DEPARTMENT OF TRANSPORTATION

Preparing Local Agencies for the Future of Connected and Autonomous Vehicles

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Final Report 2019-18

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PREPARING LOCAL AGENCIES FOR THE FUTURE OF CONNECTED AND AUTONOMOUS VEHICLES

FINAL REPORT

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EXECUTIVE SUMMARY

Connected vehicle technologies hold the potential to produce a number of safety, mobility and environmental benefits. The benefits of connected vehicle technologies are expected to be wide ranging and include reduced crashes, improved mobility and reduced emissions. Local transportation agencies, such as counties and cities can be expected to be affected by the transition to connected vehicle technologies. These agencies can also expect to benefit from connected vehicle technologies, through aspects such as a reduced need to construct roadway infrastructure (fostered by mobility improvements), increased fleet safety (e.g. maintenance vehicles in plowing operations), and other benefits. However, transitioning highway infrastructure to be ready for connected and autonomous vehicle will ultimately require a significant investment in infrastructure upgrades, new technologies, and power and connectivity. Agencies are already grappling with how and where to invest scarce resources to meet existing needs and addressing CAV adds an additional burden. As a result, there is a need for local agencies to not only understand what the potential benefits of connected vehicle technologies are, but also how they should be preparing for the transition to such technologies for the infrastructure and fleets that they manage.

This toolbox was developed to provide a summary of information that local agencies should be aware of to prepare for CAVs. Although autonomous vehicles (AVs) and connected vehicles (CVs) are distinct technologies, for simplicity, the term CAV is used throughout the toolbox. In general, AVs are able to conduct driving tasks either with or without human intervention and are also referred to as self-driving vehicles. However, AVs can also utilize connected vehicle (CV) technology to gather real-time information such as traffic conditions.

The main goal of this toolbox is to assist local agencies in preparing for CAVs in the short term—5 to 10 years.

Since local agencies are not generally expected to have the resources to become test beds, this report provides information so that local agencies can leverage ongoing activities and resources to prepare for CAVs. For instance, when restriping, an agency could invest additional resources to ensure pavement markings are compatible with upcoming standards for autonomous vehicles.

Due to the changing nature of CAV technologies and implementation timelines, the information in this toolbox provides information and recommendations based on knowledge available at this snapshot in time.

The toolbox is organized according to the following:

- Description of autonomous and connected vehicle technology and potential implementation timeline
- Description and recommendations for addressing infrastructure needs including the following:
    - Pavement markings
    - Signing

    - Traffic signals
    - Maintenance
    - Consistency and standardization
    - Data capture and information sharing and inventory
    - Communications infrastructure
    - High-resolution mapping and other infrastructure enhancements
- Seven case studies that summarize how agencies have addressed different aspects of getting ready for CAVs

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

Connected and autonomous vehicle (CAV) technologies hold the potential to result in a number of safety, mobility, and environmental benefits for the users and operators of the nation's surface transportation system. These technologies, which include vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) technologies, use the wireless exchange of data to allow vehicles to communicate between one another and with the highway infrastructure. The benefits of connected vehicle technologies are expected to be wide ranging and include reduced crash rates and severity, improved mobility, and reduced emissions.

Local transportation agencies, such as counties and cities, which manage a significant portion of the Minnesota roadway network, can be expected to be affected by the transition to connected vehicle technologies. These agencies can also expect to benefit from connected vehicle technologies through aspects such as a reduced need to construct roadway infrastructure (fostered by mobility improvements), increased fleet safety (e.g., maintenance vehicles in plowing operations), and other benefits. However, transitioning highway infrastructure to be ready for CAVs will ultimately require a significant investment in infrastructure upgrades, new technologies, and power and connectivity.

Agency staff are already grappling with how and where to invest scarce resources to meet existing needs. As a result, there is a need for local agencies to not only understand what the potential benefits of CAV technologies are, but also how they can be preparing for and potentially leveraging the transition to such technologies for the infrastructure and fleets that they manage.

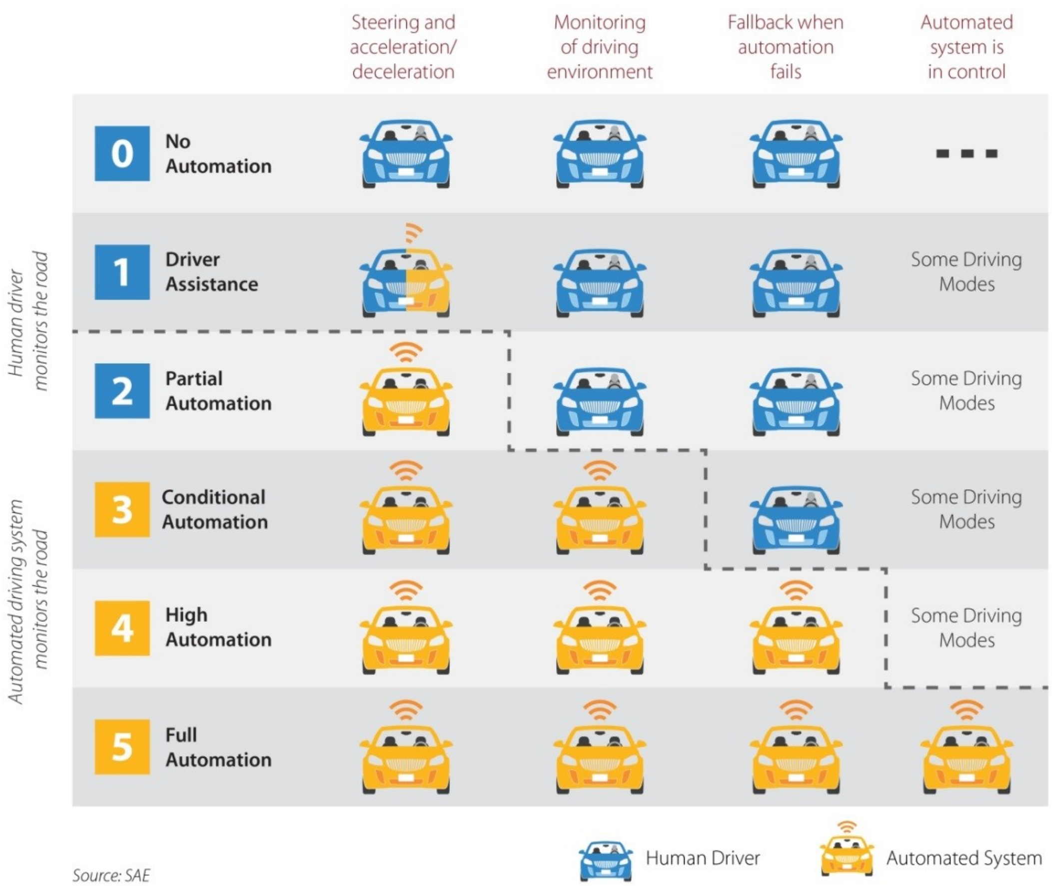
This report summarizes current information and research on the infrastructure and technologies that local agencies should be aware of to prepare for CAVs and to support research, development, and implementation efforts on their systems.

1.2 AUTONOMOUS VERSUS CONNECTED VEHICLES

Autonomous and connected vehicles are distinct technologies. In general, autonomous vehicles (AVs) are able to conduct driving tasks either with or without human intervention (Arseneau 2018). They are also referred to as self-driving vehicles. AV technology removes a portion or all control from a human driver (Atkins Denmark 2017).

AVs rely on sensors and equipment within the vehicle to gather and process information about the roadway environment such as high-performance global positioning system (GPS) or camera data. AVs do not require connected vehicle (CV) technology, since, by definition, they can independently navigate the roadway. However, they can utilize CV technology to gather real-time information such as traffic conditions (Murtha et al. 2015).

The level of automation may vary from minor driver assistance, such as back-up assist, to full automation, which does not require an intervention from a human driver (Atkins Denmark 2017). The five levels of automation, as defined by the Society of Automotive Engineers (SAE) and adopted by the National Highway Traffic Safety Administration (NHSTA) (CAAT 2018) are shown in Figure 1-1.



Society of Automotive Engineers from Iowa DOT 2017a

Figure 1-1. Levels of automation

Driver assist technologies, such as adaptive cruise control or collision avoidance systems, are common AV applications that work in concert with a human driver.

CVs have advanced technologies allowing them to communicate to external systems such as other vehicles or the roadway infrastructure (Arseneau 2018). The concept of CVs does not necessarily imply that the vehicle is making choices for the driver. CVs supply information to the driver to help them make better choices. An example of a CV technology is dynamic route navigation (Atkins Denmark 2017).

V2I and V2V systems allow vehicles to share sensor data allowing them an updated picture of the roadway (Flockett 2017). For instance, a vehicle could transmit a signal when it encounters an issue such as a pothole. This information can subsequently be communicated to other vehicles as well as to the corresponding transportation agency that can then resolve the issue (Hyatt 2018).

Communication technologies such as connected, dedicated short-range communication (DSRC) and automotive long-term evolution (LTE) allows vehicles to communicate with the driver, other vehicles (vehicle to vehicle referred to as V2V), the roadway (vehicle to infrastructure referred to as V2I), or pedestrians (Flockett 2017). DSRC uses the 5.9 GHz spectrum of radio waves to utilize the high speed at which large volumes of data can be transferred.

Although there are distinctions between the CAV technologies, significant overlap exists making it difficult to differentiate infrastructure elements that are specific to one or the other. Additionally, the direction the two technologies will ultimately take is still largely unknown, making it difficult to project whether one will be more dominant or the two will ultimately be intertwined into one system. As a result, this toolbox addresses issues common to both and the term CAV is used for the remainder of this report unless clarification is needed about a specific technology.

1.3 OVERVIEW OF RESOURCE/SCOPE

The main goal of this toolbox is to assist local agencies in preparing for CAVs in the short term—5 to 10 years. Since local agencies are not generally expected to have the resources to become test beds, this report provides information so that local agencies can leverage ongoing activities and resources to prepare for CAVs. For instance, when restriping, an agency could invest additional resources to ensure pavement markings are compatible with CAVs.

Some information is provided in this toolbox about CAV technologies such as smart intersections. However, this toolbox is not intended as a guide for agencies to invest in technologies or services for CAV infrastructure applications. Each application is unique and the available technology and information is frequently changing. As a result, agencies wishing to significantly invest in technology, communication, or power to address CAVs should work with vendors and experts to select the best technologies for their particular situation.

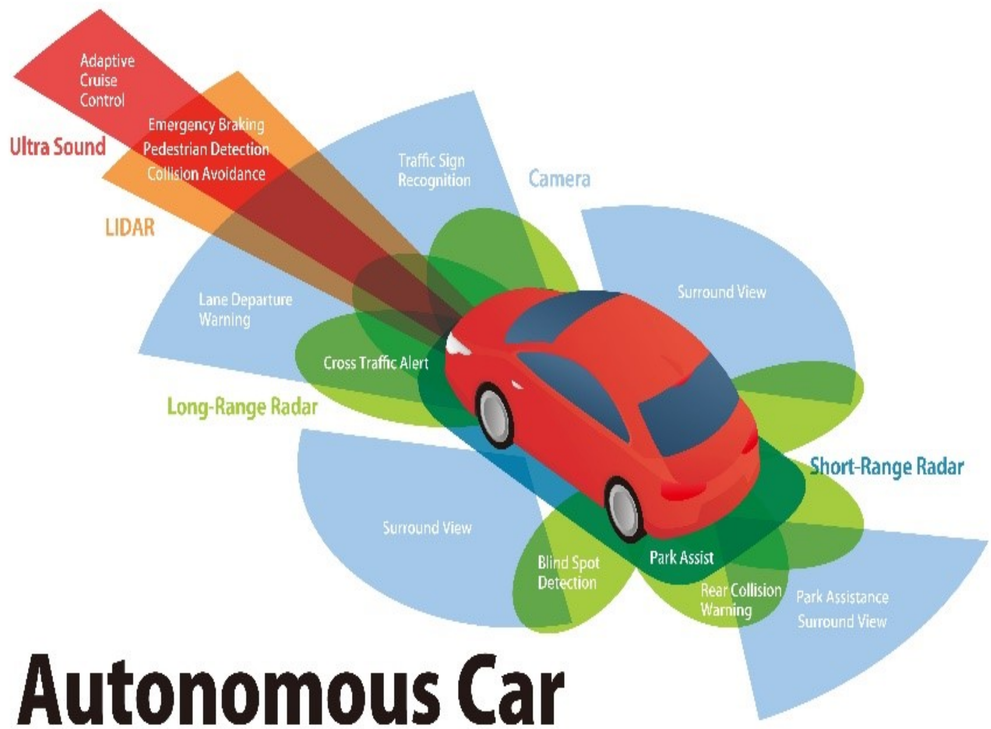
The information gathered in this toolbox was the culmination of an exhaustive web and literature review, listening at several national conferences on CAVs, and discussion with experts. Due to the changing nature of CAV technologies and implementation timelines, the information in this toolbox provides information and recommendations based on knowledge available at a snapshot in time.

CHAPTER 2: IMPLEMENTATION SCENARIO AND TIMELINE

2.1 STATE OF TECHNOLOGY

Due to proprietary concerns, auto manufacturers have chosen not to disclose either the technologies that will guide CAVs nor the algorithms used for wayfinding. As a result, the likely impact and infrastructure needs most commonly cited by experts are summarized.

The first generation CAVs are using a set of sensors to gather information from the surrounding environment. A GPS and time reference is necessary for position tracking (Arseneau et al. 2015). Optical cameras and forward-image processing are used to identify pavement markings to determine position along the roadway (see Figure 2-1), identify roadway signs and signals, and detect moving objects such as pedestrians (McMahon 2018, Metz 2018, Schwab 2017).



Shutterstock
Figure 2-1. Sensor array

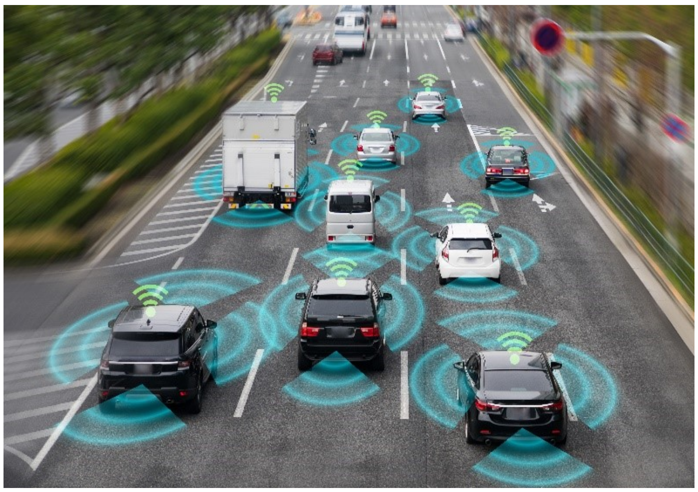
Multiple cameras can also be used to calculate the distance to various objects (Metz 2018).

Other technologies include radar, light detection and ranging (LIDAR), and ultrasonic technology to measure distances to objects or generate an image of surroundings. Laser mapping tools are also used to determine position since GPS is currently not sufficient (Vock 2016, Smith 2017). Inertial navigation systems can monitor and calculate position, speed, and direction using motion and rotation sensors (Arseneau et al. 2015). Cameras and radar are currently the main sensors for current CAVs (Hada 2016).

Some systems are using data from multiple cameras, LIDAR, radar, and ultrasonic sensors along with image processing and deep neural networks to train the processing system to detect and recognize objects such as identifying lane lines or presence of a pedestrian (Wong 2018, Virgo 2017).

Toyota confirmed their cameras and millimeter wave systems will be standard equipment on most Toyota vehicles (Bradley 2018). Cameras detect roadway infrastructure items such as lane lines, signs, and traffic signal state, and LIDAR detects other vehicles and objects. The sensors provide the capability for pedestrian collision mitigation, adaptive cruise control, lane keep assist, and auto high beam.

The next generation of vehicles will require three-dimensional (3D) maps. Some agencies are already investing in high-resolution maps. In addition, groups like Waymo LLC have equipped vehicles with LIDAR and are driving road targeted roadways that are used to create maps (see Figure 2-2).



Shutterstock

Figure 2-2. Fully automated vehicle corridor

After mapping is complete, CAVs can use the maps along with their own LIDAR sensors, which will compare the mapped environment to their readings, thus being able to detect objects such as roadway discontinuities or pedestrians (Metz 2018).

2.2 TIMELINE

Numerous reports have outlined an expected timeline for adoption of different levels of CAVs based on a number of factors such as projections of available technologies, expectations of driver acceptance, fleet turnover, and readiness of the roadway infrastructure. In general, more is unknown than known about the likely implementation scenario and timeline for full automation—with estimates ranging from a few years to 40 years (Johnson 2017, Isaac 2016) For instance, the Iowa Department of Transportation (DOT) conducted analysis of different adoption scenarios and projected that 20% of their fleet will be AVs by 2025, assuming an aggressive adoption scenario, and 2040, assuming a conservative adoption scenario (Iowa DOT 2017a).

An informal poll of 300 automotive, energy, and technology executives conducted at Bloomberg New Energy Finance's Future of Mobility Summit suggests that commercial deployment of Level 4 AVs will start around 2020 and, five years later, Level 5 fully autonomous vehicles will debut (Gerdes 2018).

The first wave of fully automated vehicles is expected to be in corridors where supporting infrastructure technologies, such as high-definition and inventory mapping, have taken place (National Safety Council 2018). Until full fleet penetration is achieved, the use of fully autonomous vehicles may require dedicated lanes or separation from other traffic, or only be allowed to operate on certain roads (Johnson 2017, Litman 2018).

Some sources believe some cities will be ready to adopt fully autonomous vehicles in the next 5 to 10 years, but roadways are expected to be reasonably similar to current roadways for at least the next 20 years since the infrastructure will need to be maintained for human drivers for some time (Knight 2016, Johnson 2017). Waymo LLC's chief executive officer (CEO) cautioned that there will be a long period of overlap between AVs and the 270 million registered personally owned vehicles on the road today (Abuelsamid 2018).

Several experts have suggested that deployment will be gradual with more automated driver assist technologies incorporated into luxury automobiles, closely followed by mainstream brands (Red Chalk Group n.d.). Early building blocks for AVs are already available as advanced driver assistance systems (Red Chalk Group n.d.). Most manufacturers offer Level 1 automation, such as adaptive cruise control (see Figure 2-3), lane keep assist, or blind-spot monitoring, and some offer Level 2 automation (such as Tesla Autopilot and Audi Traffic Jam Assist) (Thompson 2017).

https://www.toyotaofgrapevine.com/blog/2017/september/28/video-learn-about-dynamic-radar-cruise-control.htm

Figure 2-3. Dynamic radar cruise control

Gradual integration of automated technology in the passenger vehicle fleet will occur alongside autonomous shared mobility fleets (robo-taxis) (Red Chalk Group n.d.). Waymo plans to launch its automated ride hailing service in Phoenix in 2018 (Abuelsamid 2018), and fully automated vehicles are currently functioning in controlled settings such as autonomous taxi service in Dubai and London's Heathrow airport (Caughill 2017).

In the short term (2020), dedicated lanes for CAVs will likely be needed to minimize interaction between CAVs and human-driven vehicles in order to take advantage of connected technology. Longer term (2050), regular vehicles are expected to still be on the roadway, but there may be dedicated lanes for human driven vehicles while driverless vehicles are the norm. Ben Pierce of HDR (2018) suggested there would be a rise in other modes such as scooters, electric bikes, and segways that would fill in ”the last mile gap.”

The most commonly agreed on scenario for passenger vehicles in the short term is enhanced driver assist systems. Truck platooning is the most proximate truck technology (see Figure 2-4).

TTI 2016
Figure 2-4. Truck platooning

Under normal driving, trucks ideally follow other vehicles at 500 feet or more to allow the driver time to perceive and react and to account for brake lag and differences in braking power. Platooning links two or more trucks that have platooning capability and can allow following at distances of 30 to 50 feet, since the vehicles themselves are able to communicate reducing perception/reaction time and brake lag between vehicles to almost nothing. Fuel efficiency is the primary driver for trucking companies to adopt platooning (Carpenter 2018).Truck platooning will require enhanced infrastructure such as quality lane lines and enhanced signs. For the purposes of this report, it is assumed that these are the likely scenarios for the next 5 to 10 years.

CHAPTER 3: INFRASTRUCTURE NEEDS

As noted in Section 2.2, the most likely scenarios for CAVs in the next 10 to 5 years that will need to be planned for by local agencies include gradual integration of automated technology and truck platooning. The main infrastructure needs include the following areas:

- Pavement markings
- Signing
- Traffic signals
- Maintenance
- Consistency and standardization
- Data capture and information sharing and inventory
- Communication infrastructure
- High-resolution mapping

Information relevant to the topics above was gathered through a review of the literature, participation in related conferences and workshops, and communications with experts. Each topic summarizes background information about needs for CAVs related to the topic and then makes recommendations about potential approaches agencies could take to prepare for CAVs.

A set of case studies was also developed to demonstrate how several agencies have approached preparations for CAVs (Chapter 4).

3.1 PAVEMENT MARKINGS

3.1.1 Background

Current CAV systems use cameras and image processing to identify lane markings to determine vehicle positon. As a result, pavement markings are particularly important for CAVs (Moylan 2018, Knight 2016, Volk 2016). Several demonstrations of automated vehicles have failed due to inconsistent pavement markings, underscoring the need for consistency (RetroTec n.d., Sage 2016, Flockett 2017). For instance, Volvo's semi-autonomous prototype sporadically refused to drive itself due to inconsistent lane markings when unveiled at a press event at the Los Angeles Auto Show (Sage 2016). Additionally, the Federal Highway Administration (FHWA) has stated that automakers have indicated that pavement markings are the most significant infrastructure characteristic needed for CAVs (PPP 2018).

Longitudinal pavement markings provide two functions for CAVs. First, they indicate the forward road alignment (see Figure 3-1). Second, they are used to locate the vehicle within the cross section of the road. (Hansra 2016)

Hansra 2016 from NCHRP 20-102(06): Road Markings for Machine Vision panel, illustrator unknown

Figure 3-1. Use of cameras and image processing to identify lane lines

Currently, CAVs depend on their ability to decipher a lane or road surface. Discontinuities make it difficult for the sensors to predict where the vehicle is in the lane, causing the vehicle to rely on other features such as the edge of roadway, which is more difficult due to lower contrast and consistency (RSMA 2017). Another particular concern is overlapping markings that occur when markings are repainted but some evidence of the former markings remain (an example is shown in Figure 3-2).

Shutterstock

Figure 3-2. Example of overlapping pavement markings

Although overlapping pavement markings occur most frequently in work zones, they also occur along regular roadways.

Lane markings are equally important for current advanced driver-assistance systems (ADAS), such as lane departure warning (LDW), which typically rely on a forward-looking camera that detects and/or tracks pavement markings and warns the driver at the onset of unintended lane departures. Lane keep assistance (LKA) relies on similar technologies to keep a vehicle positioned within its lane (Carlson and Ullman 2017). Lane markings are also important for regular drivers particularly during nighttime and wet conditions. As a result, improving pavement markings has a wider impact than just CAVs.

California has already begun addressing pavement markings on a wide scale for CAVs. Caltrans Director Malcolm Dougherty indicated that all lane lines going forward will be six inches wide. They plan to transition the state's roughly 50,000 highways and interstates within the next two to three years with the majority of the work being done during regular maintenance and construction work (Ayre 2017).

Currently, pavement marking factors that are the most important to machine visioning are not well quantified. Davies (2016) evaluated retroreflectivity, contrast ratio, and width of pavement markings to assess how these have an impact on machine-vison performance. Retroreflectivity was found to be the most important factor for nighttime performance, but during the daytime, retroreflectivity had little impact on performance. The luminance contrast ratio was the most important factor for daytime machine-vision performance.

The U.S. DOT has been working with the American Association of Motor Vehicle Administrators (AAMVA) to develop a unified national framework for fully autonomous vehicle guidelines (Knight 2016). A joint task force of the Society of Automotive Engineers (SAE) and American Association of State Highway and Transportation Officials (AASHTO) was in the process of developing specifications for pavement markings, which will provide guidance on a base performance level that agencies can use to update and maintain roadways to a level of readiness for CAVs that rely on consistent pavement-marking detection (Carlson and Ullman 2017).

Texas A&M University is conducting NCHRP 20-102, Road Markings for Machine Vision, which is developing information on the performance characteristics of pavement markings that impact the ability of machine visioning systems to recognize them. The study is evaluating a variety of forward-facing machine vision systems to represent as many current and near future technologies possible. Ultimately, project results will be used to assist the AASHTO/SAE Working Group in developing guidelines.

The researchers are studying center lines, no-passing zone markings, lane lines, which includes dotted extensions for ramps, and edge lines. The factors that are being evaluated include pavement marking presence, type of marking (flush, raised, recessed, or temporary), contrast between the pavement and the marking during daytime conditions (including contrast markings, different angles of the sun, and the effects of shadows), retroreflectivity of the marking during nighttime conditions (including the effect of illumination) and different weather conditions (rain, fog, etc.), pavement uniformity (including sealed cracks and patching), vehicle speed, and the impact of other substances on the road such as snow, sand, salt, and water (NCHRP 20-102(06) 2018).

3M conducted a pilot program in conjunction with the Michigan DOT (MDOT) to design new pavement markings, signing, and other connected vehicle infrastructure to facilitate AVs (Schwab 2017). They reported that contrast is key to positioning and have developed a product that is white in the middle with black edging, along with wet reflectivity, to assist with visibility during rain events (Schwab 2017, O'Keefe 2017) (see Figure 3-3).

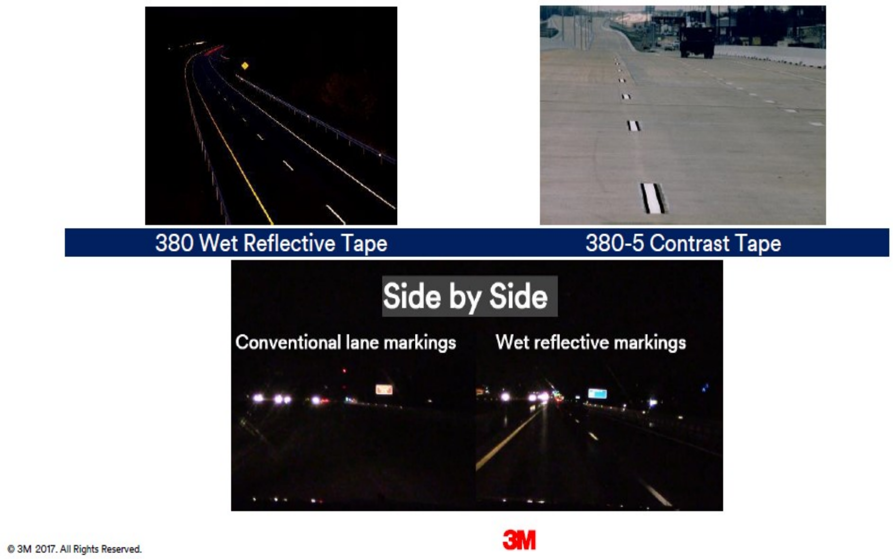


Figure 3-3. Wet-reflective pavement markings

Durability is also important. More advanced pavement markings will include features that will allow AV sensors to detect lines outside the vision-based spectrum and will facilitate lane detection in most extreme weather conditions (Hyatt 2018).

The U.S. DOT announced the Manual on Uniform Traffic Control Devices (MUTCD) would be updated to consider CAVs but did not provide any timeline on when those standards would be available (USDOT 2018). The Markings Committee of the national Committee on Uniform Traffic Control Devices (NCUTCD) is developing "Road Readiness Criteria for Automated Vehicle Technologies," which will provide minimum, desired, and optimal criteria for pavement markings. These criteria are not yet publicly available but are expected to cover lane width, lane line length, gore markings, and retroreflectivity levels.

3.1.2 Recommendations Available to Date

1. One simple recommendation is to place lane lines immediately after resurfacing. Agencies frequently wait to stripe roads after constructing or resurfacing roads. Since CAV depend on lane lines, they may be unable to function when they encounter an unstriped road (McMahon 2018).

2. As noted above, presence of good quality lines is one of the most critical needs for the current generation of CAVs. As a result, a program to update and maintain lane lines may be the most easily addressed CAV need. Ed Bradley with Toyota (2018) reiterated the importance of lane lines. He indicated consistent and uniform lane markings were important. Consistency includes use of consistent markings but also consist maintenance and replacement.

3. Bradley also noted that any improvements that help human drivers will also be beneficial for CAVs. He was asked about unpaved roads but did not have any recommendations since, without markings, current CAV technology will find these roadway types challenging.

4. Although national standards and guidance on pavement markings are not yet available, there are suggestions that the standards will include a minimum criteria of a 6-inch edge, lane, and center lines (Figure 3-4), with a retroreflectivity level of 35 mcd.

Case Study

California is installing 6-inch lane lines. They plan to complete highways and interstates within 2 to 3 years. Updates will be made along with regular maintenance and construction.

Figure 3-4. Case study: 6-inch lanes lines in California

5. Products are already available that show initial promise for CAVs. 3M has two commercially available products geared toward CAVs. Liquid pavement markings with 3M Optics provide markings that are more visible in the rain or other low-visibility conditions. 3M has also developed a high contrast and high retroreflective pavement marking tape (similar to what is shown in Figure 3-5). The tape provides a black edge with white or yellow markings and was optimized for both human and machine detection (3M 2018a).

https://www.sunrisesafetyservices.com/product/permanent-3m-contrast-tape/ © 2019 Sunrise Safety Services. All Rights Reserved

Figure 3-5. High contrast markings

3.2 SIGNING

3.2.1 Background

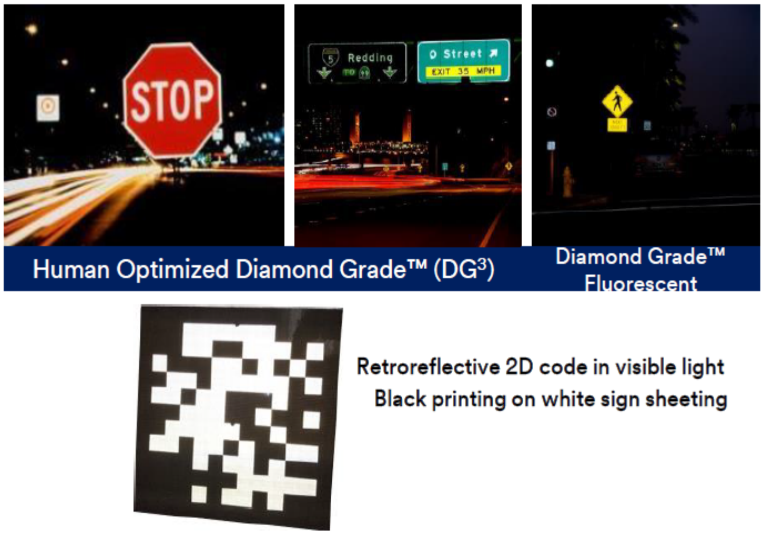
The first generation of CAVs use optical cameras for sign recognition. As a result, the vehicle has to first notice and then read the lettering the way humans do (McMahon 2018). Machine-vision systems capture an image, such as a street sign, and then classify the sign using feature extraction and matching (Snyder et al. 2018). Similar to pavement markings, current CAV systems are confused by damaged, faded, or noncompliant signs (Sage 2016) (see Figure 3-6).

FHWA (left) and Shutterstock (two images on the right)

Figure 3-6. Examples of problematic signage with sign blocked (left) and damaged signs (right)

CAV systems also rely to a greater degree on signing to provide needed information. As a result, CAVs require signing to be consistently placed and maintained at a much higher level than the current practice (Johnson 2017).

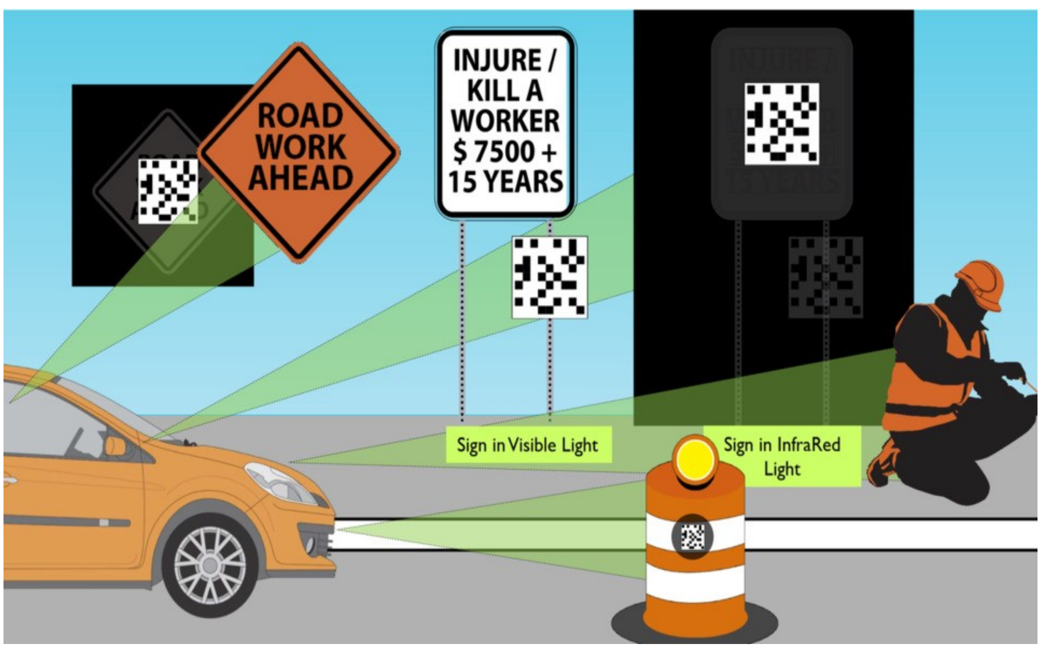
As CAV systems become more sophisticated, it is expected the systems will need enhanced signs that offer redundancies in case one component, such as GPS, fails (Veoni 2017). Additionally, the infrastructure will need to support both human and machine vision for some time, requiring signing that is visible to humans and machines in any road conditions (3M 2017) (see Figure 3-7).



Smith 2017

Figure 3-7. Machine-readable signs

3M is testing a prototype street sign that has the ability to detect an on-coming vehicle and then transmit roadway information such as curve advisory speed (O'Keefe 2017). Additionally, 3M has developed signs with embedded smart codes that can be read by a vehicle sensor (Moylan 2018). The information is encoded using special films and inks, which infrared cameras can read (Schwab 2017, O'Keefe 2017) (see Figure 3-8).



www.forconstructionpros.com/asphalt/article/20867242/how-connected-vehicles-make-work-zones-safer

Figure 3-8. Sign in visible and infrared light, with barcode

Smart codes can refer the vehicle back to a central database with regularly updated information about the road (Hyatt 2018). Other sign technologies may include Bluetooth beacons or radio frequency identification device (RFID) to make signage machine readable.

3.2.2 Recommendations Available to Date

Several recommendations are suggested that can assist local agencies in preparing for CAVs.

1. Current autonomous vehicle software uses “neural networks,” which “learn” to identify objects through studying a library of images (Bliss 2017). As a result, non-standard, blocked, damaged, or faded signing can result in misclassification (see previous Figure 3-6). Consequently, consistent use and placement of signs as well as proper maintenance and replacement can aid CAVs in correctly interpreting signs.

2. Consider use of signs with smart codes when available. The 3M barcode can be incorporated into the sign face and the size changed to address user needs. In general, the code is 65% of the sign and is optically transparent rendering it invisible to a human driver (see previous Figure 3-8). The sign can be read by a vehicle with an infrared (IR) light source at a distance similar to that of a human driver. The car code can include information such as GPS coordinates, sign installation date, maintenance date, and so forth. Current tests have evaluated the codes for up to two months with no loss of visibility for either the driver or machine vision (Snyder et al. 2018).

3. Signing, such as 3M’s diamond grade reflective sheeting may help enable traffic sign recognition for CAVs (3M 2018a) (see previous Figure 3-7). The sheeting can return 50% of the light during nighttime driving and is readable over a range of angles and during inclement weather (Snyder et al. 2018).

4. Ensure signs are appropriately placed. A human driver can infer how to react when presented with inconsistent messages. A CAV is much less able to do so.
    a. **Example 1:** A work zone has a reduced speed limit, but workers neglect to cover up regular speed signs. While a human driver understands the speed limit has not changed, a CAV may infer the speed limit has increased for that stretch of roadway.
    b. **Example 2:** Ideally, chevrons are consistently spaced so that a driver can see at least two signs until the change in alignment eliminates the need for the signs. Consistent spacing provides some sense of curve sharpness for the driver. In some cases, driveways and other obstructions make it difficult to consistently place chevrons. A human driver can more easily identify and interpret curve radius to make necessary speed adjustments. CAVs are less able to accomplish this task on the fly, underscoring the need for consistent sign placement.

3.3 TRAFFIC SIGNALS

3.3.1 Background

At a minimum, CAVs will need to detect and identify traffic signals, along with pavement markings and signing. Ultimately, CVs will integrate with traffic signals and rely on traffic signal controllers that generate Signal Phase and Timing (SPaT) messages, including green, yellow, red, and the amount of time left until the next phase (USDOT n.d.). Krechmer et al. 2016 suggest that as traffic signal controllers are upgraded, new model controllers should include internet protocol (IP)-ready ports and National Transportation Communications for Intelligent System Protocol (NTCIP) compliance for full-scale CV deployment and the ability for integration into advanced traffic management systems (ATMS).

MnDOT has begun efforts to integrate SPaT into snow and ice maintenance operations. (SPaT messages are governed by the SAE's J2735 DSRC message set dictionary.) The approach is being planned as part of a larger connected corridor effort. Under this approach, maintenance vehicles would receive priority at signals, as well as provide warnings to vehicles in their vicinity via dynamic message system (DMS) signs. This will allow maintenance vehicles to keep moving without disruption for faster plowing times, more efficient gang plowing operations, and reduced plowing disruption, resulting in more complete snow removal and more even application of treatment materials. A concept of operations (ConOps) document was developed for the corridor to guide deployment (WSP Consulting 2018).

The connected corridor is planned along the TH-55 corridor between downtown Minneapolis and I-494 to the west. The corridor will be outfitted with CV communications infrastructure, including DSRC, 4G LTE, and, longer-term, cellular V2X. (Cellular V2X is an emerging communications technology that allows data to be transmitted between vehicles and multiple recipients [other vehicles, infrastructure, mobile devices, the cloud, etc.].) DSRC will use a 5.9 GHz broadcast radio infrastructure to communicate SPaT information in real-time at signalized intersections. This will enable the exchange of information between vehicles and with infrastructure, including at traffic signals and ramp meters, to facilitate applications to improve safety and efficiency.

Under this concept, traffic signal controllers equipped with SPaT software will generate a signal status message on signal phasing and timing that will be received by a maintenance vehicle approaching an intersection. Signal status messages would be generated at the controller and transmitted via DSRC roadside units to reach vehicles. The maintenance vehicle would then send a signal request message back to the controller via DSRC requesting signal priority. The controller will process the request and determine if the priority request can be granted. Roadside equipment will then broadcast a response to the maintenance vehicle on whether the request was granted.

Similarly, maintenance vehicles will send out a message via DSRC that will be received at roadside units near DMS signs. This broadcast will trigger a message to be posted indicating that maintenance activities are occurring ahead.

Along with the DSRC field units facilitating communications between vehicles and controllers, backhaul communications are also planned for the connected corridor. This will be facilitated by the fiber-optic loop that consists of a 10 gigabit Ethernet-over-fiber connection and is already in place along TH-55.

3.3.2 Recommendations Available to Date

Future needs will depend heavily on the direction CAV technology goes and the extent to which an agency wants to provide features such as smart intersections. At present, vehicle manufacturers are closely guarding the specifics of the technologies that they are already or plan to incorporate into their models; when combined with changing criteria and needs, it is difficult to make one size fit all recommendations for traffic signal design or upgrades.

The simplest recommendation is to ensure enough space for additional hardware and communications during replacement of traffic signal controllers. A survey of the project technical advisory panel (TAP) indicated that most signal vendors have already anticipated these needs and are the best resource when considering upgrading or implementing signals. Additionally, agencies will need to work with vendors to determine which communications technologies will be required to allow vehicles to send and receive data in conjunction with signal controllers as technologies evolve.

3.4 MAINTENANCE

3.4.1 Background

Maintenance will be an important aspect of accommodating AVs. Maintenance refers to maintenance of any roadway features, such as roadway surface, signing, or markings. Addressing pavement marking and signing were the subjects of previous sections. As a result, this section focuses on pavement and winter weather maintenance.

Significant degradations in roadway surface condition poses a significant concern for CAVs since it is uncertain how imaging systems may interpret these surface conditions. Several examples are provided in Figure 3-9.

Shutterstock
Figure 3-9. Examples of road surface degradation

Poorly maintained road conditions can also make it difficult for a CAV to predict the behavior of other road users. As noted by RSMA (2017), a driver can judge the behavior of a bicyclist who swerves around a pothole, but it is difficult for CAVs to make the same assessment. Additionally, presence of snow and rain obscure pavement markings and signing, making it difficult for camera systems to detect and interpret them (Johnson 2017). As a result, it may be necessary to maintain roads to a higher standard than for human drivers.

3.4.2 Recommendations Available to Date

At this point, it is unknown the extent to which additional maintenance may be needed to accommodate CAVs. As a result, the best recommendation at this time is to maintain or implement timely maintenance, particularly when significant surface degradation, such as potholes, occur.

Aside from that, it is likely that, as the sensors employed by CAVs grow and improve, the capability for vehicles to detect maintenance issues (such as potholes and faded pavement markings) and report them back to an agency via roadside units will follow suit. In this respect, two-way communications between vehicles and agencies will take on added importance, including in the area of roadway maintenance.

3.5 CONSISTENCY AND STANDARDIZATION

3.5.1 Background

In addition to the quality of signing and markings, CAVs are confused by inconsistent markings, signing, and signals. Standard measures do exist, as outlined in the MUTCD. However, there is sufficient latitude that a variety of practices result. For instance, the MUTCD recommends yellow centerline markings for urban arterials and collectors with a traveled way of 20 feet or more and annual average daily traffic (AADT) of 4,000 vehicles per day (vpd) or more (FHWA 2012). However, some agencies regularly place centerlines for all but local neighborhood roadways, while others follow the minimum recommendations resulting in inconsistent application, which makes it difficult for a CAV to anticipate.

Another example of inconsistency is that some traffic signals are vertical while or others are horizontal (Sage 2016). Lane markings, signing, and traffic control practices can vary across state lines, and even across jurisdictions within the same state.

Neural network algorithms learn to interpret roadway features using libraries of common images. CAV algorithms are looking for traffic signals with certain colors in a certain position and place markings and signing in similar positions with similar meanings (Knight 2016). As a result, inconsistent traffic control makes it difficult for CAVs to interpret meanings and significance.

Paul Carlson, a research engineer focused on infrastructure at Texas A&M University, responds to calls asking how to accommodate CAVs. His advice is to aim for consistency: “Make up your mind, people! Do you want your traffic lights vertical or horizontal?” (Sage 2016).

3.5.2 Recommendations Available to Date

- Recommendations to address consistency are obviously to review signing and marking practices to ensure signing and markings are consistent in terms of type of sign used, placement, and application. For instance, are stop bars consistently placed?
- As agencies consider more specialized applications for CAVs, such as use of smart signs, the deployment plan should ensure they are used consistently. For instance, smart-coded stop signs should be applied throughout a corridor.
- Ed Bradley with Toyota (2018) reiterated on consistency. This includes consistent application of markings and signing as well as consist maintenance and replacement.

3.6 DATA CAPTURE AND INFORMATION SHARING AND INVENTORY

3.6.1 Background

Longer term, there is an expectation is that CAVs will collect and share data as road and traffic conditions change. For instance, a lead vehicle encountering congestion can share this information with other vehicles so subsequent vehicles can adjust accordingly. Or, a fallen tree could be detected and shared with the corresponding agency and following vehicles.

Transportation agencies may capture data created by CAVs, which can be used to enhance and optimize transportation networks (Murtha et al. 2015). This requires the ability to collect and share data in real-time. It is currently anticipated that this technology will be cellular, connected-vehicle radios, or Bluetooth beacons placed on the side of the roadway (McMahon 2018).

Farah et al. (2018) indicate a road database inventory will be one of the most fundamental elements and will require highly detailed information such as lane geometry, horizontal and vertical curve characteristics, and speed limits. Some features will require decimeter-level accuracy, such as stop bars and some signs.

Traffic management centers will also need the capability to collect and process data from both the infrastructure and vehicles (PSC and CAR 2017). In addition to the ability to process data, agencies will also need to develop inventories of roadway features.

Needs for real-time information include the following:

- Traffic flow and traffic incidents
- Hazard warnings (Figure 3-10)
- Environmental conditions
- Traffic signs
- Road closures
- Major traffic events

Shutterstock

Figure 3-10. Warning system

Examples of V2I applications that require inventorying and data sharing include the following (Patil

- Curve speed warning
- Red light violation warning
- Stop sign gap assist
- Spot weather information warning
- Smart roadside
- Transit pedestrian warning
- Reduce speed/work zone warning
- Pedestrian in crosswalk

Toyota confirmed that early V2I or V2V applications include the following (Bradley 2018):

- Intersection turn assist, which informs drivers of approaching vehicles that may be hidden from view
- Red light caution application, which warns the driver to brake if their vehicle is not decelerating enough to come to a stop
- Signal timing application, which informs the driver of the signal timing change from red to green
- Cooperative adaptive cruise control, which adapts the cruise control when the lead vehicle also has V2V connectivity
- Emergency vehicle notification application, which informs the driver of the location and direction of a nearby emergency vehicle

3.6.2 Recommendations Available to Date

1) **Address inventory needs for truck platooning**: In the short term, truck platooning and CAV commercial vehicles will require inventories of roadway features. As a result, these items may be the early focus for agencies wishing to begin data inventories. In the early stages, truck platooning will likely only occur on uninterrupted flow facilities. Truck platoon planning will require the following inventory items at a minimum (O'Rourke 2017).
    - Bridge heights
    - Speed limits
    - Load restrictions particularly for bridges since spacing of platoons differs from current bridge assessment practices (Caprani 2018)
    - Truck routes
    - Operational constraints

2) **Take stock of existing inventories**: As a first step, agencies can take stock of which inventories they already have available. This includes a list of inventoried items as well as data dictionaries that include items such as accuracy and reliability, how and when data were collected or updated, and spatial information (i.e., projection system used, description of linear referencing process).

    Reporting accuracy of an inventory item is important since CAV systems are better able to deal with inaccuracies if the inaccuracies are known. For instance, if a sign location was collected to within ± 25 feet, vehicle algorithms can account for the expected range. Systems are less able to account for inconsistent accuracy. For instance, some signs were collected within 1 foot and others were collected within 50 feet. A TAP member described a conversation with a Toyota representative who indicated one of the most important elements of a roadway inventory is an estimate of the accuracy and reliability of the data.

3) **Prioritize inventory collection**: Expected V2I applications were listed in the previous Background subsection. Agencies can decide which are likely to have the most benefit and prioritize accordingly. New York City selected red light violation warning, speed compliance, curve speed compliance, and oversized vehicle compliance as their smart city CAV applications. The Tampa, Florida CV pilot program infrastructure applications included pedestrian safety and wrong-way entry prevention.

   From there, data needs depend on the individual application. For example, a curve-speed warning system would require an inventory of horizontal curve locations and characteristics such as radius, super elevation, and shoulder type and width. In this example, it would also be advantageous to examine how curve advisory speeds are set within the jurisdiction and ensure they are set consistently.

   Common items suggested for roadway inventories include the following (Farah et al. 2018, Bauer and Mayr 2003, Shields 2016s):

   - Traffic signals
   - Crosswalks
   - Roadway curvature (horizontal and vertical)
   - Pavement surface quality
   - Speed limits
   - Elements, such as signs or signals, which have limited sight distance making it difficult for CAVs to identify

   The NYC Smart City coalition guided data collection using the following questions (Rausch 2018):

   - What can be collected (i.e., what raw data are available)?
   - What will the data be used for?
   - What should be collected given the cost?

3.7 COMMUNICATIONS INFRASTRUCTURE

3.7.1 Background

At the simplest end, infrastructure can provide information necessary for CAVs, such as digital maps, weather and roadway conditions, traffic conditions, signal information, etc. However, the full power of CAVs can only be realized if the system is also able to collect, process, and share data from CAVs. For instance, a subsequent vehicle can avoid a fallen tree if a previous vehicle is able to share that information (McMahon 2018). How a vehicle obtains information from its surroundings is crucial to its success on the street (Eldredge 2016).

CAV systems will require electricity and communications to allow connectivity between the vehicle and infrastructure. This requires wireless connectivity networks within urban areas (Murtha et al. 2015). Ben Pierce, transportation technology lead for HDR, recommends ensuring conduit for power and fiber optic cables are available for new and reconstructed infrastructure (McMahon 2018). Additionally, backhaul communications will be needed to transmit CV data to a transportation operations center (Krechmer et al. 2016).

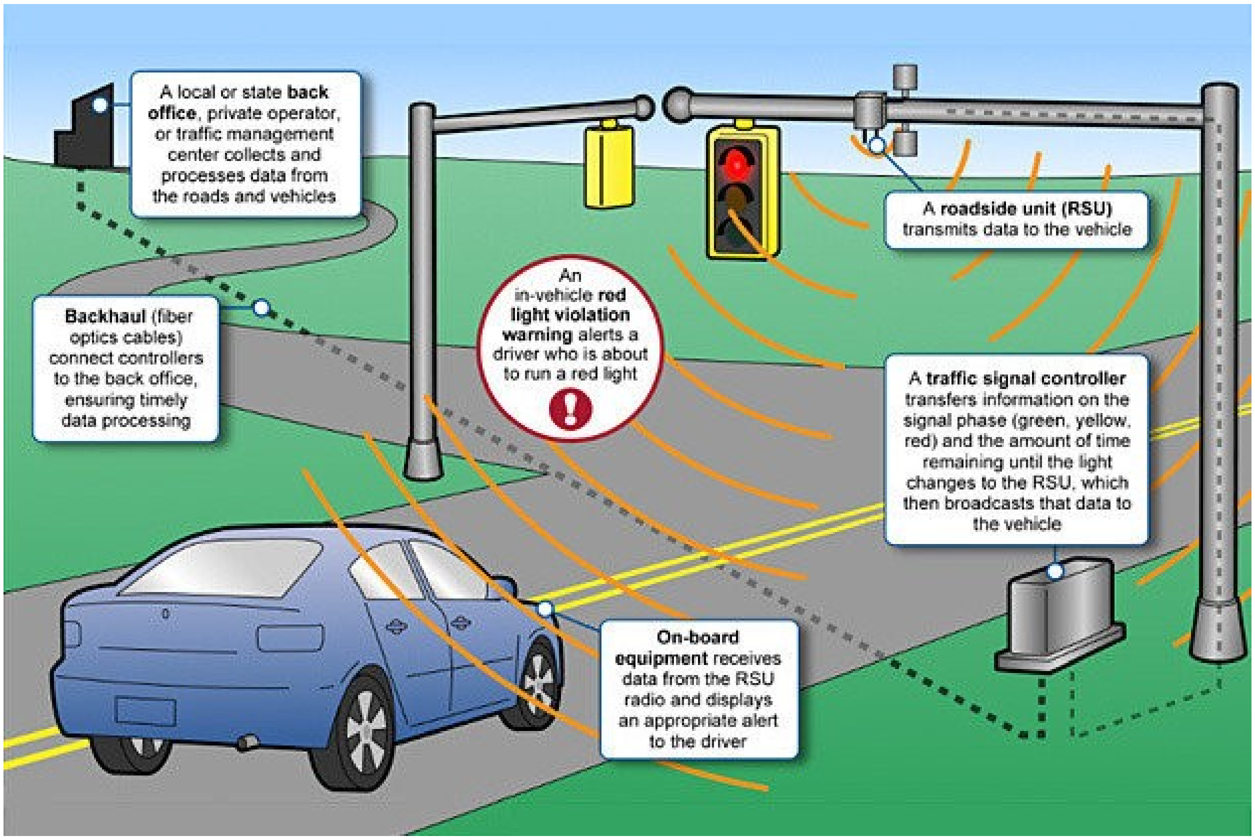
Roadside equipment (RSE) is agency-owned communications and processing infrastructure that allows an agency to collect and share data with CAVs. RSE houses V2I communications, such as DSRC and processing capabilities

DSRC is a two-way, short- to medium-range wireless communication system that allows transmission of very large amounts of data. More simply, it is a secure and reliable wireless communications technology that allows CVs and infrastructure to talk to each other. The system communicates using vehicle onboard units and roadside units (DriveOhio n.d.).

A communications system typically consists of the following (Brugeman 2017):

- Roadside units
- Traffic signal controllers
- Traffic management center
- On-board communications
- Communication links
- Support functions

An example of a communication setup is shown in Figure 3-11.



U.S. Government Accountability Office (GAO) from Cooney 2016

Figure 3-11. Example of communication setup

Roadside units (RSUs) — RSUs provide wireless communication between roadside infrastructure and on-board units. They are placed along the roadside and send and receive data from on-board vehicle units (OBUs), such as speed, location, and time. RSUs can be attached to an existing utility pole or camera poles, dynamic message signs, toll gantries, or other existing infrastructure and share a power source (NCTCOG 2017). The main function of the RSU is to facilitate communication between vehicles and infrastructure by transferring data over DSRC in accordance with industry standards. The RSU can also be integrated with a backhaul system to enable distant management (FLUIDMESH n.d.).

On-board vehicle units (OBUs) — OBUs receive warnings and other communication from the RSUs and can send position and other information to RSUs for V2I connectivity (NCTCOG 2017).

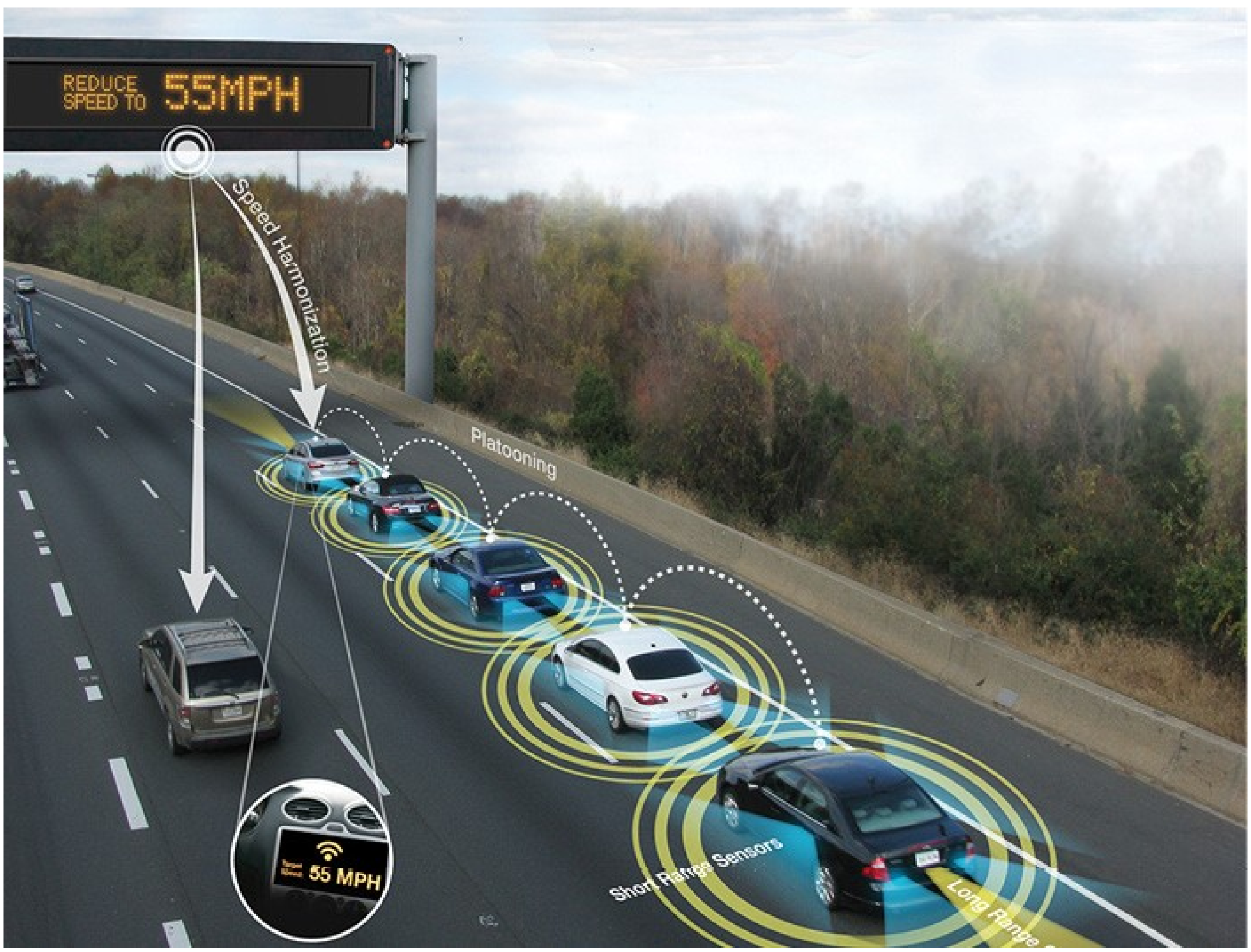
Backhaul communication, such as fiber optic cable, is used to collect information and transmit it between the RSU and a central server (NCTCOG 2017).

Although there are no good estimates on the amount of data, CAV sensors collect many megabytes of data every minute (Knight 2016). The NYC Smart City coalition indicated the 1.2 million vehicles in New York City (NYC) would broadcast 83 terabytes (TBs) of data per day, and the 13,000 SPaT- and map-enabled intersections broadcast 3 TBs of data per day. Increase in communications may mean beefing up cell networks and devices for DSRC so that cameras and sensors along a roadway can communicate consistently with vehicles (Rausch 2018). Experts agree additional bandwidth will be needed, but no common recommendations are available since it depends on a number of factors such as the amount and type of information being collected or shared and number of vehicles sharing information.

Secure communications between highway agencies and RSUs is typically fiber optic (PSC and CAR 2017). Florida has a statewide fiber optic network to connect management centers and infrastructure (i.e., intersections). Whenever possible, they are replacing copper communication cables with fiber optic given that fiber has high-bandwidth security, is resistant to electromagnetic interference and surge, is small and light weight, and is lower cost (Murtha et al. 2015).

Virginia is also using fiber optic because it is reliable and secure. The Virginia Telecommunications Act of 1996 requires telecommunications providers to allow competing vendors to have access to facilities to enable deployment of broadband. It also mandates removal of state and local barriers to telecommunications competition (Gustafson 2018).

Several agencies have made investments to prepare for CAV communication needs (see Figure 3-12 and Figure 3-13).



U.S. DOT

Figure 3-12. Communication array

Case Study – Traffic Signal Communications

Duluth, Minnesota is building a local TMC that includes fiber optic interconnect. Communication will be supplemented with cellular modem at suburban/rural signals.

Estimated radio communication equipment is less than $1,000.

Expected future CAV applications: intersection collision warning systems and intersection warning.

Lund 2018

Figure 3-13. Case study: Traffic signal communications in Duluth, Minnesota

Ohio has placed fiber optic cable along a 35-mile stretch (Columbus West to East Liberty) to provide Wi-Fi for sensors along the highway to communicate with CAVs. Ohio selected 6-inch conduit that can support seven different fiber cables. Additionally, they are placing communication towers using DSRC. Short-range radio transmitters will also be installed every 2,000 feet (600 meters) along the route (Sabin 2017, DriveOhio 2018).

The Pennsylvania Turnpike is installing fiber optic cable along 550 miles of the turnpike to handle tolling data and current intelligent transportation system (ITS) applications. They are including future data needs for CAVs. The installation is using a public-private partnership (PPP or P3), which takes advantage of private-sector expertise in installing, operating, marketing, and maintaining the fiber optic (DuPuis 2016).

The North Central Texas Region is developing a plan to expand their communication network to allow better communication within and between agencies as well as facilitate infrastructure operations, advanced traveler information, and traffic management. The plan will also allow fire and police to leverage the network to improve incident response and management. The region has implemented more than 423 miles of fiber optic cable and 226 miles of wireless communication infrastructure and plans to add an additional 124 miles of fiber optic cable (NCTCOG 2017).

Palm Beach, California considered installing the backbone of a fiber optic network along the main roads in town during a large-scale utility project already burying overhead power, phone, and cable television lines. The ultimate cost for the fiber optic was $3.8 million with a cost of $600,000 for the first phase. The fiber optic system could be used to remotely monitor traffic, control traffic signals, and allow for more rapid police and fire-rescue communications. Additionally, the system could accommodate future needs for CAVs. The measure was ultimately defeated due to the cost and uncertainty about benefits (Kelly 2017a and 2017b). This illustrates how agencies need to consider the uncertainty and risk against the potential benefits when making investments.

3.7.2 Recommendations Available to Date

1. Agencies should communicate with vendors when considering communication infrastructure needs. Specific needs will vary, and the evolution of technology will require a targeted analysis. For instance, the U.S. DOT has requirements for roadside units (Perry et al. 2017) that can be addressed by vendors for each specific situation.

2. The Florida Smart City Coalition reported they had found technology for many of their CAV obtaining a better understanding of potential vendors' depth and resources. They also suggested doing fixed fee contracts when investing in signal and other technology, so the vendor has to provide the specified service (Frey 2018).

3. Improvements in broadband speed will be necessary for V2I applications. The needs are specific to expected applications and can vary as new systems and technologies come into play. The FHWA (2013) suggests considering leaving space for future needs to minimize excavation. FHWA's "Dig Once" initiative suggests coordination of highway construction with installation of broadband. Although not specifically geared to CAV infrastructure, planning future needs for CAVs allows them to be incorporated into current activities, ideally resulting in reduced costs and disruptions due to repeated excavation. Once capacity is in place, any new company can route fiber through the existing infrastructure, which can significantly cut the cost of broadband deployment (PSC and CAR 2017, FHWA 2013).

   This was reiterated by an I-80 future-proofing study for the Iowa DOT, which suggested laying fiber optic and continuous power lines along I-80 to provide a base layer for future RSE, thus minimizing future disruptions (Iowa DOT 2017a). The study also suggested the system consider needs for future advanced cellular capability, cameras, and sensors.

4. The Iowa DOT future-proofing study (Iowa DOT 2017a) suggests that, although RSE was originally a physical infrastructure, advances in computing power, cloud storage, and evolving cellular communication speed could evolve into a virtual rather than physical infrastructure. The study recommendation was to allow flexibility in planning for RSE that allows for either virtual or physical RSE.

5. Consider future communication needs as part of roadway plans. Virginia, for instance, is currently including build-out and expansion of the traffic system communications network in plans for roadway improvements or new construction (Gustafson 2018).

6. Several agencies are replacing copper communication cables with fiber optic because fiber has high-bandwidth security and is resistant to electromagnetic interference and surge. It is also smaller and lighter weight and lower cost.

7. Several agencies are installing 6-inch conduit to support current and future needs.

8. Ed Bradley (2018) of Toyota recently stressed that he sees DSRC as the right direction rather than cellular (5G communication). Toyota plans to start deployment for DSRC V2V and V2I connectivity in production vehicles in 2021 with the technology available in most of their lineup by the mid-2020s. However, other groups feel 5G is the future direction in communications.

3.8 HIGH-RESOLUTION MAPPING AND OTHER INFRASTRUCTURE ENHANCEMENTS

3.8.1 Background

Many CAV technologies require higher resolution information about the roadway cross section and characteristics than a human driver. For instance, the CAV systems need the exact location of a stop bar or exact width of the roadway (to within centimeters, which are fractions of an inch). Ultimately, this will require high-definition mapping as well as the ability to store the data needed for high-resolution maps so that vehicles can access them (Knight 2016)

One aspect of high-definition mapping is to tell the vehicle where it is in 3D space and what is around it. For instance, a concrete median barrier might be located 3.45 feet from the vehicle. Another aspect is telling the vehicle what is around it, so that the vehicle's system can differentiate between objects that should be in a particular location (such as a stop sign) and other objects (i.e., a pedestrian or an object in the roadway).

Initial components are in place to assist Minnesota agencies in high-definition mapping efforts. MnDOT, in conjunction with other state agencies and institutions (including cities and counties), operates the Minnesota Continuously Operating Reference Station Network (MnCORS) network. The network consists of receivers at more than 130 known positions that take global navigation satellite system (GNSS) signals to provide survey-grade positioning corrections. In this capacity, the system allows for precise GPS positioning.

Position and mapping for CV/AV applications are important components, and it is reasonable to expect that MnCORS will be a critical piece in ensuring map accuracy. For example, roadway geometry and attribute data will need to be broadcast to vehicles and this information must be highly accurate. MnCORS will play a role in establishing and maintaining the accuracy of that feature location information.

Vehicle position information will also be a component of AV/CV deployments and MnCORS will play a role here as well. Based on the *Minnesota Department of Transportation Connected Corridor System Concept of Operations* document (WSP Consulting 2018), position correction data will be received from MnCORS and translated into a Radio Technical Commission for Maritime Services (RTCM) correction message for vehicles. This corrected message would be transmitted to vehicles and used by the connected corridor system to enable functions such as SPaT applications, snowplow priority systems, etc.

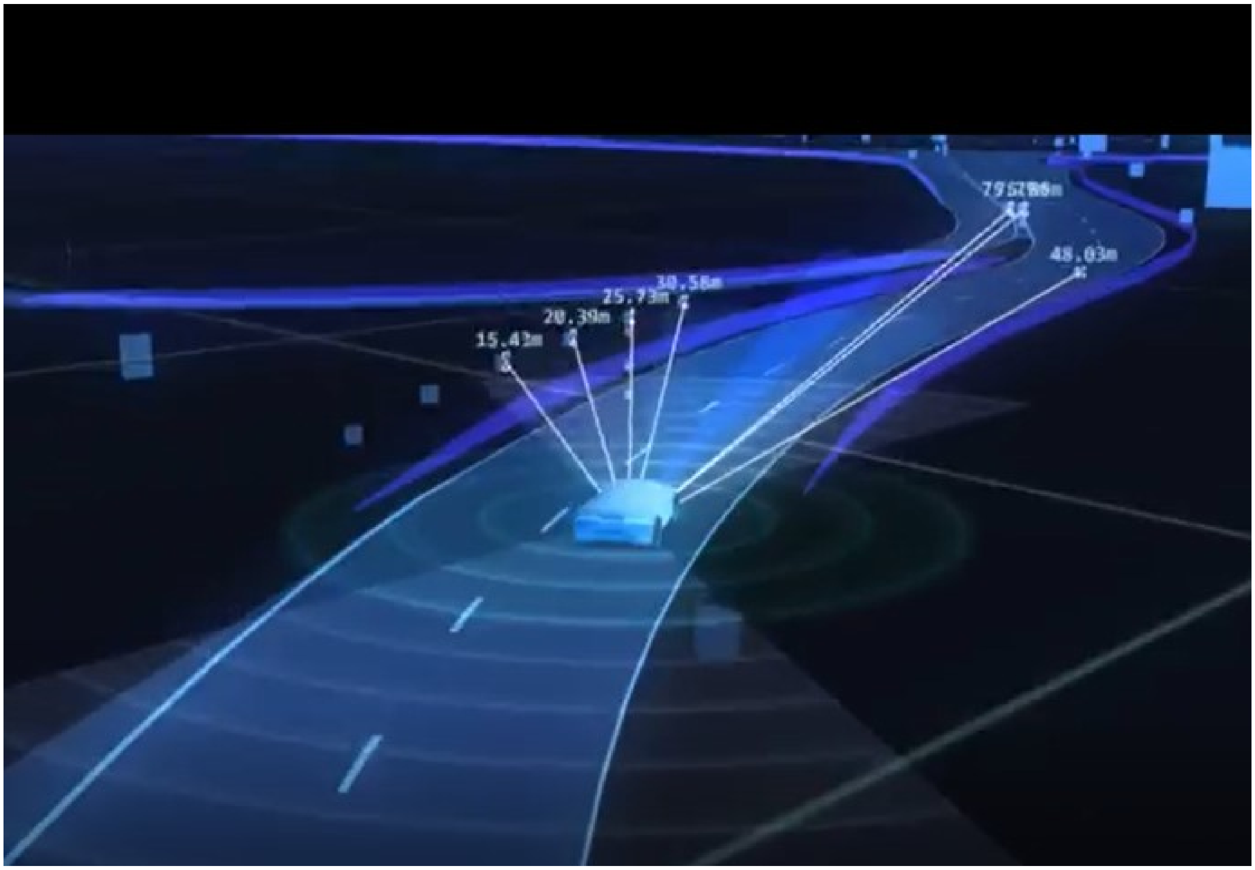
3.8.2 Recommendations Available to Date

The cost of collecting high-definition maps is challenging. As a result, unless an agency plans to develop dedicated CAV corridors, high-resolution mapping is likely something agencies will wait to undertake until they have a better sense of where the technology is going and what is needed. When an agency decides to invest in high-definition mapping, some guidance may be needed to address liability issues. For instance, if an agency provides a high-definition map and something changes, what are their responsibilities to update it? Additionally, as Vardhan (2017) suggests, privacy issues should be addressed. For instance, high-resolution mapping could include private residences.

The Iowa DOT commissioned a study to assist them with future-proofing I-80 and suggestions included providing GPS reference markers within the median of I-80 as a supplement to the Iowa Real-Time Network (IaRTN) and standard GPS (Iowa DOT 2017a). Current phone-level GPS can estimate position to within 10 to 20 feet, and GPS accuracy can be improved by triangulating from one additional known location. With reference markers, CAVs can calculate their distance from a reference marker with existing steering and navigation.

Longer term, high-resolution LIDAR and cameras on CAVs themselves may play a crucial role in providing much of the high-definition map information needed. Additionally, vendors, such as Waze, may have reliable sources of data.

Other suggestions are use of visual reference markers for optically based CAVs, radar/LIDAR-friendly reference markers, or position correction broadcasts that provide GPS correction factors (Arsenau 2018) (see Figure 3-14).



Arsenau 2018

Figure 3-14. Infrastructure reference solutions

CHAPTER 4: CASE STUDIES

Several case studies were conducted and are covered in this chapter to summarize activities other agencies were engaged in to prepare for CAVs:

Case Study 1: Partnership between 3M and Michigan to test CAV technologies along a freeway work zone

Case Study 2: Planning coalition developed by Los Angeles

Case Study 3: Example of interagency collaboration (Drive Ohio)

Case Studies 4 and 5: Examples of traffic management center activities (Iowa and Virginia)

Case Study 6: Rural application that involves installation of fiber optic (Wyoming)

Case Study 7: Application of smart intersections

4.1 CASE STUDY: 3M/MICHIGAN PARTNERSHIP ON I-75

4.1.1 Overview

In 2017, the Michigan DOT (MDOT) partnered with 3M to conduct a 100-day test of 3M Connected Roads prototype solutions for vehicle-to-infrastructure and self-driving vehicle technologies. The study was conducted on a 3.3-mile construction work zone along I-75 (Figure 4-1). The project showcased the nation's first connected vehicle technology in a freeway work zone.

American Center for Mobility, www.dbusiness.com

Figure 4-1. I-75 in Michigan

4.1.2 Approach

The I-75 modernization project positioned Michigan to be among the first states to test connected vehicles. Technologies conducted with 3M included the following:

- 3M Stamark all-weather tape to improve lane detection for both humans and automated vehicles
- Retroreflective signs with smart sign technology (see Figure 4-2)
  - 10 signs were embedded with 2D barcodes, which were detectable only by vehicles
  - 5 signs were fitted with regular 2D barcodes, which could be viewed by humans and vehicles
- DSRC devices

Figure 4-2. Embedded 2D signs

3M designed the barcode signs to meet current signing specifications and avoided significantly altering the physical appearance of the sign (Snyder et al. 2018). The updated materials used in the signs provided better markings for human drivers as well as greater machine vision. Figure 4-3 summarizes the key findings about the signs.

Key Findings

- Signs weathered well
- Signs were visible up to 328 feet at highway speeds
- Partnership allowed 3M to gain better understanding of data needs and uses of technologies

Figure 4-3. 3M/Michigan partnership on I-75 key findings about the signs

4.1.3 What They Found

A camera and sensor system were used to evaluate the signs from a moving vehicle. The test vehicle collected data at 18 to 55 mph (30 to 90 kph) from either the right or center lane of traffic. In general, the researchers found that the embedded 2D barcodes could be captured on moving vehicles traveling at posted speed limits up to 328 feet (100 meters) away (Snyder et al. 2018, 3M 2018b).

Accelerated weather testing was conducted on the 2D barcode signs. They found that after 1,500 hours of accelerated weathering, no decrease in retroreflective light was noted (Snyder et al. 2018).

The partnership between 3M and MDOT included demonstrations and collaboration between the two organizations as well as with automotive original equipment manufacturers (OEMs) and sensor suppliers. The organizations were able to gain a clearer understanding of the data needs and uses for the technologies tested (3M 2018b).

4.1.4 When

The project was initiated in 2017. The first stage of the I-75 construction project was in the final stages as of November 2018.

4.1.5 Resources

3M. 2018b. *"Motor City" Detroit Merging Automotive & Infrastructure Innovation with 3M Connected Roads I-75 Test Corridor Case Study*. multimedia.3m.com/mws/media/1572737O/michigan-test-corridor-case-study.pdf.

Shenouda, Stephanie. 2017. 3M, MDOT Partner on I-75 Connected Work Zone. *DBusiness Magazine*. www.dbusiness.com/daily-news/Annual-2017/3M-MDOT-Partner-on-I-75-Connected-Work-Zone.

Snyder, James, Doug Dunn, James Howard, Travis Potts, and Kris Hansen. 2018. *“Invisible” 2D Bar Code to Enable Machine Readability of Road Signs – Material and Software Solutions*. 3M Transportation Safety Division, St. Paul, MN. https://multimedia.3m.com/mws/media/1584051O/2d-barcode-whitepaper.pdf.

Telematics Talk staff. 2017. Magna to Help Michigan DOT, 3M Develop Vehicle-to-Infrastructure Connected Work Zone. *TelematicsTalk*. www.telematicstalk.com/magna-help-michigan-dot-3m-develop-vehicle-infrastructure-connected-work-zone.

4.2 CASE STUDY: LOS ANGELES PLANNING FOR CAV

4.2.1 Background

The Strategic Action Plan was developed by the Coalition for Transportation Technology. This is a consortium of agencies in the Los Angeles County region that are working together to prepare for and take advantage of opportunities that arise from new transportation technologies. The consortium consists of the Los Angeles DOT (LADOT), Caltrans, the Los Angeles County Metropolitan Transportation Authority (Metro), the Southern California Association of Governments (SCAG), and the County of Los Angeles Public Works Department.

CAV activities in Los Angeles are primarily planning-related at this point in time (see Figure 4.4).

Figure 4-4. Summary of early activities

Activities include identifying and pursuing funding opportunities as they arise for pilot projects and equipment procurement. Pilot projects are expected to vary in terms of technology and modal focus. For example, local ports have expressed interest in automated goods movement technology. Transit authorities are interested in combining advanced transit signal priority and CV technologies to improve travel time for busses.

Planning also includes cataloging the available data streams/sources in the region that have a direct impact on transportation. This includes documenting what the data stream is, where it is coming from (field location), who collects and owns the data, and how it is currently used. This cataloging also serves as a gap analysis as data needs can also be identified and addressed going forward.

Los Angeles plans to invest in their infrastructure to be prepared for AVs. In the near term, the plan is to invest in data infrastructure, such as the installation of advanced transportation controller (ATC) cabinets that are CV-ready. Regional ITS architecture updates will also be undertaken to incorporate AV and CV components as they emerge.

Finally, there is recognition that lane markings are likely to be a critical component of AV operations, and the city intends to invest in markings to enhance the effectiveness of lane departure systems in the near term. For the long term, the regional coalition will be working with vehicle manufacturers to understand which technologies may need to be embedded in the pavement during pavement resurfacing (and new construction).

4.2.2 What Problem is Being Addressed

The primary problems that the region intends to address long term through CAV technologies are increased mobility, reduced emissions, and improved safety. Increased mobility will allow for continued travel despite population growth and limits to infrastructure capacity. Reduced emissions will be the result of improved traffic flow and reduced congestion. Finally, improved safety will be the result of vehicles communicating with one another and infrastructure to avoid crashes with one another.

4.2.3 Approach

The problem of preparing for AV/CV overall is being approached by breaking activities into short-, mid-, and long-term timelines. Short-term activities include those that can be pursued in 2017–2018. This timeframe includes activities such as funding applications, planning activities, research, and an update of the regional ITS architecture. It also includes investing in basic materials, such as pavement markings, that will be utilized by existing and future vehicles. As well as infrastructure, it also includes investing in advanced traffic controllers, for example, that will have CV compatibility. Mid-term activities are those with a 3 to 5 year horizon (2019–2021). These activities include systems integration and pilot projects. Finally, long-term activities are those that will be addressed over a 6 to 10 year timeframe (2022–2027). Long-term efforts include technology testing and evaluations, continued funding applications, and wider deployments.

There has also been discussion of creating a dedicated staff position to be housed at one of the coalition member’s offices that would be focused on AV and CV technology. Staff would track developments and allow the coalition to be aware of new standards as they are introduced, identify opportunities to integrate infrastructure technologies into future construction or maintenance projects, and support regional interoperability of systems. Such a staff position would also coordinate and pursue funding and partnership opportunities as they present themselves.

4.2.4 Where

The technologies will be implemented along the roadways of the Los Angeles (LA) region. Initially, infrastructure installations and upgrades would likely happen along higher traffic volume roadways in the region (interstates, freeways, and arterials). Of course, other investments, such as improved pavement markings, would be installed along more than these roadways as the opportunities arise.

From an agency's fleet perspective, there is a recognition that CV technologies should be implemented into future vehicle fleets by respective agencies during procurement. For example, future transit vehicles would implement blind spot detection systems.

4.2.5 When

In one respect, solutions are currently being implemented. This is primarily true of lane markings, which are being incorporated as the city resurfaces roadways. Los Angeles has plans to resurface approximately 2,200 lane miles of roadway each year. The same is true for deployment of ATC cabinets that are CV-ready.

However, in most respects, CAV technology deployments are anticipated to occur over the next 10 years as opportunities present themselves. If the timelines outlined in the Strategic Action Plan are followed, some technology deployments will occur in the 2019 through 2021 timeframe. However, that appears to be contingent on funding opportunities that would then spur pilot projects.

4.2.6 Implementation

Basic CAV-enabling technologies and infrastructure are being implemented currently. This includes ATC cabinets that are CV ready, as well as the installation of improved pavement markings to assist with AV technologies. Local jurisdictions elsewhere can pursue similar installations in preparation for AV and CV in their areas.

More advanced implementation is still in the planning stages and is anticipated to occur over the coming decade. Over that time, prospective pilot tests are expected to occur, and the review of which infrastructure and data sources are available will be ongoing. Planning efforts will aid the region in understanding what still may need to be acquired and installed. Once again, local agencies elsewhere can pursue a similar approach, focusing on planning efforts to make an orderly transition as more AV and CV technologies and deployment opportunities emerge.

4.2.7 Benefits

The primary benefits expected from CAV as systems are deployed in the Los Angeles region include increased mobility for residents, reduced vehicle emissions, and improved safety for all users (including pedestrians). Increased mobility ranges from preventing roadway gridlock as the population expands, as well as allowing residents, such as the young and the elderly, with new options for travel. Reduced emissions are tied to improved traffic flow (platooning), signal progression, etc. Finally, improved safety will produce the benefits of reduced numbers of injuries and deaths, as well as financial savings from reduced property damage and medical care.

4.2.8 Lessons Learned

No lessons learned have yet been identified from this deployment. However, partnership and cooperation between agencies/entities across a region from the beginning emerged as a best practice. The approach that the Los Angeles area appears to be following is to take small steps in advance to begin preparing for AV/CV, and this is being done in a coordinated manner through the efforts of the Coalition for Transportation Technology.

4.2.9 Resources

ITE SoCal. 2017. LA Regions Coalition for Transportation Technology. https://www.socalite.org/single-post/2017/05/05/LA-Regions-Coalition-for-Transportation-Technology.

Kimley Horn. 2016. *Coalition for Transportation Technology Strategic Action Plan*. drive.google.com/file/d/0B5EV0bct6PTgUTlSQUJnTU1GSGs/view.

Urban MOBILITY in a Digital Age: A Transportation Technology Strategy for Los Angeles. http://www.urbanmobilityla.com/.

4.3 CASE STUDY: INTERAGENCY COLLABORATION, OHIO

4.3.1 Background

Making investments in CAV infrastructure can become problematic when agencies that need to coordinate projects have different priorities or objectives, or are protective of their own turf. Ohio made a decision early on to take a collaborative approach to investing in smart mobility and was able to gather a number of agencies under one umbrella to coordinate smart mobility goals and activities. This allowed the state to become a leader in encouraging testing and deployment of CAV technology.

Many public and private organizations across Ohio are engaged in the research, development, and testing of CAV technologies. DriveOhio (Figure 4-5) connects all of these entities together under one umbrella, creating a more comprehensive and collaborative environment that makes it easier to drive advancements in smart mobility.

DriveOhio

The Future of Smart Mobility

Drive.ohio.gov

Figure 4-5. DriveOhio logo

DriveOhio includes the following agencies: Transportation Research Center, U.S. DOT, City of Columbus and The Columbus Partnership, The Ohio State University Center for Automotive Research (CAR), American Electric Power, Jobs Ohio, The Ohio Turnpike and Infrastructure Commission, the Ohio DOT (ODOT), The Council of Governments (City of Dublin, City of Marysville, Union County, and the Marysville-Union County Port Authority), and the Ohio Environmental Protection Agency (EPA). A few examples of what some of these agencies are working on and how they are approaching it follow.

4.3.2 Description of the Technology

An example of technology that one of the agencies (the Ohio Turnpike and Infrastructure Commission) is working on is DSRC, two-way, short- to medium-range wireless communications that allow large numbers of vehicles to communicate with one another and with sensors on the roadway.

In order to deploy DSRC and other technologies, a fiber network was necessary for the smart mobility initiative to become a reality. Smart mobility will improve safety and traffic flow along the US-33 corridor and in Dublin and Marysville. The US-33 corridor has the potential of becoming the first test bed for CAVs in Ohio. The smart mobility projects cover 164 miles of roadway.

4.3.3 Approach

The commission will install DSRC technology along a 61-mile stretch of the turnpike from milepost 126.4 in Erie County to milepost 187.5 in Portage County. The turnpike also will outfit 40 turnpike vehicles, most of which will be snowplows, with onboard units to collect usage data on the fleet's activity. The data should help turnpike staff find ways to improve the fleet's efficiency.

Many parts of Ohio with several agencies are participating in projects updating infrastructure to accommodate the growing demand for CV technology. As another example, the 33 Smart Mobility Corridor is a 35-mile highway corridor northwest of Columbus, Ohio. The corridor crosses three counties (Franklin, Union, and Logan) and connects the cities of Marysville and Dublin to Honda's North America Campus and points beyond.

4.3.4 When

In 2016, a $5.9 million U.S. DOT grant was awarded to fund the purchase of DSRC. In 2017, Ohio Governor John Kasich announced $45 million for improvements to the Transportation Research Center in support of the development of smart mobility and AV technologies. In 2018, Kasich signed an Executive Order establishing DriveOhio and an Executive Order authorizing AV research to take place on state highways across Ohio.

4.3.5 Cost

Governor Kasich has said he hopes to make Ohio a center for development of the autonomous driving industry. The commission, which has publicly supported that goal, is appropriating $714,000 of its 2017 capital budget for CV technology (Christ 2016). The lion's share of the commission's $121.4 million capital budget will be used for the traditional basics: pavement replacement and resurfacing and bridge repairs and rehabilitation. Still, the investment marks a new era of transportation technology funding.

The authority has been increasingly exploring AV technology in recent years since Randy Cole became executive director of the Ohio Turnpike Commission. Cole, on November 30, 2015, joined Kasich in announcing Ohio's plans to invest $15 million to create the 35-mile Smart Mobility Corridor outside of Columbus. The stretch of road on US 33 between Dublin and East Liberty will act as a testing ground for CAVs and will be outfitted with high-capacity fiber optic cable that will collect and share data on self-driving vehicle operations.

4.3.6 Implementation

The turnpike already is equipped with a fiber network along its entire 241-mile stretch, making exploration into CV technology easier than on other roads. It already is a testing ground for self-driving vehicles through a partnership with the self-driving truck vehicle company, Otto.

4.3.7 Resources

Christ, Ginger. 2016. Ohio Turnpike to Put New Focus on Connected Vehicles in 2017. *The Plain Dealer*. www.cleveland.com/metro/index.ssf/2016/12/ohio_turnpike_to_put_new_focus.html.

33 Smart Mobility Corridor Collaboration. www.33smartcorridor.com/collaborate.

DriveOhio. drive.ohio.gov.

4.4 CASE STUDY: TRAFFIC MANAGEMENT CENTER (USING IOWA AS AN EXAMPLE)

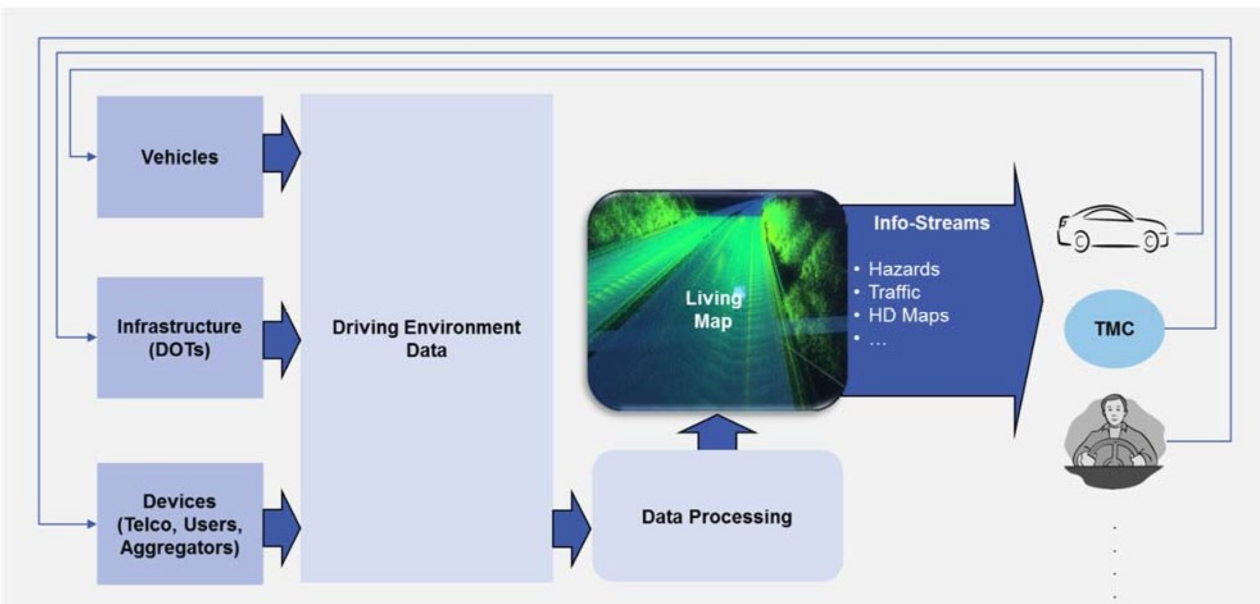
4.4.1 Summary

The Iowa DOT is investing to significantly improve road safety and efficiency by reducing human error from many driving situations for passenger, freight, and fleet vehicles. Improving the availability of data to support automated driving functions as they become commercially available is one step in this direction. Developing an AV-ready environment better enables the Iowa DOT to deliver a safe, reliable, and efficient transportation system (Iowa DOT 2017b).

The state is partnering with the private sector and academia (the University of Iowa and Iowa State University) to develop and execute a roadmap that lays out the Iowa DOT's priority use cases for AV deployment. The roadmap includes research and development and stakeholder outreach. The goals for this project are designed to create an environment where automated driving and advanced transportation technologies can thrive in Iowa.

4.4.2 Description of the Technology

The goals of this project are to build new capabilities that will assist people to drive more effectively and move freight more efficiently. The infrastructure will be designed to create an environment where automated driving and advanced transportation technologies can thrive in Iowa. This will be achieved by capturing driving environment data, processing the data into a living map, and disseminating this information into streams of hazard data, traffic data, and high-definition (HD) maps served to the public through the Traffic Management Center's various methods of data delivery. A conceptual diagram of the proposed architecture is shown in Figure 4-6.



Iowa DOT 2017b

Figure 4-6. Iowa DOT information architecture

4.4.3 What Problem is Being Addressed

To ensure mobility and safe operation of the statewide transportation system, the Traffic Management Center is focused on building new capabilities that will assist people in driving more effectively and moving freight more efficiently than today, facilitate highly automated driving as it becomes available, and make Iowa a leader in offering an AV-ready environment. The Iowa DOT intends to work with its partners to develop and deploy a set of key capabilities to the driving public. These capabilities center on the following:

- Real-time hazard alerts for crashes, weather, work zones, obstacles, traffic jams, and special events for use by drivers and AVs
- Predictive weather and traffic conditions for use by drivers and AVs
- Real-time data feeds for use by AVs including HD maps for key corridors (see Figure 4-7)

Data Feeds

- Road weather
- Road hazards
- Road construction
- Lane closures
- Variable speed advisories
- Dynamic message signs
- Road surface conditions
- General weather
- Truck parking
- Traffic signal status/timing
- Traffic sensors
- Maintenance automated vehicle location activity tracking
- State fleet probe data
- HD spatial data
- Emergency vehicle alerts

Figure 4-7. Iowa DOT data feeds

4.4.4 Approach

In particular, the Iowa DOT envisions an automotive-grade information architecture, which can continuously provide an up-to-date view of driving conditions to enhance the vehicle's decision making and control functions. This information architecture is an array of information flows to and from vehicles, the infrastructure (e.g., roadside sensors), and devices (e.g., smartphones). This information is typically collected and managed by a variety of participants, such as DOTs, telecommunications companies (Telcos), and private sector data aggregators who combine information from multiple sources. A key component of the architecture is a living map, which is a central function that synthesizes this wide array of data to provide a continuously updated representation of the driving environment. This map combines content from the road infrastructure, vehicle sensors, and other mobile devices, with HD spatial data.

Data from the living map may be distributed as a series of information streams that can be used by humans, vehicles, and infrastructure owners/operators to improve safety, mobility, and efficiency throughout the transportation network. These information streams may include specific types of data or may be offered in the form of centrally-generated alerts, driving condition predictions, or other pre-processed information (Iowa DOT 2017b).

4.4.5 Where

Iowa is taking a statewide approach.

4.4.6 When

A realistic view of the industry pace will keep the Iowa DOT’s research, demonstration, and pilots in line with what can be most useful and deployable at scale. This functionality will evolve to handle an increasingly broad variety of driving environments over time.

4.4.7 Cost

Costs vary based on individual project components.

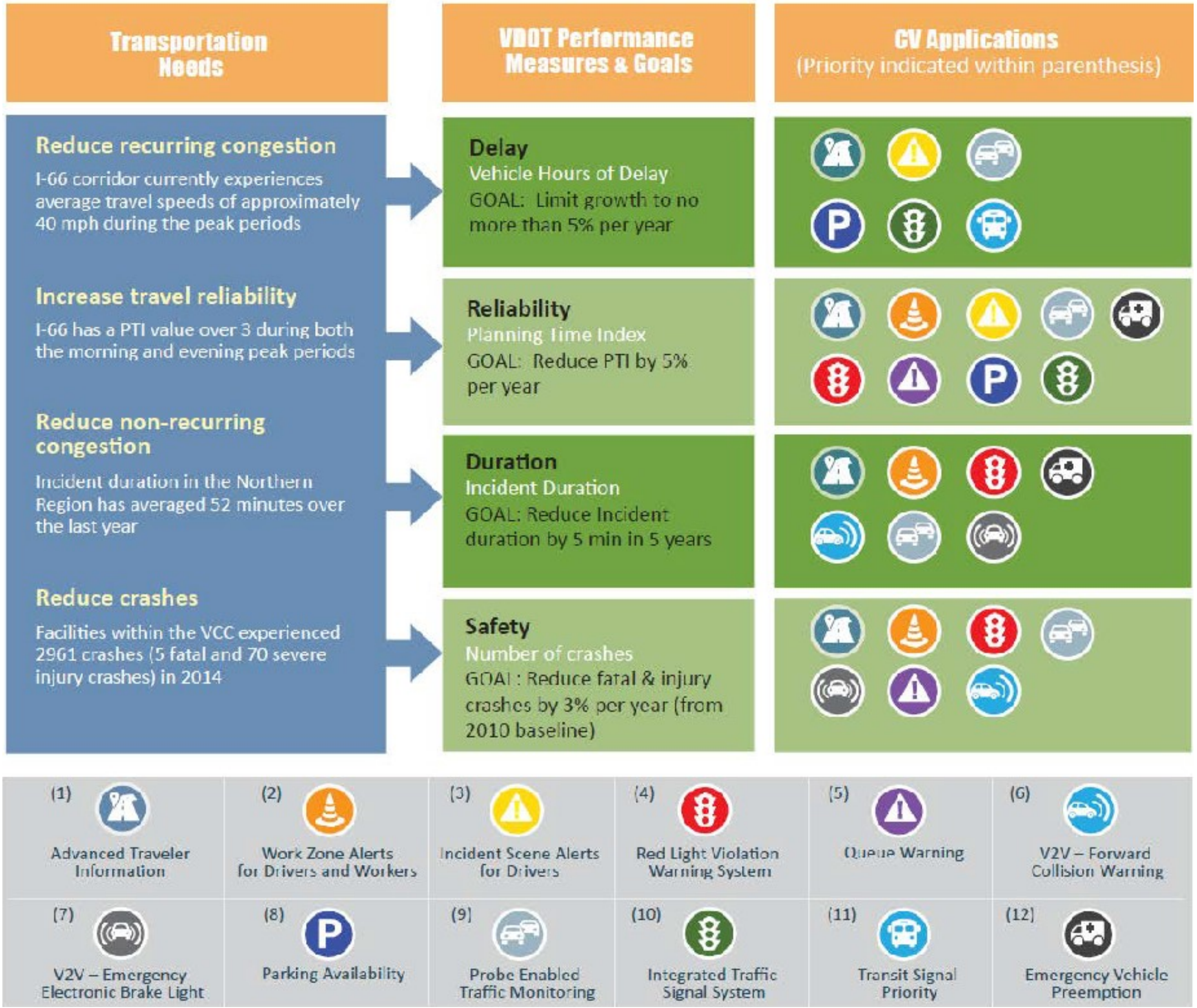
4.4.8 Resources

Iowa DOT. 2017b. *Automated Vehicle Technologies Project: Vision Document Final*. Iowa Department of Transportation, Ames, IA. https://www.iowadot.gov/pdf_files/IowaVisionDocument.pdf.

4.5 CASE STUDY: TRAFFIC MANAGEMENT CENTER (USING VIRGINIA AS AN EXAMPLE)

4.5.1 Background

The Virginia DOT (VDOT) is taking steps to integrate five of their traffic management centers (TMCs). Along with creating a more cohesive traffic and emergency communication network, an upgraded Advanced Traffic Management System allows for automated, real-time traffic management as well as the integration of emerging technology such as CVs (see Figure 4-8).



VDOT 2017

Figure 4-8. VDOT's operational goals

4.5.2 Description of the Technology

The expectation is that CAVs will collect and share data about traffic and road conditions. For instance, subsequent vehicles can expect congestion if a lead vehicle first encounters it and shares the information with other vehicles. In order to do that, data needs to be collected and shared in real-time. Current anticipation is this technology is going to be cellular, CV radios or Bluetooth beacons that are placed on the side of the roadway (McMahon 2018).

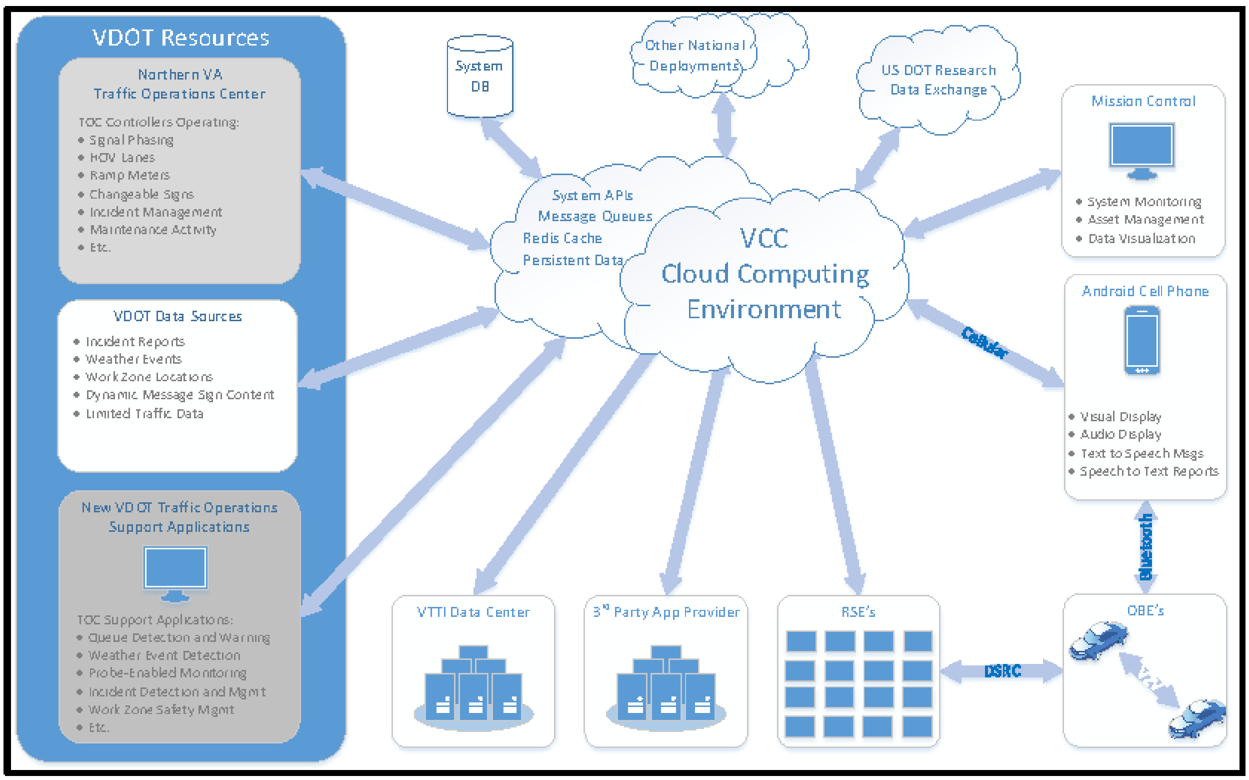
4.5.3 What Problem is Being Addressed

TMCs need the capabilities to collect and process aggregated data from both infrastructure and vehicles (PSC and CAR 2017). There are needs for real-time information of the following: traffic flow and traffic incidents, hazard warnings, environmental conditions, traffic signs, road closures, and major traffic events. It is crucial that existing TMCs coordinate collaborative efforts and share data through the use of various emergency technologies and communication capabilities.

4.5.4 Approach

Through the utilization of updated integrated data, collection and sharing systems will allow for such things as updated messages to be sent by digital signs about weather or incidents or work zones. The data will also be shared by VDOT, Virginia State Police, and 911 centers.

The concept for data integration and sharing is the Virginia Connected Corridor (VCC) cloud computing environment (see Figure 4-9), which will connect to RSE unites and then be able to receive and broadcast messages to passing vehicles.



VDOT 2017

Figure 4-9. Virginia Connected Corridor cloud computing concept

Additionally, VDOT has created SmarterRoads, which is a data portal that users can access online. The cloud-based portal has raw data for various sources including road conditions, incidents, work zones, and road signs. The data portal continuously connects to different data sets and then makes that data available to subscribers.

4.5.5 Where

The first phase of the conversion was slated for April at the traffic centers in Staunton, Salem, and Richmond. The second phase launched in Hampton Roads in September 2017, and the third phase will bring in the Northern Virginia TMC (scheduled for March 2018). The plan's final phase (slated for late 2018) will integrate the traffic and lane closure portion of the technology into the system.

4.5.6 Cost

It will cost an estimated $13.9 million to build and implement, and $11.9 million to operate and maintain over the life of the initial four-year contract.

4.5.7 Resources

VDOT. 2017. *Connected and Automated Vehicle Program Plan*. Virginia Department of Transportation, Richmond, VA. https://www.virginiadot.org/programs/resources/cav/Release_Final_VDOT_CAV_Program_Plan_Fall_2017.pdf.

VDOT. Connected and Automated Vehicle Program. VDOT Leading the Way in Using Technology to Improve Safety and Mobility. www.virginiadot.org/programs/connected_and_automated_vehicles.asp.

VDOT. SmarterRoads. https://smarterroads.org/login.

4.6 CASE STUDY: WYOMING CONNECTED VEHICLE PILOT

4.6.1 Summary

The U.S. DOT has awarded cooperative agreements collectively worth more than $45 million to three pilot sites in New York City, Wyoming, and Tampa, Florida to implement a suite of CV applications and technologies tailored to meet each region's unique transportation needs. These pilot sites are helping CVs make the final leap into real-world deployment, so that they can deliver on their promises to increase safety, improve personal mobility, enhance economic productivity, reduce environmental impacts, and transform public agency operations. Moreover, these sites are laying the groundwork for even more dramatic transformations as other areas follow in their footsteps.

The Wyoming pilot site is a rural application. It focuses on I-80, which runs 402 miles along Wyoming's southern border and is an essential east-west connector for freight and passenger travel. The corridor averages more than 32 million tons of freight deliveries each year. A lack of alternate routes means truck volume can reach as much as 70 percent during seasonal peaks. Wyoming's extreme weather, including blowing snow in winter and fog and high winds in summer, create dangerous conditions for drivers on I-80 (see Figure 4-10). Crash rates are 3 to 5 times higher in winter due to low visibility.

Shutterstock

Figure 4-10. Low-visibility and poor winter highway surface conditions for truckers

In 2015, the U.S. DOT selected Wyoming as one of three locations to test and deploy advanced DSRC technology to improve safety and mobility. In the connected vehicle pilot (CVP), the Wyoming DOT (WYDOT) will use vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and infrastructure-to-vehicle (I2V) connectivity to improve monitoring and reporting of road conditions to vehicles on I-80.

4.6.2 Description of the Technology

The pilot includes 75 roadside units, which will receive and broadcast messages using DSRC technology that will be installed along sections of I-80. The units will be installed at locations along the corridor based on identified hotspots. Additionally, 400 instrumented fleet vehicles will be deployed. These vehicles are equipped with DSRC-connected onboard units that broadcast basic safety messages, share alerts and advisories, and collect environmental data through mobile weather sensors. Snowplows and highway patrol vehicles, which are registered with WYDOT will be included in testing of the technology.

The data collected by fleets and roadside units gives drivers in Wyoming improved travel information through services like the Wyoming 511 app (Figure 4-11) and the commercial vehicle operator portal (CVOP). Road impact forecasts tailored for commercial vehicles are provided for a 72-hour period.

www.wyoroad.info

Figure 4-11. Wyoming 511 road condition and traffic information reporting app logo

4.6.3 What Problem is Being Addressed

The V2V, V2I, and I2V applications support a range of services and can be made directly available to fleets that are participating in the pilot or through WYDOT's traveler information resources.

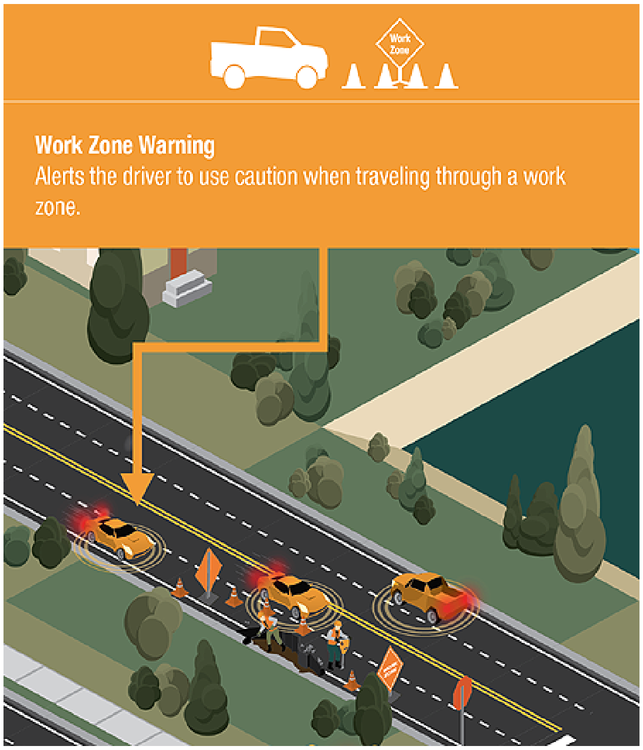
4.6.4 Approach

Specific applications include the following (WYDOT 2017):

Forward Collision Warning: The system issues an alert if there is a threat of a front-end collision with another CV in the same travel lane and direction. A forward collision warning will help drivers avoid or reduce the severity of front-to-rear vehicle collisions. The system provides a warning only and does not take control of the vehicle.

I2V Situational Awareness: The system provides relevant road condition information such as weather alerts, speed restrictions, vehicle restrictions, road conditions, incidents, parking, and road closures. The relevant information is broadcast from RSUs to connected vehicles.

Work Zone Warning: The system (Figure 4-12) communicates work-zone conditions to approaching vehicles. Information about work-zone activities or restriction information is provided. This includes obstructions in a vehicle's travel lane, lane closures, lane shifts, speed reductions, or vehicles entering or exiting the work zone.



www.its.dot.gov/infographs/workzone_warning.htm

Figure 4-12. Work zone warning

Spot Weather Impact Warning: This system enables road condition information specific to a location to be broadcast from a RSU to a CV. This includes situations such as fog or icy roads.

Distress Notification: This system allows CVs to communicate a distress status in the situation when a vehicle's sensors detect a scenario that may require assistance. The distress status can also be activated manually.

4.6.5 Where

The pilot study is along the 402 miles of I-80 on Wyoming's southern border.

4.6.6 When

As of June 2018, the following schedule was in place:

- Phase 1: Concept and Development (up to 12 months): September 2015
- Phase 2: Design, Build and Test: September 2016 to August 2018
- Phase 3: Maintain and Operate Pilot: August 2018 to December 2019
- Transition: Tentatively December 2019 to October 2020
- Post-Pilot Operations: Ongoing routine operations

4.6.7 Cost

The pilot for Wyoming was $4.4 million from the U.S. DOT to WYDOT for the design and deployment phase of the project.

4.6.8 Resources

U.S. DOT Office of the Assistant Secretary for Research and Technology Intelligent Transportation Systems Joint Program Office. Connected Vehicle Pilot Deployment Program. Program Overview. https://www.its.dot.gov/pilots/pilots_overview.htm.

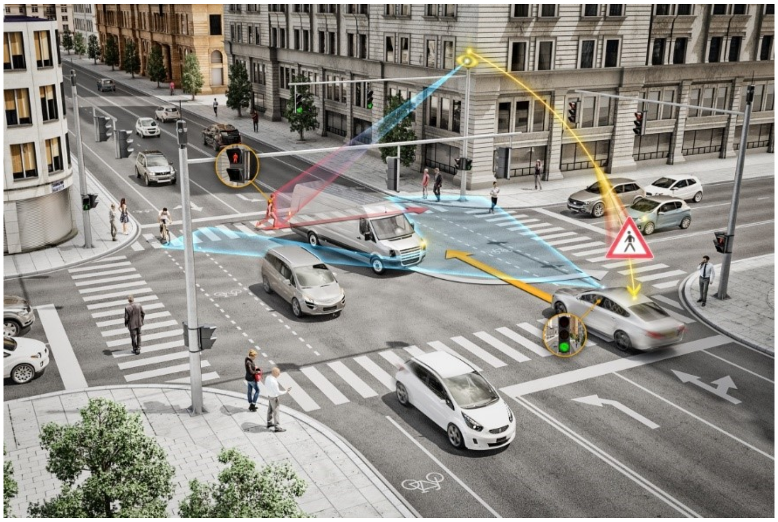
WYDOT. 2016. WYDOT receives grant for connected vehicle program on I-80. http://www.dot.state.wy.us/news/wydot-receives-grant-for-connected-vehicle-program-on-i-80.

WYDOT. 2017. Wyoming DOT Connected Vehicle Pilot. https://wydotcvp.wyoroad.info.

4.7 CASE STUDY: SMART INTERSECTIONS

4.7.1 Background

Smart intersections employ DSRC or other communication systems to provide V2I applications to improve intersection operations and reduce crashes (see Figure 4-13).



www.smartcitiesworld.net/news/news/smart-intersection-aims-to-increase-safety-2422

Figure 4-13. Illustration of a smart intersection

Several groups are piloting smart intersection technology such as the automotive manufacturing company Continental (SmartCities World 2017), a partnership between Honda and the City of Marysville, Ohio (PR Newswire 2018), the City of Detroit in partnership with Miovision (Vock 2018), and Rapid Flow in partnership with Pittsburgh, Pennsylvania.

In essence, smart intersections can detect situations such as a vehicle about to run a red light or a pedestrian and then communicate the information and potentially an appropriate response to vehicles with connected technology.

The smart intersection technology, Scalable Urban Traffic Control (SURTRAC), piloted by Rapid Flow is summarized below.

4.7.2 Description of the Technology

SURTRAC is a smart-traffic light control system that optimizes the flow of traffic at already signalized intersections through the integration of its proprietary software with existing traffic control machines. The SURTRAC team designed a smart traffic control system that optimizes signal timings while allocating green time to different intersection phases based on vehicle presence, vehicle count, and flow-through data collected by vehicle presence detectors at intersections (Carnegie Mellon 2014).

This team has worked with the Pittsburgh Public Works Department and has multiple successes in controlling green light time at intersections. Software has been successfully implemented at nine intersections in the East Liberty area of Pittsburgh, initially, and then adding nine additional intersections for a total of 18 along the corridor. Pittsburgh and SURTRAC planned to add another 31 intersections by mid-2015.

SURTRAC is designed to optimize all modes of travel to include pedestrians, cyclists, transit, and vehicles, unlike other smart intersections that focus only on vehicle traffic flow.

Two technical ideas that govern the SURTRAC operating system are as follows:

- Schedule-driven intersection control, where traffic is analyzed at each intersection
- Schedule-driven coordination, where schedules are communicated downstream to other intersections

Figure 4-14 summarizes the potential benefits from use of this system.

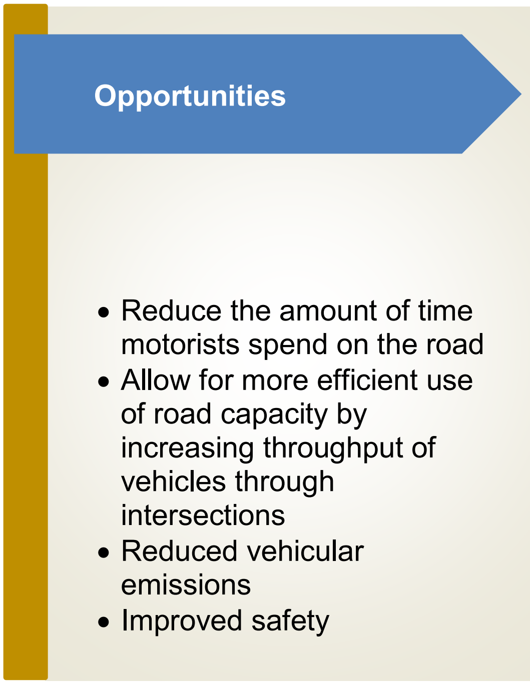


Figure 4-14. SURTRAC technology opportunities

The control process and technology for the SURTRAC traffic control system can be summarized as follows:

- Live-time traffic is extracted from the sensory data systems/feeds which include closed-circuit television (CCTV) cameras
- Computes a phase schedule that optimizes traffic flow and when to change phases
- Communicates to other intersections downstream

SURTRAC equipment operates and communicates with each other in compliance with the DSRC technology protocol, designed under the auspices of the International Telecommunications Union (ITU).

SURTRAC was implemented in nine intersections in Pittsburgh in May of 2012. Comparing the previously existing traffic control to the SURTRAC in regards to traffic flow, travel time, speed, number of stops, wait time, fuel consumption, and emissions, all had improvements of 20% to 40 %. Then, the project was expanded by adding nine more intersections, making 18 intersections that were controlled by SURTRAC. Pittsburgh has plans to implement this technology in approximately 150 intersections.

The bottom line is that SURTRAC takes a totally decentralized approach to control of traffic in a road network: each intersection allocates its green time independently based on actual incoming vehicle flows, and then projected outflows are communicated to neighboring intersections to increase their visibility of future incoming traffic.

4.7.3 Obstacles

- Privacy concerns from the use of CCTV

- Perceived bias toward motorists rather than other travel modes
- Delayed reaction to faults in implementation due to drivers getting accustomed and dependent on the traffic signal plans

4.7.4 Cost

SURTRAC software costs $20,000 per intersection. The deployment and maintenance of the SURTRAC system would also require expert knowledge of its operations to be carried out successfully. Thus, the team intends to provide prospective agencies or machine manufacturers with the required training on how to deploy the system to ensure effective roll out of the platform at intersections (Carnegie Mellon 2014).

4.7.5 Implementation

The SURTRAC system is designed as an add-on/plugin for existing traffic control installations as a means to optimize their operations. It is targeted at OEMs of traffic control systems. SURTRAC uses much of the same traffic sensor functionality that is already in place on roads today.

Pending their receipt of the patent application in 2014 and hopefully the success of the pilot project, SURTRAC should be able to successfully solicit funds from private investors.

4.7.6 Benefits

The SURTRAC technology delivers three key benefits to road users, which could be categorized into the following:

- An improvement in traffic congestion, thus reducing the amount of time motorists spend on roads
- Improved vehicular flow and road usage patterns, allowing for more efficient use of road capacity by increasing throughput of vehicles through intersections
- A reduction in greenhouse gas and particulate matter emissions

From this pilot project, the team was able to record significant savings in travel time and reduced emission levels showing results of 26% less time spent by vehicles on the roads with vehicles spending 41% less time idling and experiencing 31% fewer stops. The SURTRAC technology was also able to reduce vehicular emissions by 21% based on data collected from the intersections (Carnegie Mellon 2014).

4.7.7 Resources

Rapid Flow. SURTRAC Smart Traffic Signals. [www.rapidflowtech.com.](http://www.rapidflowtech.com)

Carnegie Mellon. 2014. *SUTRAC Smart Traffic Light, Non-Market Strategy Analysis Project Report*. Carnegie Mellon University, Pittsburgh, PA.

CHAPTER 5: CONCLUSIONS

This toolbox was developed to provide a summary of information that local agencies should be aware of to prepare for CAVs. The main goal of this toolbox is to assist local agencies in preparing for CAVs in the short term—5 to 10 years. Since local agencies are not generally expected to have the resources to become test beds, this report provides information so that local agencies can leverage ongoing activities and resources to prepare for CAVs.

The most likely scenarios for CAVs in the next 5 to 10 years, which will need to be planned for by local agencies, include gradual integration of automated technology and truck platooning. The main conclusions for addressing infrastructure needs include the following.

Pavement Markings: The main conclusion for how agencies can best address pavement markings in the short term is to place lane lines after resurfacing, maintain quality lane lines, and, at some point, use 6-inch lane lines.

Signing: The main recommendation for signing is to maintain signs in good condition/retroreflectivity and ensure signs are not blocked.

Maintenance: At this point, it is unknown the extent to which additional maintenance may be needed to accommodate CAVs. As a result, the best recommendation at this time is to maintain or implement timely maintenance, particularly when significant surface degradation occurs, such as potholes.

Consistency and Standardization: Recommendations to address consistency are obviously to review signing and marking practices to ensure signing and markings are consistent in terms of type of sign used, placement, and application.

Data Capture and Information Sharing and Inventory: The main conclusion is to develop inventories of features most likely to be impacted by CAVs, such as features relevant to truck platooning or safety messaging. Documentation of how items were collected as well as accuracy of data collection and reporting is also recommended.

Communication Infrastructure: The main recommendation for communication infrastructure is to consider future communication needs in highway plans, as well as communicate with vendors when upgrades are considered.

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