA 2015).

Lanes dedicated to self-driving vehicles will not require additional width to accommodate for human error. Lane width could be closer to actual vehicle width, and be reduced by as much as 20 percent—for a width of about eight feet—if vehicle dimensions roughly remain constant. For mixed traffic situations, reductions even to ten feet could also benefit conventional cars, pedestrians, and bicyclists, because they discourage risky driving behavior and lower vehicle speeds, thus increasing safety (Karim 2015).

Increased performance of CAVs strengthens the arguments for performing road diets in some areas. For example, the number and width of lanes could be reduced. In the long term, medians could be removed or narrowed, since a safety buffer between traffic in opposing directions is no longer needed. Space saved could be repurposed for sidewalks, bike lanes, green space, etc.

The positive impact of connected and automated vehicles on road throughput and efficiency could also help avoid road expansions.

Access Management

Because people will want to be picked up and dropped off as close to their destination as possible, self-driving cars will increase the need for drop-off and pick-up points. At the site level, the priority will shift from parking to drop-off and pick-up areas. The rapid growth of ride-hailing services like Uber and Lyft has already created a need for such points, and this need will only increase with shared automated vehicles. The same will be true with privately owned self-driving cars, as these will drop off their

[1] See Appendix A for a detailed definition of DSRC.

passengers and then park themselves. These drop-off and pick-up points will appear in areas beyond airports and train stations, such as by office buildings, commercial areas, cultural and sport venues, and apartment buildings.

Curbside and onsite parking, bus stops, taxi stands, turn lanes, frontage and service roads could be retrofitted into drop-off/pick-up areas. For new developments, entirely new designs for drop-off/pick-up points could appear, such as pull-offs, cul-de-sacs, frontage roads, separate drop-off and pick-up areas, and passenger waiting areas. In return, the form, location, and design of curb cuts could change.

With the increase in drop-off/pick-up areas, potential conflicts with non-motorized traffic on sidewalks and bike lanes may increase as well, so it is important to consider this in new developments and retrofit projects. In dense areas, one drop-off/pick-up area could serve multiple buildings or blocks, just like bus stops are placed in strategic locations.

To ensure efficiency, transportation agencies may create some design standards for drop-off and pick-up areas. At the local level in the very long term, communities might decide to include requirements about drop-off and pick-up locations in their zoning ordinances, such as dimensions, supply based on the type of land use, and how to address developments with smaller setbacks.

New Infrastructure

New infrastructure investments could be necessary to maximize the benefits of these vehicle innovations, and many of these projects would require extensive resources and funding. The Transportation Research Board is funding a research project (TRB 2017) to define potential business models for deployment of the infrastructure needed to support CAV use.

These new infrastructure types include highly detailed maps needed for automated driving. Federal, state, and local public agencies could play a role in map creation, depending on what is relevant at their level. For example, they could contribute to the development of open standards for maps, which would allow for a broad interoperability of automated driving systems. They could also collect and publish pertinent data on lane closures, work zones, and weather.

Data Exchange Partnerships

State, regional, county, or local government agencies could partner with private organizations to exchange data for existing ITS applications, as well as for connected and automated vehicles.[2] Many transportation departments have partnered with companies that offer map and location-based services, such as Waze, HERE, or INRIX.

Data partnership examples. The Michigan Department of Transportation (MDOT) has partnered with HERE since 2009 in a two-way exchange of data. HERE also is creating a precision HD map of Mcity.

The Waze Connected Citizens Program is a two-way free data share with public partners that started in 2014. Waze, with 65 million active monthly users, gives public agencies data about system-generated traffic jams and user-reported traffic incidents, including jams, accidents, hazards, construction, potholes,

[2] More examples of ITS applications using private probe vehicle data can be found in the 2011 report *Private Probe Vehicle Data for Real-Time Applications* by Texas Transportation Institute and Lee Engineering. https://www.azmag.gov/Documents/ITS_2011-10-27_Private-Probe-Vehicle-Data-for-RealTime-Applications-Final-Report.pdf

roadkill, stopped vehicles, objects on the road, and missing signs. Thanks to this information, agencies can respond faster to crashes and congestion, use data for planning and infrastructure investment decisions, increase efficiency of operations, and monitor pavement condition.

In turn, public agencies give data to Waze according to specific data formats and categories, including feeds from road sensors, real-time traffic data, and planned road work and road closures. Waze users then get updates on these conditions through the Waze app. In the United States, 72 partnerships currently exist between cities, counties, state DOTs and Waze, though none are in Michigan (Waze 2016). Waze also has partnered with Esri, a company that provides geographic information systems (GIS) software to many state and local governments. This partnership could make data sharing with Waze easier, cheaper, and faster for cities that already use Esri mapping software.

In some areas, broadband deployment exists, but improvements in speed are needed, because fast internet connections are necessary for V2I applications using DSRC[3]. One of the most effective ways for communities to support the deployment of broadband by private companies is to have a "dig once" policy that recommends laying a single tube in the ground through which all Internet wires go (FHWA 2013). According to the Federal Highway Administration (FHWA), once the tube is in place, any new company can route its fiber through the existing conduit, thus cutting the cost of broadband deployment by up to 90 percent.

New Infrastructure for V2I Communication

Federal, state, and local public agencies are working with the automotive industry and research community to develop, test, and deploy the necessary infrastructure to support V2I applications. As these applications and supporting hardware are constantly evolving, it is imperative that governments be kept abreast of which technologies automakers and suppliers are using and plan to use in the future. In this way, governments can ensure they are installing the latest available technology and can identify whether it is upgradable or open-source.

The infrastructure needed to support V2I communication includes both road infrastructure- and user-related (vehicle) equipment (see Figure 3).

Infrastructure-related:

- Roadside units (RSUs): Devices that transmit and receive data from nearby vehicles. The RSU can be fixed or portable, and contains a processor, data storage, and communications capabilities. Currently, RSUs use DSRC or other wireless communications technologies
- Traffic signal controllers: Devices that generate the Signal Phase and Timing (SPaT) message (green, yellow, red, and the amount of time left until the next phase) and transmit that signal to the RSUs
- Traffic management center: System that collects and processes aggregated data from infrastructure and vehicles
- Backhaul communications: A secure communications network between the highway agency and RSUs (typically fiber optic)
- Support functions: Functions that ensure security of data transmission and maintenance

[3] See Appendix A for a detailed definition of DSRC.

User-related:

- Onboard equipment: Devices located in the vehicle (standard equipment or after-market device) that communicate to the RSUs and process and store data
- Nomadic device: Device carried by a pedestrian, bicyclist, or wheelchair user that provides information to vehicle drivers

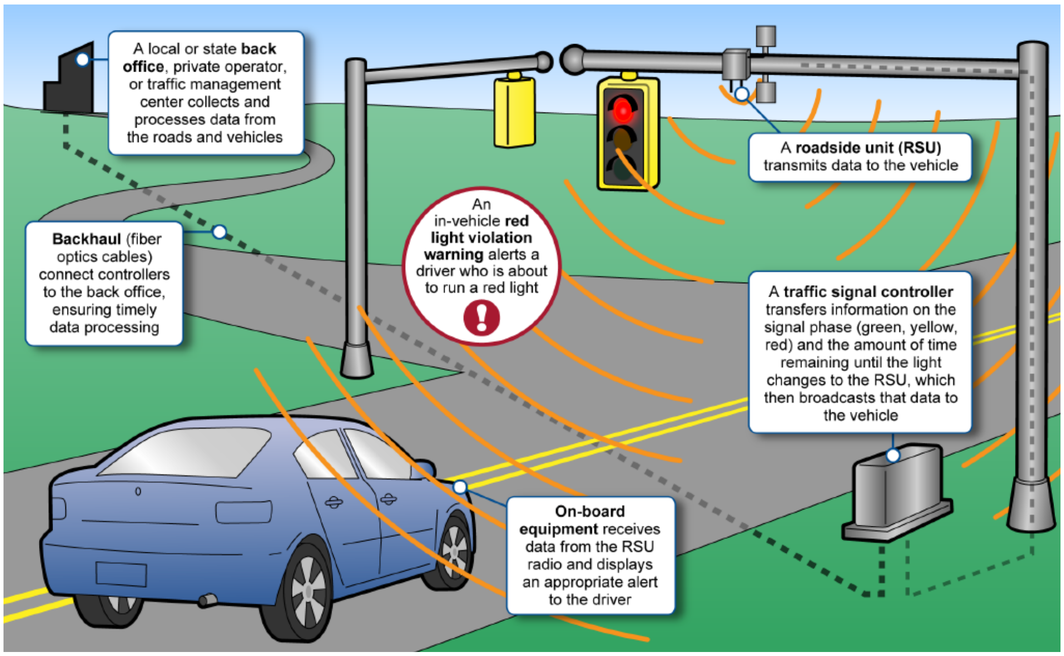


FIGURE 3: Example of V2I application and roadside equipment (Source: GAO 2015)

National pilot deployments and testing facilities. Below is a list of current testbed locations in the United States. Note, however, that new facilities are being planned and built all the time.

- Early state connected vehicle programs: e.g., Michigan Data Use Analysis and Processing (DUAP) and Arizona Emergency Vehicle Infrastructure Integration (VII)
- Connected vehicle test beds: Novi, Michigan; other test beds in California, Arizona, Tennessee, Virginia, Florida, and New York
- United States Department of Transportation (U.S. DOT) connected vehicle safety pilot model deployment: Ann Arbor
- U.S. DOT connected vehicle pilot deployment: New York City, New York; Wyoming along Interstate 80; and Tampa, Florida
- Consortia: Mobility Transformation Center (MTC)/Mcity, GoMentum Station, Accelerate Texas, American Center for Mobility (Michigan)

Cost estimates. Deployment costs are expected to drop over time. Based on pilot projects and estimates, the average cost of deploying an RSU is $51,650 per unit (GAO 2015; AASHTO 2014; NCHRP 2013). However, if there is existing fiber backhaul, RSU deployment can cost less. The U.S. DOT developed the Cost Overview for Planning Ideas and Logical Organization Tool (CO-PILOT) to estimate high-level costs for 56 V2I applications based on AASHTO's estimations.[4] The FHWA has also started developing a V2I deployment guidance document that can help governments in the decision-making process (FHWA 2014).

Local and state authorities will likely bear the costs, but efforts will be eligible for federal aid highway funding, according to FHWA's draft guidance on V2I deployment. By emphasizing the benefits of V2I applications, governments will be able tap into specific funding programs to reach goals such as air quality and safety.

Potential deployment timeline. Deployment will be voluntary, occurring over several decades (see estimated timeline in Figure 4). The U.S. DOT estimates that, to reap the full benefits of V2I applications, around 80 percent of vehicles should receive the SPaT information; however, environmental and mobility benefits likely will occur even without widespread market penetration. AASHTO, the U.S. DOT, and Transport Canada have supported research to determine scenarios for deployment and timelines (AASHTO 2014). They estimate that 20 percent of signalized intersections will be V2I capable by 2025, and 80 percent of them by 2040. The same report estimated that 90 percent of light vehicles would be V2V equipped by 2040. Finally, early V2I deployments will likely be located at the highest-volume signalized intersections, potentially addressing 50 percent of intersection crashes. The FHWA has also started developing a V2I deployment guidance that can help governments in the decision-making process (FHWA 2014).

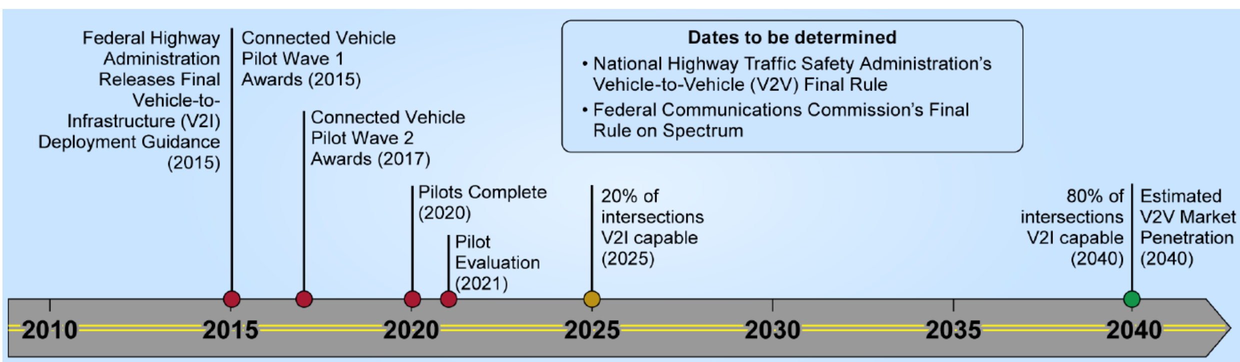


FIGURE 4: U.S. DOT's planned connected vehicle path to deployment (Source: GAO 2015)

AASHTO leads the V2I Deployment Coalition, which includes more than 15 state DOTs, U.S. DOT, and private individuals and organizations (research labs, engineering consultants, and automotive and software companies). The goal of the V2I Deployment Coalition is to deploy and operate functioning V2I infrastructure and regularly publish information about the Coalition's work.

Common standards. Establishing technical standards is essential for V2I and V2V applications and programs. SAE International, U.S. DOT, and various public and private organizations have established standards for DSRC (SAE J2735 and J2945), which will support a wide variety of V2V and V2I applications. The V2I Deployment Coalition intends to develop V2I standards, guidelines, and test specifications to support interoperability. Finally, U.S. DOT is funding the development of the Connected

[4] To access CO-PILOT, visit: https://co-pilot.noblis.org/CVP_CET/.

Vehicle Reference Implementation Architecture, the goal of which is to support the development of deployments as well as to identify potential interfaces for standardization.[5]

Michigan efforts. MDOT has its own connected vehicle program that focuses on the development of four V2I applications:

- Red-light violation warning
- Work zone warning and management
- Road weather management
- Pavement condition

Working in partnership with automotive manufacturers such as General Motors and Ford, the University of Michigan, the Road Commission for Oakland County, and a number of other partners, MDOT has set a vision and is investing in V2I deployment in Southeast Michigan, as shown in Figure 5. MDOT is also open to working with local communities in developing connected vehicle applications.

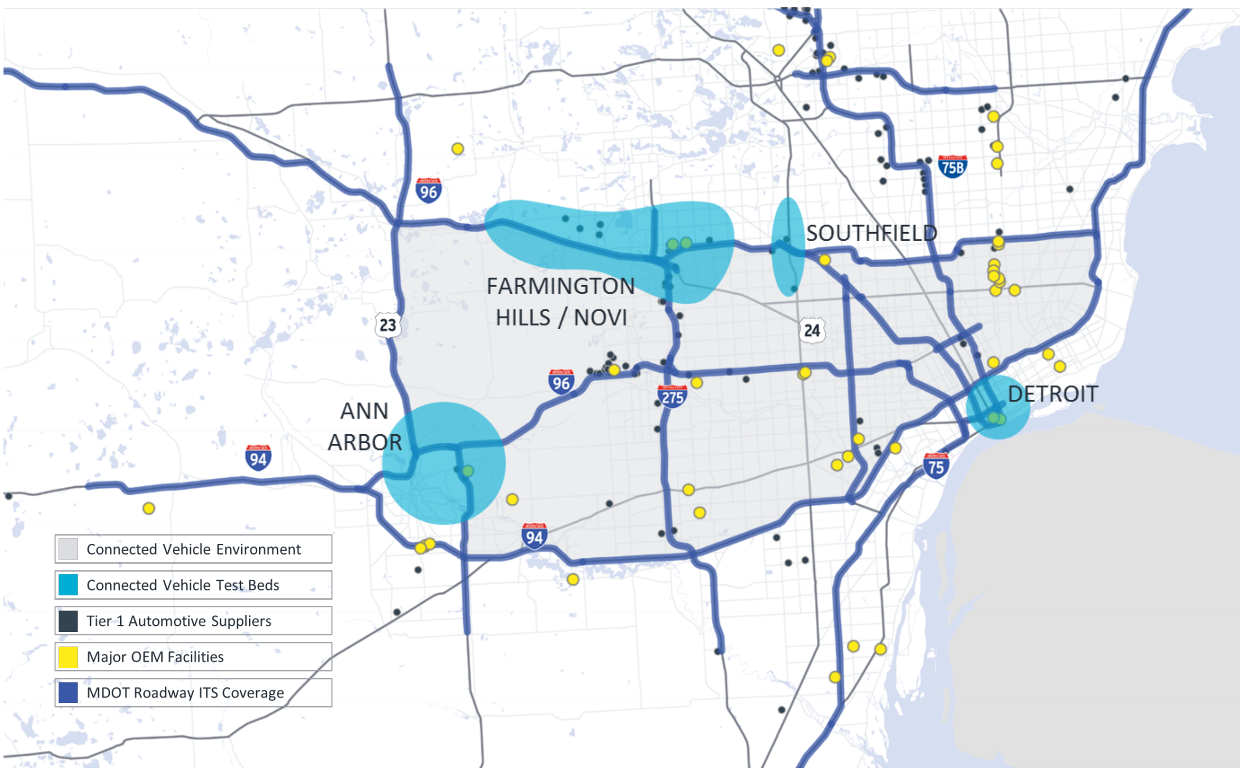


FIGURE 5: Southeast Michigan Connected Vehicle Assets (Source: MDOT presentation at the Michigan CAV Working Group – April 28, 2016, http://www.michigan.gov/documents/mdot/Michigan_CV_Working_Group_April_28_2016_523693_7.pdf)

TRANSPORTATION SYSTEM IMPACTS

Connected and automated vehicles could have profound impacts on transportation systems, though the precise magnitude of these impacts is yet unknown. Much depends on how CAVs will be used, public and

[5] More information: https://www.standards.its.dot.gov/DevelopmentActivities/CVReference

private infrastructure investment decisions, public policy and regulation, and overall transportation costs. One of the more important potential impacts is on travel demand and VMT.

Travel Demand and Vehicle Miles Traveled

As society moves toward a future where the majority of vehicles are self-driving, how and how often people travel by car and other transportation modes could change significantly. Therefore, one of the major questions surrounding CAVs is what impact this technology will have on how much we drive. The most common tool of measurement for how much we drive is VMT, defined by the FHWA as a measurement of miles traveled by vehicles within a specified region for a specified time period.

After rising steadily each decade of the 20th century, VMT has tapered off in states across the United States in recent years. In fact, in Michigan, it has been declining. For example, in 2008, Michiganders drove 101,825 million miles, whereas by 2015, that total dropped to 95,100 million miles. Given Michigan's population decline over those years, VMT per capita is a potentially more revealing measure than total VMT. Even when adjusting for changes in population, Michiganders drove less—with Michigan's VMT per capita moving from 10,179 in 2008 to 9,584 in 2015 (FHWA 2008 and 2015).

Several studies and simulations have estimated the potential impact of CAVs on VMT, specifically the impact of self-driving vehicles. These studies have been based on local case studies and on business models like automated taxis, and while it is premature to draw conclusions on the overall effect that CAVs will have on travel patterns, it is possible to identify which factors will likely increase or decrease VMT. It is also important to note that many of these factors could have an amplified effect when taken together.

Factors Potentially Increasing VMT

Vehicle miles traveled are influenced by a variety of factors, and CAV technology is most likely to affect VMT through changes in these factors. Influences that could increase VMT include:

- **Increased travel demand**. Automated vehicles promise to make transportation more convenient and affordable, particularly within car sharing or self-driving taxi programs. Self-driving cars (and other vehicle types) will eliminate one of the biggest transportation costs, the value of time, by giving people the opportunity to engage in other activities while traveling – such as work, sleep, and play. People will have fewer incentives to minimize or optimize their travel, thus potentially increasing vehicle travel (Ecenbarger 2009, Ohnsman 2014).
- **Zero-occupancy VMT.** If automated vehicles perform many empty trucking backhauls – return trips without cargo or passengers – VMT could increase due to empty vehicles traveling between a drop-off and the next pick-up.
- **Reduced trip chaining**. Automated vehicles could lower incentives for trip chaining (making stops on the way to another destination) by making zero-occupancy trips possible. For example, a self-driving vehicle could take one family member to work, then return home empty to take another person to work or to school, etc. This effect would be smaller in a car sharing or self-driving taxi scheme than with private vehicle ownership, but it still could increase VMT.

- **Shift away from public transportation and nonmotorized modes.** Increased convenience and affordability could make self-driving cars more attractive transportation options than transit, biking, or walking. A shift away from public transportation and toward lower-occupancy automated vehicles will increase travel. Self-driving transportation also promises to provide a solution for first-and-last-mile travel (the challenges of getting a commuter to and from a transit hub). While this can be seen as a desirable outcome, it may also increase vehicle travel as more people choose self-driving cars even for short trips that could be completed by walking or biking.
- **Urban form and development patterns.** Because people would be able to engage in other activities while traveling in fully automated vehicles, they may be more willing to accept a longer work commute in order to live in a more affordable home. This would give an incentive for urban sprawl, and in turn would generate more miles of travel. This is particularly likely for multiperson households for which the members of the household travel in different directions for work, school, etc.
- **Location of parking facilities.** Fully automated vehicles could make onsite parking obsolete because vehicles will be able to park themselves outside of downtown or other congested areas. If, however, these satellite parking facilities are located far from points of interest like office centers, residential, or commercial areas, VMT could increase due to empty backhauls.
- **Private ownership of automated vehicles.** Private ownership of automated vehicles would not raise VMT directly, but it may magnify the impact of other factors described in this section. For example, the private owner of a fully automated vehicle might choose to send the vehicle back home during the day to avoid expensive downtown parking.
- **Increased mobility of nondrivers.** Automated vehicles would offer underserved populations, such as those under age 16, senior citizens with difficulties driving, and persons with disabilities, greater opportunity to travel. While this has many benefits for society, it would also increase VMT.

Factors Potentially Decreasing VMT

While automated vehicles clearly have a significant potential to increase VMT, they also are likely to affect some factors in the opposite direction—reducing VMT.

- **Pay-per-use self-driving vehicle programs.** Provision of car sharing, taxis, and ride hailing services via automated vehicles are likely to discourage unnecessary travel, because people would have to evaluate the added value of each trip and pay for each one taken.
- **Lower car ownership.** If people own fewer vehicles due to a proliferation of car sharing options, unnecessary travel could be reduced.
- **Increased vehicle occupancy.** Connected and automated vehicles in car sharing or taxi fleets are likely to have technologies that make carpooling more convenient. They will have optimized route planning, making sharing part of a ride with another passenger more convenient and cheaper. Companies like Uber and Lyft that are developing self-driving taxis are already proposing services for shared rides, such as UberPOOL and Lyft Line, that will become even more attractive with automated vehicles.
- **CAVs used as first-and-last-mile solution in combination with public transportation**. If CAVs are used as feeder services to transit routes and not to replace entire trips that could be completed with transit, travel may be reduced. Adding a ride in an automated vehicle at the first-and-last-mile to a transit ride could offer a transportation solution appealing enough for some people to forego travelling solely by car.

- **Fewer vehicles**. Assuming CAV car sharing or taxi fleets become prolific, there will be fewer total vehicles on the road, thus tending to reduce VMT.
- **Less travel related to searching for parking**. One of the features that CAVs are likely to offer is the ability to easily locate available parking and drive to it. That will eliminate miles spent looking for parking.

Over the next years, more studies based on improved simulation models and actual travel monitoring must be done to determine how CAVs will impact VMT. This will help all levels of government develop and implement policies to fulfill goals relating to VMT, such as maintaining or reducing VMT to help curb greenhouse gas emissions.

Energy Consumption

Energy consumption of light-duty vehicles may vary substantially when these vehicles are equipped with automated and connected technology. To test light-duty vehicles, the National Renewable Energy Laboratory developed eight scenarios based on completed studies and simulations (Brown, Gonder, and Repac 2014). In the most positive scenario, automated vehicles could help reduce energy consumption of light-duty vehicles by 83 percent. In the most negative scenario, they could increase energy use by as much as 217 percent. This very wide difference reflects the variety of possible scenarios. At this point, the role of communities and public agencies is to develop and implement policies that would make the positive scenarios more likely.

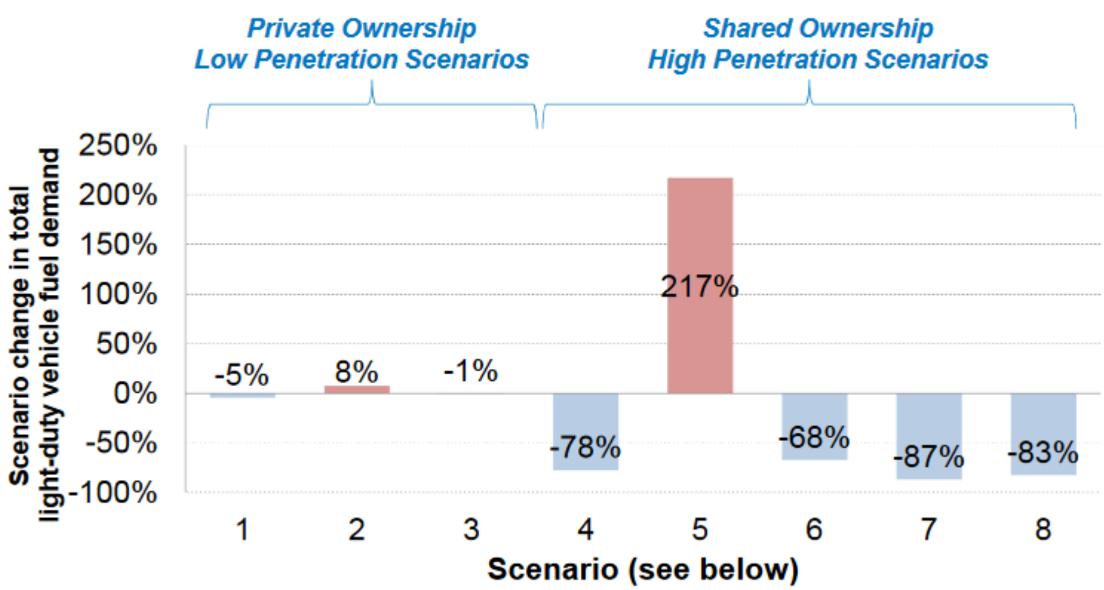


FIGURE 6: Scenarios of the energy consumption of connected and automated vehicles (Source: Brown, Gonder, and Repac 2014)

Number	Scenario name	Active effects
1	Private ownership, fuel savings only	Platooning, some efficient driving, efficient routing
2	Private ownership, fuel-use increase only	Travel by underserved populations
3	Private ownership, combined effects	Platooning, some efficient driving, efficient routing, travel by underserved populations

4	Shared vehicles, fuel savings only	Platooning, efficient driving, efficient routing, lighter vehicles, less time looking for parking, higher occupancy
5	All identified potential fuel-use increases	Travel by underserved populations, faster travel, more travel
6	Vehicle electrification	Electrification
7	All identified potential fuel savings	Platooning, efficient driving, efficient routing, lighter vehicles, less time looking for parking, higher occupancy, electrification
8	All scenarios	All effects

Parking

Various CAV technologies will have an impact on parking in terms of use, location, and design. V2V and V2I communication will enable more efficient use of existing parking supply. Vehicles will identify nearby empty parking spots and choose the best one according to passenger preference. That will allow a better distribution between areas with high demand and insufficient spots, and areas with little demand and available spots. In addition, these vehicles will no longer need to circle in search of a parking spot and will drive there directly.

Automated vehicles may be able to park by themselves after they drop off passengers. That may make locating parking on the back of lots or outside prime locations more acceptable and could also eliminate the need for onsite and on-street parking.

Without the need for a human driver to park the vehicle, self-driving cars may enable significant changes in parking design. Parking design may not need to be human centered and scaled. Parking spaces could be smaller because automated vehicles could park closer together without the need for space to open doors, the turning radius on alleys could be reduced, the surface of access areas could be reduced, and in parking structures, human-oriented amenities could be partially eliminated (lighting, elevators, etc.). Only limited access for maintenance crews would be needed (stairways).

Shared automated vehicles may have higher utilization rates and will spend more time transporting passengers or traveling to pick them up. They will spend less time parked, which will lower demand for parking, especially in commercial and office areas. This effect will increase as more people, especially urban dwellers, forego car ownership in favor of self-driving taxis.

Potential Benefits

There are several CAV-related benefits that improve parking operations, including:

- **Municipal parking construction or expansion could become unnecessary.** As parking demand diminishes as a result of increased CAV use, communities might no longer need to invest in new parking structures.
- **Communities could lower or remove minimum parking requirements.** Reduced parking demand will strengthen the case for eliminating parking requirements from zoning ordinances.
- **Some parking areas could be transformed into pick-up and drop-off locations.** As CAVs proliferate, increasing the number of pick-up and drop-off areas will become necessary. Along with reduced parking demand, this creates an opportunity to convert some parking spots into pick-up and drop-off locations.

- **Parking could be relocated to areas with lower land values.** Because CAVs will be able to park themselves, onsite parking will become less important and some parking could be relocated so that it does not take up valuable land. For example, larger automated vehicle parking outside the densest neighborhoods could be used for off-peak hours, servicing, and storage. Smaller parking areas could be located in the downtown areas mainly for peak hours, charging, or fueling. While transitioning from conventional cars to self-driving vehicles, some onsite parking could be maintained, and offsite parking could be provided for automated vehicles.
- **Land previously occupied by parking could be redeveloped.** Eliminating some parking structures or surface parking lots could open many opportunities to develop that land for other, more valuable uses such as commercial or residential.
- **Reduced parking demand could mean smaller raodways**. Reducing on-street parking demand may represent an opportunity to convert roadway lanes dedicated to parking into other uses, such as bike lanes, wider sidewalks, or green spaces.

Potential Costs

Along at least two dimensions, CAV technology also has the potential to impose costs on community parking, including:

- **A reliable source of municipal revenue could decline**. If the need for municipal parking decreases, this might reduce this revenue stream for communities. Additionally, automated vehicles may not violate parking rules, lowering revenue from parking tickets and fines.
- **Remote relocation of parking could have negative impacts**. Self-driving cars still need to park, so it is important to determine the best location for parking depending on factors such as vehicle routes and utilization rates. If parking is located too far from pick-up and drop-off points, then zero-occupancy travel will increase, which could have a negative impact on congestion and emissions.

As long as conventional and automated vehicles coexist, one scenario could be to have separate parking facilities or different floors in the same structure, to fully benefit from the parking efficiencies of self-driving cars. Parking demand will likely decrease as more self-driving cars are in circulation, so new parking structures could have features that would make reconversion to other uses easier, such as floor-to-floor heights compatible with residential or commercial uses, flat floors, and minimal ramps.

Nonmotorized Traffic

Automated driving promises many benefits for nonmotorized traffic (pedestrians and cyclists), but it also brings associated costs and risks.

Potential Benefits

Improved safety due to CAV technology is the biggest potential benefit for pedestrians and cyclists. Crashes involving pedestrians and cyclists could be avoided by automated vehicles, because these will be more effective than human drivers in identifying other roadway users and taking action in time to protect these vulnerable traffic participants.

Automated driving may make it possible to reduce the number of roadway lanes, the width of lanes, and parking. Some of the space gained by these reductions may be used to widen sidewalks, create or improve bike lanes, and alter lands that are not part of the roadway.

Potential Costs and Risks

If the traffic flow of connected and automated vehicles is prioritized, non-motorized transportation networks could become even more fragmented, especially in urban settings. For example, poorly designed pick-up and drop-off areas could intersect bike lanes too many times or force deviation of bike routes. Pedestrians and cyclists may have extended wait times at crosswalks without conventional signs and signals. Alternative solutions exist, such as tunnels or bridges, but it is important to consider whether they would be a deterrent for pedestrian or bike traffic.

During planning and design of roadways and streetscapes, the interaction between non-motorized modes and self-driving vehicles must be carefully considered to avoid unintentionally discouraging biking and walking. Best practices of Complete Streets design, which relates to taking all modes of transportation into account when planning and designing streetscapes, will be useful in this scenario.

Public Transportation

Vehicle automation and connectivity pose complex challenges for transit services and providers, but they also offer many potential benefits for public transportation, as outlined below.

Potential Benefits

Self-driving technology promises to make passenger vehicles more convenient for everyone and should expand the range of user groups that can operate vehicles; this includes youth (younger than age 16), elderly with diminished eyesight, and persons with disabilities. Ultimately, self-driving cars might encourage some users to select automated vehicles over public transportation, either through a shared-use program or vehicle ownership.

On the connected vehicle side, connectivity applications present many potential benefits for public transportation. V2V and V2I communication could improve the priority of transit in mixed traffic or of bus rapid transit, reduce collisions involving transit vehicles, optimize the efficiency and effectiveness of transit operation, and contribute to reducing the environmental impacts of transit. On the user's end, V2V and V2I could improve predictability of travel time and access to transportation information.

Automated driving could also be an opportunity for mass-transit evolution. Semi-automated transit vehicles could improve safety, and fully automated transit could be more affordable since human drivers would not be needed. In the latter scenario, transit service could be improved by extending lines, increasing frequency and offering on-demand services with shorter wait times. In low-density areas, automated transit could act as a feeder service to rail or bus rapid transit.

Another approach is fully automated shuttles, and several companies have already developed shuttles that have been deployed in several countries as pilot projects (see Appendix B for a complete list of these vehicles). Automated shuttles operate at low speeds, and route design aims to simplify traffic situations and modify the streetscape to make the automation task easier, as most routes are not currently marked or cordoned off. The goal is for the vehicle to operate with a degree of safety at least equal to that of a human driver, which is why these shuttles are currently limited to 20–25 miles per hour at maximum speed. Shuttles with ten- to 15-passenger capacities have mostly been deployed on closed campuses like universities and airports, but deployment is also branching into some downtown areas.

Potential Costs

If this mode shift is significant, it could affect the financial balance of transit and lead to reduced service, especially in lower-density areas. Equity issues and the digital divide could be exacerbated, as affluent populations might increasingly use automated cars and disadvantaged groups might primarily use public transportation.

Automated transit could represent a threat for transit drivers, as well; however, job losses could be limited, because personnel will still be necessary on transit vehicles for tasks other than driving, such as assisting persons with disabilities, providing information, surveilling fare payment, etc.

LAND USE IMPACTS

Connected and automated vehicles may have complex impacts on land use in the long term. Different deployment scenarios could lead to varied land-use outcomes, and policymakers should consider how CAVs may impact planning and zoning decisions.

Land Form

Self-driving cars may either encourage more sprawl or greater density, depending on how the vehicles are used and how the technology interacts with other factors, as detailed below.

More Sprawl Scenario

One of the biggest costs of transportation—the value of our own time spent driving—is likely to be reduced or eliminated completely thanks to self-driving vehicles. Instead of occupying time by physically driving a vehicle while in transit, people will have the opportunity to do other tasks, such as work, sleep, or relax. Transportation costs for users of car sharing or ride-hailing/taxi services will likely be lower, and costs of fuel, insurance, and parking could be lower as well. Self-driving cars will decrease travel times, as they will reduce congestion and increase road throughput. These aspects mean that commuters will be able to travel longer distances for similar travel time and can accomplish more with their time.

In this scenario, self-driving cars may increase commuter willingness to travel longer distances to and from work. Households and businesses may situate farther away from urban cores in search for more affordable rent or home prices, which will provide incentive for more sprawling, low-density urban development and will generate more travel in turn.

Greater Density Scenario

Automated vehicles will help reduce onsite parking needs and enable road diets, especially in urban cores. This will free valuable space that can be used for redevelopment, which will then increase density and walkable developments and encourage a less car-centric lifestyle.

Automated driving will also encourage use of vehicles in shared-use programs. Fleet operators of such programs will target markets that offer a large potential customer base, specifically dense urban areas. The availability and efficiency of shared automated vehicles in these areas will make these neighborhoods more attractive and more people may seek to relocate to areas with these characteristics.

Despite self-driving cars allowing people to use travel time for other activities, Marchetti's constant (the idea that the majority of people will not want to commute more than one hour) might well remain in place. People may still prefer to spend less time in their vehicles, even if they could be productive during that time.

LEGAL AND REGULATORY IMPACTS

The adoption of connected and automated vehicle systems has myriad implications for legal frameworks at all levels—federal, state, and local. This section provides a broad introduction to these implications, with particular focus on how local municipalities and agencies may be affected.

Federal Influence and Authority

The federal government, primarily through the United States Department of Transportation, is responsible for adopting and enforcing design standards for both vehicles and infrastructure.

Vehicles

Every new vehicle sold in the United States must be certified as compliant to the federal motor vehicle safety standards (FMVSS). The FMVSS are adopted and enforced by U.S. DOT National Highway Transportation and Safety Administration (NHTSA) and could have potential impacts on deployment of both automated and connected vehicle systems.

The FMVSS do not strictly prohibit driving automation functions, but they were written before driving automation was considered a relevant possibility. Thus, some FMVSS standards might incidentally affect the specific attributes of automated driving systems, though this was not the original intent. NHTSA is aware of this and commissioned a study to review all FMVSS for potential impacts on self-driving vehicles. The study found that “there are few barriers for automated vehicles to comply with FMVSS, as long as the vehicle does not significantly diverge from a conventional vehicle design” (Kim 2016). In other words, as long as a vehicle is capable of functioning as a traditional vehicle, automakers can layer any degree of driving automation capability on top of that.

NHTSA also has the authority to force a recall of vehicle systems that the agency deems to pose an unreasonable risk. The agency has stated explicitly that “a … system that allows a driver to relinquish control of the vehicle … but fails to adequately account for reasonably foreseeable situations where a distracted or inattentive driver/occupant must retake control of the vehicle at any point may be an unreasonable risk to safety” (NHTSA 2016). In other words, after a vehicle has been deployed, NHTSA can use recall authority to regulate driving automation systems regardless of whether or not FMVSS are affected.

Regarding connected vehicles, NHTSA has published an advance notice of proposed rulemaking (ANPRM), expressing intent to pursue an FMVSS requirement for a DSRC-based connected vehicle system. The ANPRM suggested that NHTSA intends for all new vehicles sold in the United States to broadcast a DSRC signal. Specific applications for connectivity would not be mandated, but NHTSA expects that automakers would adopt such DSRC applications as left-turn warning and intersection movement assist (NHTSA 2014). NHTSA delivered a proposed rule (NPRM) to the Office of Management and Budget Office of Information and Regulatory Affairs (OIRA) in January of 2016. In January 2017, the NPRM was published in the Federal Register. After receiving comments, the NPRM will be subject to additional public commentary and review by OIRA. Therefore, the potential for a future V2V mandate remains uncertain.

Infrastructure

The United States federal government does not typically own transportation infrastructure. However, the U.S. DOT—through the federal highway administration—has a strong influence on design and maintenance standards for roadways included in the National Highway System (NHS). The NHS includes the entire U.S. Interstate System as well as many other highways identified as strategic to emergency preparedness, national defense, or interstate commerce. Federal funding for transportation infrastructure is often contingent on compliance to federal standards of design and maintenance of these systems—regardless of whether a particular highway is owned by state or local entities.

In Michigan, about 1,200 centerline miles of roadway designated as part of the NHS are owned by counties or local municipalities (Dennis and Spulber 2016). If federal guidelines are updated to accommodate future advancements in CAV systems, states and municipalities may be obligated to incorporate such guidelines into design and maintenance practices to ensure continued contribution of federal funding.

U.S. DOT Automated Vehicles Policy

While the U.S. DOT does not specifically regulate automated driving systems, NHTSA has developed a policy approach on the topic. The most relevant document is NHTSA's *Preliminary Statement of Policy Concerning Automated Vehicles*, published September 19, 2016 (NHTSA 2016). The policy document provides guidance only and has no force of law. Some of the most interesting points of guidance include:

- Introduction of a voluntary 15-point safety assessment to be submitted to NHTSA prior to testing or deploying highly automated vehicles
- Acknowledgement that manufacturers are responsible for determining capability of a driving automation system with respect to the SAE 0–5 taxonomy
- Guidance to states to avoid regulating driving automation technology
- Request to states to require local testing entities to submit a 15-point safety assessment to NHTSA (Dennis and Wallace 2016)

The safety assessment requested by NHTSA includes a plan for compliance with federal, state, and local laws. Beyond that, there is not much implication of NHTSA's policy statement to local governments.

State Laws and Regulations

While the federal government regulates vehicle technology requirements, it is left to the states to regulate operation of those vehicles on public roadways. Most state vehicle codes are silent on the topic of driving automation. In states that do not expressly forbid automated vehicles, their operation remains *de facto* legal until shown otherwise (Smith 2014). As automated driving systems are increasingly tested and eventually deployed, their operation will be subject to the existing vehicle operation regulatory framework. It remains to be seen how existing requirements will be interpreted and applied.

Michigan is one of eight states whose legal code has been amended to address driving automation, and only one of three to regulate testing and deployment of automated driving systems (Dennis and Spulber 2017). Michigan's initial legislation on the topic—adopted in 2013—introduced a series of relevant definitions to the Michigan Vehicle Code, expanded the ability to use special manufacturer plates or "M-plates" for testing, and also restricted the use of automated driving systems to testing purposes only. In December 2016, a series of additional bills were signed into law, aimed at updating the 2013 legislation.

This new legislation repeals the restriction of consumer-deployed ADS and allows automated vehicles to operate on any Michigan roadway. It also establishes a legal framework for "on-demand automated motor vehicle network[s]" and allows for automated platoons of trucks to travel together at set speeds on Michigan roadways.

Michigan's legal framework does not have much implication for local authorities. The legal, regulatory, and liability frameworks that local agencies are accustomed to are not expected to change much in the short term. One exception to this is a restriction on local authorities to regulate the operation of an "on-demand automated motor vehicle network (Public Act 332 of 2016)." This legislation does not explicitly preclude local control over ADS-equipped vehicles deployed outside of an on-demand automated motor vehicle network.

Regarding connected vehicle systems, neither federal or state standards require specific provision of infrastructure by local authorities. However, various communications infrastructure projects may be eligible for federal funding. Additionally, MDOT has adopted a relatively aggressive plan for broad adoption of connected and automated vehicle technologies and is open to partnerships concerning deployment and pilot projects.

Local Enforcement

In Michigan, as in most states, local police have a central role in enforcing driver compliance to the motor vehicle code. Michigan Public Act 332 of 2016, which was signed into law in December 2016, states that "when engaged, an automated driving system … shall be considered the driver or operator of a vehicle for determining conformance to any applicable traffic or motor vehicle laws…" The protocol for citing an ADS has not been determined and is not addressed in this legislation. The procedure for ticketing an ADS is yet to be developed, however, and could be made more difficult by the restriction of local agencies to regulate on-demand automated motor vehicle networks. Additionally, no existing or pending statute provides local police agencies with guidance on enforcing traffic code for ADS that are not part of an on-demand automated motor vehicle network.

Potential Changes in Legal Landscape

As of this report's release, there are very few implications for local governments and agencies regarding the legal and regulatory impacts of connected and automated vehicle systems. However, the legal landscape could evolve in a variety of ways.

- Automated vehicle deployment: Law as we know it results from a complex interaction of legislation, regulation, and interpretation as applied to real-world requirements. As of this report's release, no ADS- equipped vehicle has been commercially deployed in a public area. Thus far, ADS public operation has been limited to testing purposes, public-private pilot programs, and restricted-access tracks. However, many industry-watchers believe that public deployment of ADS is an eventual certainty. If and when ADS-equipped vehicles begin commercial deployment, they will be subject to a myriad of existing legal frameworks, whether or not such frameworks explicitly consider driving automation. The law, as applied to self-driving vehicles, will manifest in response to the specific attributes of future vehicles and the relationship to society.

- Connected vehicle mandate*:* The U.S. DOT NHTSA is pursuing rulemaking that would mandate all new vehicles to include DSRC connectivity at a future date. The potential for this regulation's adoption is currently unknown. However, if such a regulation is adopted, there may be wide impacts on the entire surface transportation system's operation. It is not expected that any U.S. DOT mandate would impose burdens on state or local authorities. However, if state and local agencies begin to deploy infrastructure to support and/or leverage connectivity, agencies may implicitly incur added responsibility and liability for the operation of such infrastructure. It is difficult to predict how this may specifically impact local agency decision making; however, it can be assumed that existing frameworks of transportation systems service delivery and related liability will continue to apply.
- Federal legislation, regulation, and policy: As previously noted, the U.S. DOT has direct authority over the design of new vehicles, and it has indirect authority over the design of infrastructure through various funding mechanisms—most notably the Federal Aid Highway Program and standards related to the National Highway System. At this time, there are no federal requirements on either vehicles or infrastructure that impose requirements on state or local agencies specifically regarding connected and automated vehicle technology. However, it is possible that future federal policy might impose additional responsibilities to state and local authorities.
- State legislation, regulation, and policy: Local road and transportation agencies are funded through a complex system of federal, state, and local revenue. Just as federal policy could impact the responsibilities of local agencies, so could state policy. The Michigan Transportation Fund is currently distributed to county and local agencies through a complex formula based on roadway mileage, population, and various other factors. It is possible that future amendments to the formula could incorporate connected and automated vehicle technology.
- Local law and policy: As a home-rule state, Michigan allows local authorities to govern themselves as they see fit within the bounds of applicable state and federal law. Thus, local authorities in Michigan are able to impose local laws regarding operation of motor vehicles. If the legislative authority of a county or municipality adopts rules governing connected or automated vehicle technology, it will be the responsibility of local agencies to interpret and enforce such rules.
- Divergent case-law rulings: In cases for which the application of law in a hypothetical scenario is not clear, policy analysts and legal scholars might be capable of offering a reasonable guess about how the law would apply based partially on explicit laws and regulations and partially by precedents set in previous cases. In the United States, we have a history of case law that affects how both civil and common laws are applied and interpreted. Occasionally, a court will find that the correct application of a law is such that it changes the expectations of how the law works; a judgement may even overturn established precedent. As the legal framework evolves over time, divergent rulings have the potential to change the expectations of responsibilities and liabilities of local governments.

APPENDIX A: CONNECTED AND AUTOMATED VEHICLE DETAILED DESCRIPTIONS

This appendix offers more detailed (and technical) descriptions of connected and automated vehicle systems.

CONNECTED VEHICLE SYSTEMS

When industry insiders refer to connected vehicles, they usually have a specific connectivity application in mind that is most relevant to their respective business or regulatory interest. Subsequent discussions can become confusing because the term "connected vehicle" can refer to many different specific systems or implementations, each involving different hardware and software combinations. Broadly, a connected vehicle system can be defined as any system enabling the wireless exchange of digital information between a vehicle and the world. Figure 7 shows three applications of connected-vehicle technology divided into three components.

Wireless communication networks are often described with respect to the Open Systems Interconnection seven-layer model, which divides a system into seven abstract layers. For the purposes of this report, we can simplify our understanding of a connected vehicle system as having only three basic elements: network, language, and application.

The network component describes how—physically and functionally—a vehicle communicates with the outside world. The language component describes the computer languages that are used to translate binary digital communication (ones and zeroes) to operational instructions and structured data. The application component determines what is done with this information.

By analogy, it may be useful to consider two connected vehicles as similar to two humans working together. For the humans to accomplish a goal through communication, they have to be able to hear each other (be on the same network), understand each other (speak the same language), and have the same goal (share an application).

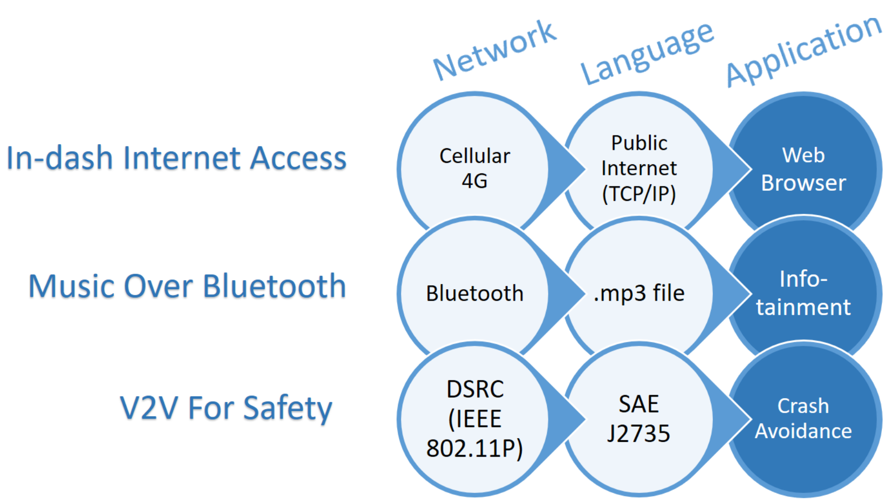


FIGURE 7: Examples of connected vehicle features. Figure developed by CAR.

U.S. DOT CONNECTED VEHICLE PROGRAM

When U.S. government agencies discuss connected vehicles, they are often implicitly referring to a specific type of connected vehicle system developed through, and defined by, the U.S. DOT Connected Vehicle Program. The U.S. DOT connected vehicle network transmits digital code over one or more government-licensed radio-frequency channels near 5.9 GHz, which is often referred to as dedicated short-range communication. The DSRC network primarily communicates using a language dictionary standardized by SAE International in SAE J2735. The most common data element is called a basic safety message (BSM). The BSM contains a vehicle's location, speed, direction, and other information, and is broadcast ten times each second.

Many different applications could be built on the DSRC network and language, but the U.S. DOT is most interested in using DSRC for safety applications. The most mature applications are crash-avoidance warning intervention systems using direct vehicle-to-vehicle communication. Many stakeholders (such as MDOT) are also working to develop vehicle-to-infrastructure applications.

U.S. DOT NHTSA has prepared a proposal to mandate that all new vehicles sold in the U.S. must broadcast the BSM over DSRC. In January 2017, the Notice of Proposed Rule Making was published in the Federal Register for review and comments, which are due in April 2017.

Automated Vehicle Systems

To be automated, a system must have the three basic functional components shown in Figure 8: monitoring, agency, and action. Automated systems that are considered intelligent also usually include feedback loops and possibly even machine learning.

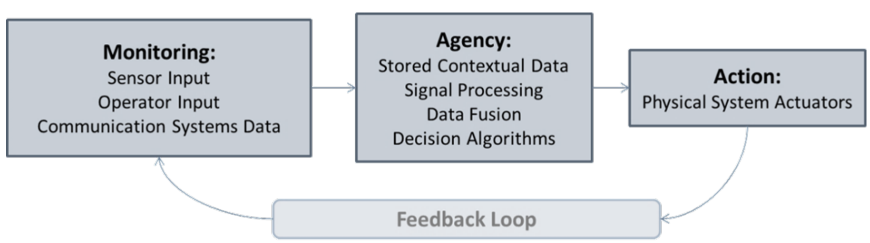


FIGURE 8: Generic automated system. Figure developed by CAR.

Modern vehicles contain dozens of automated systems, though many, such as engine control, do not directly relate to the automated physical movement of a vehicle through the world. This report uses the term "automated vehicle systems" to refer only to systems influencing the lateral and/or longitudinal motion of a vehicle.

APPENDIX B: AUTOMATED TRANSIT VEHICLES

Several companies have developed automated transit vehicles that operate as shuttles (see Figure 9). These vehicles have been deployed in several countries as pilot projects. One example of a semi-automated bus in development is the Mercedes-Benz Future Bus. This bus recognizes traffic lights, communicates with them, and safely negotiates intersections. It recognizes obstacles and pedestrians on the road and brakes autonomously. The bus driver may intervene at any time, if needed. This vehicle concept was tested in the Netherlands in July 2016 on a 20 kilometer route in real traffic. The bus has a top speed of 70 kilometers per hour (43 mph) and is suitable for bus rapid transit systems.

Navya is a French company developing electric automated systems. Their Arma, a fully automated shuttle, was deployed in 2016 as part of trials open to the public in the cities of Lyon, France and Sion, Switzerland. The shuttle is also used on a nuclear plant campus in France.

French company Easymile built the EZ10 electric automated shuttles that were used in 2014–2015 in seven deployments through EU-funded CityMobil2 Project, including Vantaa, Finland; Sophia Antipolis, France; and Lausanne, Switzerland. In the U.S., pilot demonstrations are organized in Concord, California. The shuttle is also in service in Singapore and is in trial rounds in Dubai, UAE; Wageningen, Netherlands; and Helsinki, Finland.

Dutch company 2getthere developed a Personal Rapid Transit (PRT) and a Group Rapid Transit (GRT) shuttle, with six- and 24-passenger capacities respectively. 2getthere is working on applications for fully dedicated right-of way and mixed-traffic situations. Ten PRT shuttles have been in use in Masdar, UAE since 2010 on dedicated right-of-ways.[6] 2getthere is also working with Singapore transport operator SMRT to trial GRT vehicles (Van Helsdingen 2016).

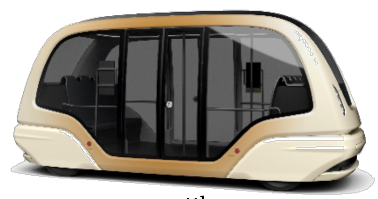
U.S.-based Local Motors has developed the electric, fully automated shuttle Olli. This shuttle made prepilot demonstrations on public roads in National Harbor, Maryland in the summer of 2016. Additional trials are expected in Las Vegas and Miami. Local Motors is also beginning to test the vehicles in Huntsville, Alabama; Berlin, Germany; Copenhagen, Denmark; and Canberra, Australia.

U.S.-based startup Auro Robotics is currently testing their driverless shuttle system at Santa Clara University in 2015 and 2016 (BCN 2016).

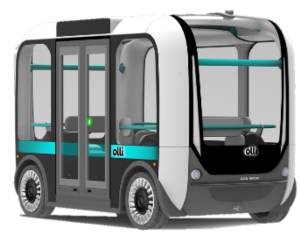
Mercedes-Benz Future Bus

Navya Arma

Easymile EZ10



2getthere



Local Motors Olli

Auro

Figure 9: Examples of automated shuttles

[6] 2getthere. http://www.2getthere.eu/projects/masdar-prt/.

U.S. DOT CONNECTED VEHICLE TRANSIT PROGRAM

The U.S. DOT Intelligent Transportation Systems Joint Program Office is leading a transit V2I research program (see Figure 10) that is bringing the connected vehicle concept to transit. The program takes the unique needs and properties of transit vehicles, operations, institutions, and travelers into account to develop tailored safety, mobility, and environmental applications. The U.S. DOT-funded research includes:

- Transit Vehicle Collision Characteristics for Connected Vehicle Applications Research: Analysis of Collisions Involving Transit Vehicles and Applicability of Connected Vehicle Solutions
- Feasibility Assessment of the Use of Transit Bus Driving Simulators
- Transit Safety Retrofit Package. This project retrofitted three University of Michigan transit buses with connected vehicle technologies. The project developed, tested, installed, deployed, and maintained three basic safety applications—emergency electronic brake lights, forward collision warning, and curve speed warning—and developed two new transit-specific safety applications—pedestrian in signalized crosswalk warning and vehicle turning right in front of bus warning.

FIGURE 10: U.S. DOT Transit V2I Program applications (Source: U.S. DOT 2015)

A semi-automated bus, fully automated bus rapid transit, or shuttles in closed campuses could be deployed in the medium term because these models allow for simplified routes and limited conflicts with other vehicles, pedestrians, and cyclists. An automated bus in mixed traffic is further from being ready for deployment (perhaps a decade or more away), given the complexity of traffic situations.

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