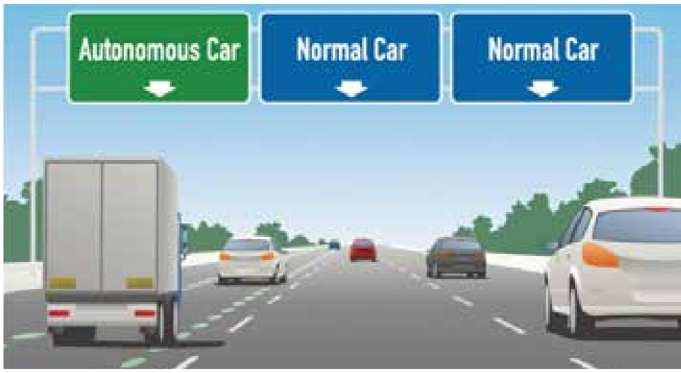
ATSSA MEMBER BUSINESS OPPORTUNITIES RELATED TO CONNECTED AND AUTOMATED VEHICLES

PREPARED UNDER CONTRACT BY AUBURN UNIVERSITY



ATSSA

SAFER ROADS SAVE LIVES

ATSSA Member Business Opportunities Related to Connected and Automated Vechicles

American Traffic Safety Services Association (ATSSA) Publication
Prepared Under Contract by Auburn University

January 2017

Overview

Highly automated vehicles (HAVs) are capable of driving on their own with limited or no human involvement in navigation and control. Per the definition adopted by the National Highway Traffic Safety Administration (NHTSA), there are six levels of automation (Levels 0-2: driver assistance and Levels 3-5: HAV), each of which requires its own specification and marketplace considerations. This project conducted a thorough market analysis of the impact of autonomous vehicle (AV), connected vehicle (CV), and connected automated vehicle (CAV) technologies on American Traffic Safety Services Association (ATSSA) members' business opportunities based on the comprehensive literature review, interviews with experts (e.g., state department of transportation (DOT) officials, ATSSA members, original equipment manufacturers (OEMs), and researchers), and analysis of the latest policy guidelines and published online sources. This publication summarizes the AV/CV/CAV industry's expectations for time frames of market availability of these technologies, and discusses the business opportunities and challenges that ATSSA members might face with the emergence of the AV/CV/CAV technologies.

For a thorough understanding of the impact of AV/CV/CAV technologies on ATSSA members' business opportunities, a comprehensive literature review and three surveys were conducted to gather necessary information. Questionnaires and detailed results of an ATSSA member online survey and interviews with several state DOTs and OEMs are summarized in Appendices A, B, and C, respectively. The online survey of ATSSA members provided a framework in which to determine which information to include in this publication, as this information is most relevant to ATSSA members' businesses. Interviews conducted with OEMs and DOTs were used to determine current AV/CV/CAV deployment and investment plans and timelines as well as the potential impact on transportation infrastructure.

A total of 30 ATSSA members responded to the online survey. Most of the respondents were either manufacturers (53%) or contractors (31%), and their major business area was reported to be temporary traffic control devices, traffic signs, guardrail, and pavement markings. The majority of the respondents' knowledge levels of CAV technologies were average or below average and had no prior experience of working with these technologies. However, a large portion (81%) is interested in doing work with CAV technologies. As the majority of respondents are interested in gaining knowledge about CAV technologies, they were asked to report the type of information they are interested in, and the content of this publication was aggregated and organized based on their responses. A detailed summary of survey respondents can be found in Appendix A. This publication contains four chapters and focuses on new technologies and their impact on ATSSA members' business opportunities. Chapter 1 introduces the concept of AV/CV/CAV technologies, definitions of the levels of automation, technologies involved for each level of automation, and a predicted/proposed implementation timeline. Chapter 2 discusses the current deployment and investment plan by the U.S. DOT and other state DOTs, estimated budget for infrastructure improvement, and current AV/CV/CAV deployment and investment plans by auto manufacturers and OEMs. Chapter 3 presents an analysis of the impacts of AV/CV/CAV technologies on ATSSA member business opportunities, including effects on pavement markings, signs, temporary traffic control devices, roadside safety devices, traffic signals, high friction surfacing, and rumble strips. Chapter 4 summarizes key findings and provides a list of recommendations. ■

Acknowledgements

This publication was prepared by Auburn University (AU) under contract with ATSSA. AU performed an extensive investigation of existing technical literature and research and conducted three surveys for this study to come up with the recommendations. ATSSA would like to recognize the principal researchers Dr. Huaguo Zhou (associate professor, Department of Civil Engineering, AU), Dr. Mahdi Pour-Rouholamin (postdoctoral research associate, AU), Md Atiquzzaman (Ph.D. graduate student, AU), Allison Shacklett (undergraduate student, AU), Beijia Zhang (M.Sc. graduate student, AU), Fatemeh Baratian-Ghorghi (Ph.D. graduate student, AU), Jin Wang (Ph.D. graduate student, AU), Dan Xu (M.Sc. graduate student, AU), Raghunandan Baireddy (M.Sc. graduate student, AU), and Robert Cofield (Ph.D. graduate student, AU).

In addition, we acknowledge the participation, support, contributions, and inputs of the survey and interview participants from the ATSSA, state DOTs, and OEMs. Finally, we express our gratitude to the following individuals who served on the expert panel and provided valuable feedback to enhance the quality of the final publication:

Brian Watson
Director of New Programs, ATSSA

Ross Sheckler, P.E.
Calamar Research

Rob Dingess
President, Mercer Strategic Alliance Inc.

W.D. Baldwin
Associate Vice President and Northwest Region Traffic Leader, HDR

Chris Brookes
Work Zone Delivery Engineer, Michigan Department of Transportation (MDOT)

Joe Jeffrey
President, Road-Tech Safety Services Inc.

Todd Foster
Vice President of ITS Engineering, Ver-Mac Inc.

Greg Driskell
President, Professional Pavement Products (PPP)

Scott Deschampes
Director of Operations, Worksafe Traffic Control Industries

Table of Contents

List of Figures

List of Tables

List of Acronyms

AASHTO	Association of State Highway and Transportation Officials
ABS	Anti-Lock Brake System
ACC	Adaptive Cruise Control
ATIS	Advanced Traveler Information Systems
ATSSA	American Traffic Safety Services Association
AV	Autonomous Vehicle
CACC	Cooperative Adaptive Cruise Control
CV	Connected Vehicle
CAV	Connected Automated Vehicle
DOT	Department of Transportation
DSR	Dynamic Steering Response
DSRC	Dedicated Short Range Communications
ESC	Electronic Stability Control
FCW	Front Collision Warning
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
GPS	Global Positioning System
HAV	Highly Automated Vehicle
IEEE	Institute of Electrical and Electronics Engineers
IMU	Inertial Measurement Units
ITS	Intelligent Transportation Systems
LCA	Lane Change Assist
LDW	Lane Departure Warning
Lidar	Light Detection and Ranging
LoA	Level of Automation
MUTCD	Manual on Uniform Traffic Control Devices
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
OEM	Original Equipment Manufacturer
PDC	Park Distance Control
RFID	Radio Frequency Identification
RSE	Roadside Equipment
RTK	Real Time Kinematic
SAE	Society of Automotive Engineers
SPaT	Signal Phase and Timing
TTI	Texas Transportation Institute
U.S. DOT	United States Department of Transportation
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-Everything

Chapter 1: Introduction

Introduction to AV/CV/CAV Technologies

The future of transportation is being revolutionized with the inclusion of automation into our vehicles. In recent years, a significant investment has been made in autonomous vehicle (AV), connected vehicle (CV), and connected automated vehicle (CAV) technologies to improve safety and mobility on our roadways, with some highly automated vehicles (HAVs) already being tested. According to the U.S. Department of Transportation (U.S. DOT), AV technologies can operate in isolation from other vehicles using in-vehicle sensors only, while CV technologies take advantage of communication with nearby vehicles and infrastructure. CAV can be defined as the combined integration of AV and CV technologies on the same vehicle, meaning that it leverages both AV and CV capabilities. Figure 1.1 shows the concept of connected automation by U.S. DOT. Though AV and CV refer to different concepts, many of the technologies overlap (Center for Advanced Automotive Technology 2016).

HAV is a new term in the recent federal automated vehicles policy to represent Society of Automotive Engineers (SAE) International Levels 3-5 vehicles with automated systems responsible for monitoring the driving environment (NHTSA 2016). An HAV is equipped with several advanced sensor technologies (e.g., GPS, IMU, camera, LiDAR, RADAR, SONAR) combined with computing capabilities that enable the vehicle to perform all possible driving functions such as steering, braking, and acceleration with limited assistance or the absence of a human operator. Given their capability of driving on their own, these vehicles are also called self-driving or driverless vehicles. CV refers to vehicles that can communicate with each other and the infrastructure through vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), or vehicle-to-everything (V2X) technologies, so that every vehicle on the road is aware of the location of other nearby vehicles and roadside objects. Drivers receive notifications and alerts of dangerous situations, such as potential forward collisions, signal timing changes, or a pedestrian on a crosswalk.

CV/AV/CAV technologies may provide benefits such as crash reduction, travel-time dependability, productivity improvement, and improved energy efficiency. Despite the benefits these technologies may provide to future road users in terms of mobility and safety, there are still concerns and issues surrounding their use. Regarding HAV technologies, it should be mentioned that little is known about the type of roadway infrastructure required, since they are not commercially available yet. Today's roads may not be completely reliable to serve these self-driving vehicles. As CAVs rely primarily on infrastructure and gathered data from their surroundings, a major issue is that the current infrastructure is inconsistent, chaotic, or undefined despite the best efforts of state DOTs. Therefore, more emphasis on the infrastructure support for these systems is likely to be required, although auto manufacturers are working toward AV technologies that can operate even in the worst road conditions. Additionally, some liability concerns still exist that might impede these vehicles being tested on roadways. As for CV technologies, it is noteworthy that competing automakers have shown a limited willingness to work together. This lack of cooperation decelerates the emergence of CVs and causes problems with standardization, which is necessary for communication purposes (Chris Hendrickson 2014). However, some European countries and Japan have formed formal alliances to build out and develop specifications designed for accelerating the deployment of CVs.

Although AV research is widespread nationally, and efforts are being made to prepare transportation systems for the upcoming change, AV-related legislation has not been approved in every state. Figure 1.2 depicts the states with enacted AV legislation as of June 2016. As shown in this

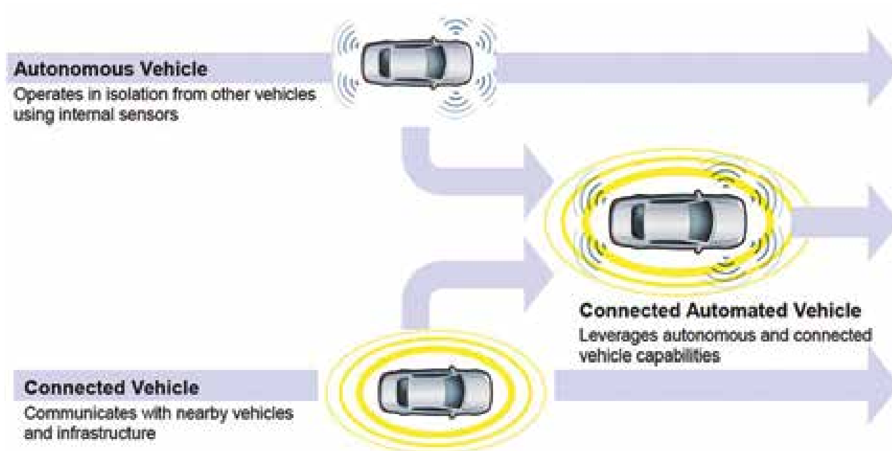


Figure 1-1 Connected Automation Concept (U.S. DOT 2015)

figure, six states, including Michigan, Florida, Nevada, California, North Dakota, and Tennessee, and the District of Columbia, have already passed legislation pertaining to AV technology. Several states have legislation under consideration. Proposed legislation has failed, however, in Oregon, Texas, Colorado, Oklahoma, and New Hampshire. Notably, in 2015, 16 states introduced legislation related to AV in contrast with previous years with 12, 9, and 6 in 2014, 2013, and 2012, respectively. This increasing trend in the number of states with AV legislations further highlights the accelerated introduction of AV in the near future. However, some experts believe that the emergence of distinct and inconsistent AV legislations from different states may hinder innovation in this field (Bomey 2016). The recently issued federal guidance document on AVs also strongly encourages the states to allow U.S. DOT alone to regulate the performance of AV technology and vehicles (NHTSA 2016).

In order to safely test AV/CV/CAV on current roadways without inadvertently impacting current vehicle technologies, several states such as Nevada, California, and Florida have already enacted legislation that explicitly allows for the operation of AV/CV/CAV under certain conditions. For instance, in April of 2016, Florida enacted a law that eliminates the requirement that a driver be present in the test vehicle. Figure 1-3 shows the locations of current AV/CV pilot projects, test facilities, and other activities on a national map.

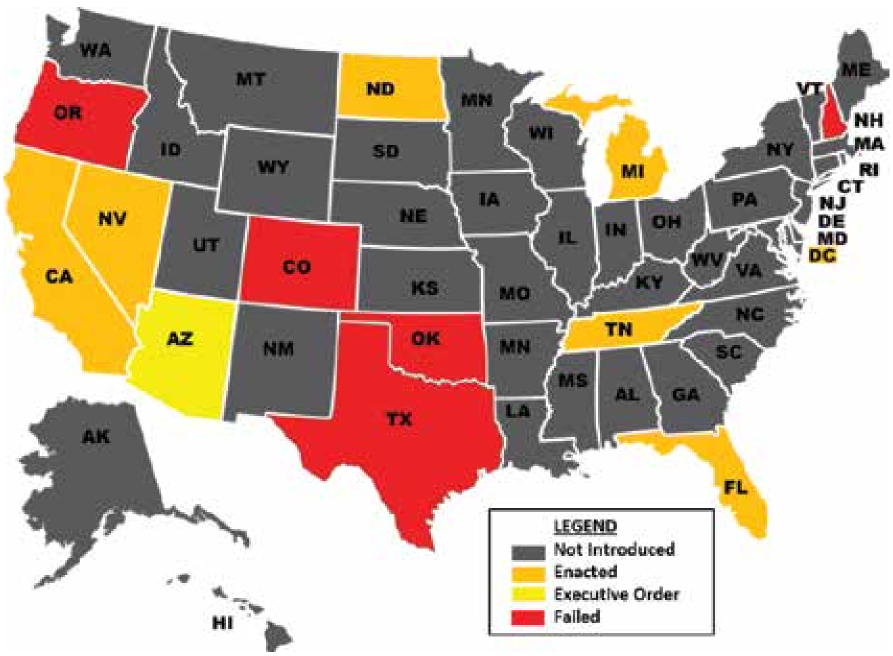


Figure 1-2 AV Legislation in Each State (Florida DOT 2016)

Figure 1-3 AV/CV Testing Locations in the U.S. (Muller 2016)

Table 1.1 Levels of Automation Classified by Two Different Agencies

Levels of Automation						
Agencies	**Level 0**	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Level 5**
NHTSA	No Automation	Function-specific Automation	Combined Function Automation	Limited Self-Driving Automation	Full Self-Driving Automation	
SAE	No Automation	Driver Assistance	Partial Automation	Conditional Automation	High Automation	Full Automation

Table 1.2 Technologies for Each Level of Automation

Level of Automation	Technologies
Driver Assistance (Levels 0-2)	Lane Change Assist (LCA)*
	Park Distance Control (PDC)*
	Lane Departure Warning (LDW)*
	Front Collision Warning (FCW)*
	Anti-Lock Brake System (ABS)*
	Electronic Stability Control (ESC)*
	Dynamic Steering Response(DSR)*
	Stop Sign Gap Assist
	Blind-Spot Warning*
	Visual Pedestrian Detection*
	Red Light Violation Warning
	Real-Time Kinematic (RTK) GPS
	Advanced Traveler Information Systems (ATIS)*
	Adaptive Cruise Control (ACC) Including Stop & Go*
	Collision Detection Braking*
	Automatic Braking System*
	Emergency Brake*
	Park Assist (2018)*
	Lane-Keeping Assist*
	Cooperative Adaptive Cruise Control (CACC)
	Automatic Parking*
	Automatic Lane Change*
	Adaptive Cruise Control with Lane-Keeping*
	Gap Assist at Signalized and Unsignalized Intersections (2040)
	Pedestrian in Signalized Crosswalk Warning (2040)
	Pre-collision Pedestrian Braking*
Highly Automated Vechicles (HAV) (Levels 3-5)	Highway Chauffeur*
	Parking Garage Pilot (2018-2020)
	Highway Auto Pilot (Highway Convoy) (2020-2024)
	Urban & Suburban Pilot*

**Technologies already available in one or more automobile makes/models.*

Levels of Automation (LoA)

The levels of automation (LoA) describe which tasks the operators (drivers) and the automation system are responsible for in different implementation stages of automated vehicle technology. The LoA can guide the transportation industry to educate related personnel about the technological advancements in vehicles. It also simplifies communication and improves collaboration between technicians and legislators from DOTs and original equipment manufacturers (OEMs). Table 1.1 summarizes the classifications of LoA by two different agencies (i.e., NHTSA and SAE) in the U.S. (U.S. DOT 2013, SAE 2014), as various agencies have differing word choices. LoAs are classified from no automation to full automation.

The recent federal automated vehicles policy (NHTSA 2016) adopts the SAE International definition for LoA and draws a distinction between Levels 0-2 and 3-5 based on whether the human operator or the automated system is primarily responsible for monitoring the driving environment. The main feature of Levels 0-2 automation technologies is to assist drivers in one or more driving functions. However, Levels 3-5 technologies have been named as HAV, which can be defined as a vehicle that is capable of driving on its own with limited or no human involvement in navigation and control.

Technologies for Each Level of Automation

Table 1.2 represents various technologies categorized in each level of automation according to the SAE definition adopted in the new federal automated vehicles policy. Many of the driver assistance technologies in Levels 0-2, presented in Table 1.2, are already commercially available. Other high-level automations (Level 3 or above) are predicted to be available commercially in the near future.

Predicted/Proposed Implementation Timeline

As CV/AV technologies continue to evolve rapidly, many transportation agencies are planning for required infrastructure changes to accommodate these technologies. It has been predicted that transportation planners and engineers will primarily be concerned with defining performance, testing, and reporting requirements of AVs for operation on public roadways. Transportation authorities may support policies that encourage or require automation in new vehicles, if several years of testing suggest that AVs have a significant potential to improve the safety and operation of our transportation network (Litman 2015). Figure 1-4 shows the U.S. DOT's predicted CV infrastructure implementation timeline. According to this timeline, important infrastructure milestones include: 1) dedicated short range communications (DSRC) operationally deployed on traffic signals in 2018; 2) CV-enabled active traffic management (ATM) and DSRC on 20% traffic signals in 2025; and 3) system-wide ATM and DSRC on more than 80% of traffic signals in 2040. In terms of vehicles, important milestones include: 1) embedded cellular in many new vehicles in 2015; 2) first DSRC in light vehicles for model year 2020; 3) embedded cellular in most vehicles in 2035; and 4) DSRC in more than 90% of light vehicles in 2040. Additionally, the American Association of State Highway and Transportation Officials (AASHTO) Connected Vehicle Deployment Coalition has anticipated considerable infrastructure changes by 2040, which can be described as follows (U.S. DOT 2014):

- Up to 80% (250,000) of traffic signal locations will be V2I-enabled
- Up to 25,000 of other locations will be V2I-enabled
- Accurate, real-time, localized traveler information will be on 90% or more of roadways
- Next-generation, multimodal, information-driven ATM will be deployed system-wide. ■

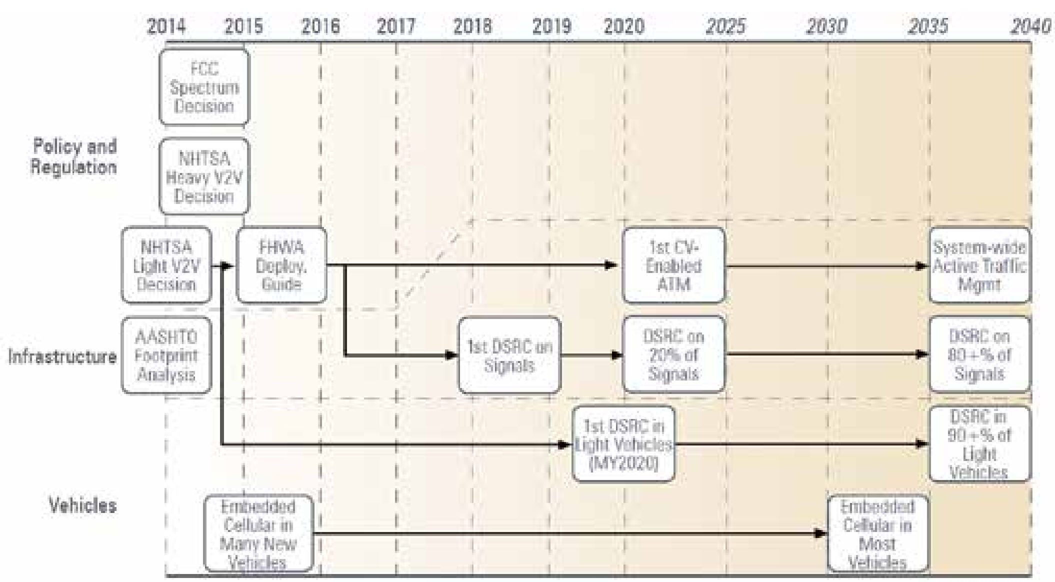


Figure 1-4 Estimated CV Infrastructure Deployment Milestones (U.S. DOT 2014)

Chapter 2: Current CV/AV Deployment and Investment Plan

A number of researchers at University Transportation Centers or within state DOTs are investigating driving in a connected environment to determine required actions prior to implementing CV/AV. Table 2.1 summarizes efforts being made by the U.S. DOT and 14 states. This information was collected by reviewing the existing literature and/or from the interviews conducted with 10 state DOTs.

Table 2.1 Federal Pilot and State DOT Projects on CV/AV

State	Pilot Project or Plan	Timeline	Budget	Objectives	References
New York	CV Federal Pilot Program: Install V2V technology in Midtown Manhattan and V2I technology throughout Midtown	2015–2019	$20M	Install V2V technology in 10,000 city-owned vehicles including cars, buses, and limousines	(U.S. DOT 2016)
Wyoming	CV Federal Pilot Program: Efficient and safe movement of freight	2015–2019	$5M	Decrease the number of weather-related incidents for enhancement of safety and reduction of incident delays along the I-80 east–west corridor	(U.S. DOT 2016)
Florida	CV Federal Pilot Program: Solve peak hour congestion in downtown Tampa	2015–2019	$17M	Protect the city's pedestrians by equipping their smartphones with the same connected technology being put into the vehicles	(U.S. DOT 2016)
	Pilot project 1: Assessing advanced driver assistant systems (ADAS)	Phase I completed between 2014 and 2015; Phase II under consideration as of June 2016	N/A	To determine the effectiveness of "MobilEye" technology (consists of a forward-looking camera and an LED display) in preventing avoidable traffic accidents	(FDOT 2014)
	Pilot project 2: AV/CV/Intelligent Transportation Systems (ITS) freight applications	Three-phase study beginning in 2014. Each phase expected to last for 12–18 months	N/A	To show that AV technologies are capable of improving safety and efficiency in freight operations	(FDOT 2014)
California	One California CV Deployment	2014–2015	N/A	Test bed was in Oakland, mainly testing DSRC technology without emphasis on other infrastructure aspects	(California DOT 2015)

State	Pilot Project or Plan	Timeline	Budget	Objectives	References
Colorado	The I-70 Mountain Corridor CV Project	2017–2018	$10M	Enabling real-time traffic management, providing traveler information and safety applications along the I-70 mountain corridor in order to maximize safety and mobility	(Colorado DOT 2016)
	C-470 Express Lanes Widening (to accommodate a toll lane in each direction)	2016–2019	N/A	Installing ITS elements such as DSRC, cellular, satellite radio	Interview with CDOT
	Central 70	2017–2022	N/A	Installing ITS elements such as DSRC, cellular, satellite radio	Interview with CDOT
Iowa	AV Technologies	2017	N/A	Demonstration of high-definition mapping, predictive traffic modeling with Iowa state, validating modeling, demonstration of actual vehicle	Interview with Iowa DOT
Arizona	Maricopa County DOT SMART[1] Drive Program, Anthem Test Bed	2011–2012	N/A	Connecting the vehicle to infrastructure deployed on the roadway and making more responsive use of technology in actual driving conditions	(Maricopa County DOT 2012)
Michigan	CV Safety Pilot in Ann Arbor	2.5 year	$18M	To determine the effectiveness of the safety applications at reducing crashes and how real-world drivers will respond to the safety applications	(Sawyer 2016)
Minnesota	Minnesota CV Pilot Deployment Project	2015–2020	N/A	To address real-world problems by applying CV technology to demonstrate measurable impacts to the mobility and safety of travelers in Minnesota, while also providing operating efficiencies to maintenance and transit vehicles	(Johnson 2016)
Nevada	Faraday Future Factory	2016–2018	$1B	Transform the state into a major manufacturing hub for the next generation of electric and autonomous cars	(Zolfagharif 2016)
Pennsylvania	CV/AV 2040 Vision	2014	N/A	To assess the implications of connected and autonomous vehicles on the management and operation of Pennsylvania's surface transportation system	(Hendrickson, Biehler, and Mashayekh 2014)
Tennessee	SmartWay in Memphis, Nashville, Chattanooga, and Knoxville	System in use as of 2016	N/A	SmartWay system is managed through four TMCs[2] and consists of 475 cameras, 163 message signs, 1,015 roadway detection systems and 49 video detection systems	(Tennessee DOT 2016)

1 - Systematically Managed ARTerial (SMART) roadway systems
2 - Transportation Management Centers

State	Pilot Project or Plan	Timeline	Budget	Objectives	References
Virginia	CV and AV Program Plan: Automated Corridor	Phase II (2012–2015), Phase III (2015–2017)	N/A	Part of the Pooled Fund Study. Connected-vehicle test sites in northern Virginia and on Virginia's Smart Road	(Gustafson 2016)
Nebraska	Smart City Lincoln Vision program	Funding requested from DOT in Feb 2016	Estimated $120M	AV/CV and electrically powered transit signal priority	(Nebraska DOT 2016)
Utah	Testing three different kind of CV technologies for deployment	2015	N/A	Cooperative adaptive cruise control for trucks; on-board weather monitoring sensors on trucks; and communication between transit vehicles and signal cabinets to enable preemption control	(Davidson 2015)
Oregon	Connected and automated vehicles strategic framework	2014–2015	N/A	To lay the groundwork for Oregon to be prepared to lead in the implementation of a CV/cooperative systems transportation portfolio; and/or to avoid being caught by surprise as developments in this area evolve quickly	(ODOT 2015)

Major takeaways from the interviews with state DOTs and review of the DOT's plans are presented in the following section. Detailed results of the interviews with state DOTs are presented in Appendix B.

1. **Federal CV Program:** U.S. DOT has announced that New York City, I-80 east–west corridor in Wyoming, and Tampa, Fla., will receive up to $42 million to pilot next-generation CV technologies (U.S. DOT 2015):
    - $20 million will be used for the New York City project, which includes upgrading traffic signals with V2I technology along avenues between 14th Street and 66th Street in Manhattan. The same technology will also be installed in Brooklyn (Automotive-fleet 2015).
    - $17 million will be used to address rush-hour congestion in downtown Tampa and to protect the city's pedestrians by equipping their smartphones with the connected technology.
    - $5 million will be used for V2V and V2I technologies in Wyoming to focus on movement of freight through the I-80 east–west corridor, which is critical to commercial heavy-duty vehicles moving across the northern part of the country.

2. **Applications:** DOTs are focusing on the application of AV/CV/CAV in the following areas:
    - Transit/Freight/Snow Plow Signal Priority
        - o Lesson learned from Maricopa County DOT Smart Drive Program is that DSRC radio is environmentally robust, and it is viable for traffic signal priority V2X communications
    - Freeway DSRC units and links between them and roadway systems
    - Research Applications: Test beds with DSRC-equipped intersections for use in testing CVs
    - Work Zones (mostly CV application): Sending signals for end of queue warning to vehicles, alerting to changing work zone conditions
    - Gathering weather data.

DOTs are mainly focusing on infrastructure adaptations for CV (e.g., DSRC), and Departments of Motor Vehicles (DMVs) are focusing on legislature changes for AV. Michigan and Iowa are exceptions. Both are investing research on AV, working on 3-D mapping, and keeping lane markings and signage up to date. Florida has a combined AV/CV freight application and is installing MobilEye's Advanced Driver Assistant System (ADAS) on about 50 vehicles.

3. **Infrastructure Changes:** Some DOTs have recommended the following infrastructure changes:
   - CV: Installing DSRC
   - AV: Updating striping/signage for clear reading; and highly accurate 3-D map

The most common feedback received from state DOT officials indicated that DOTs were not planning for considerable infrastructure changes, as the goal of AV technologies is to work on the worst road conditions. However, some state DOTs were planning for DSRC installation to facilitate CV technologies.

4. **Timeline:** Several test beds are already up and running. The others need four to five years for DSRC deployment. Two of the 10 interviewed transportation agencies (i.e., Colorado and Nevada DOT) have started the DSRC installation. The remaining interviewed agencies (except Michigan and Iowa DOT) have planned for installing DSRC and are awaiting federal or other sources of funding.

5. **Funding:** Many DOTs interviewed submitted application plans during the Wave I of the federal CV pilot deployment program. Furthermore, there is a Wave II for funding, and DOTs hope to receive these federal funds. Another source of funding for local agencies is SmartCity Challenge (The City of Lincoln, Nebraska 2016). Other funding sources include federal government grants and funding through air-quality agencies.

Some state DOTs without pilot projects have already included CV/AV/CAV in their statewide ITS strategic plans or 2040 planning horizon, such as:

Massachusetts: MassDOT incorporated the emerging standards of the CV Program in its Statewide ITS Strategic Plan (MassDOT 2013).

New Mexico: AV technologies are in its 2040 planning horizon (New Mexico DOT 2015).

North Carolina: Started a comprehensive study to look at AV from the state perspective.

North Dakota: On March 20, 2015, legislators approved a measure to study CAVs.

Oregon: "AV/CV Strategic Framework" was selected as a 2014–2015 "High Priority" project (ODOT 2015).

Pennsylvania: Pennsylvania DOT commissioned a one-year project, Connected and Autonomous Vehicles 2040 Vision, involving researchers at Carnegie Mellon University to assess the implications of AV/CV on the management and operation of the state's surface transportation system.

Utah: Currently, the Utah DOT is testing three different kinds of CV technologies for deployment: 1) cooperative adaptive cruise control for trucks; 2) onboard weather monitoring sensors on trucks; and 3) communication between transit vehicles and signal cabinets to enable preemption control (Davidson 2015).

Texas: One of the objectives of Texas DOT's (TxDOT's) ITS strategic plan is to deploy and operate ITS technologies and services to reduce crashes and fatalities. As CV technologies mature, TxDOT will be able to participate in the infrastructure elements of the Intersection Collision Avoidance Service (Seymour, et al. 2014).

Washington: WSDOT is considering deployment of automated red-light-running enforcement, highway-rail crossing, and speed enforcement, including speed enforcement in construction or maintenance work zones (WSDOT 2009).

Florida: Florida's ITS strategic plan aligns with the goals outlined in the 2025 Florida Transportation Plan. Core objectives of this plan include investigating, deploying, and expanding CV opportunities while continuing to support FHWA's CV initiative. This initiative includes use of novel technologies, such as wireless communications, vehicle sensors, onboard computer processing, GPS navigation, and smart infrastructure to potentially alter travel on roadways. DSRC has been adopted as the communication protocol for CV (FDOT 2014).

Current Deployment and Investment Plan by Auto Manufacturers and OEMs

This section outlines the latest predictions as to when HAVs (Levels 3-5) will be available on the market (see Table 2.2). The driving automation timeline is dependent on the perceived needs of the auto industry and the gradual evolution of their systems toward fully autonomous driving. Automobile companies Mercedes and Tesla have released or are soon to release self-driving features that provide some degree of automation. In 2016, Uber implemented the use of self-driving taxis in Pittsburgh, despite concerns from safety experts that the technology was not yet ready for full deployment in real-world traffic (Dwoskin and Fung 2016) (Figure 2.1). Previously, Tesla and Google were expected to be the first to release fully autonomous car technology in 2018; however, regulatory approval may take one to three years thereafter (Autonomous Car Forecasts 2016). It is anticipated that, by 2025, driverless cars will be in use all over the nation. By the end of the forecast period (2040), it is expected that nearly 75% of all vehicles will be autonomous (IEEE 2012).

Table 2.2 Predicted Autonomy Timeline by Various Manufacturers

Year	Manufacturer	Level of Automation (NHTSA)	Technology
2016	Mercedes	3	Highway Pilot
	General Motors	2	Super Cruise
	Tesla	3	Autonomously for 90% of distances driven
	Uber	4	Fully autonomous
	Toyota	3	Automated Highway Driving Assist
2017	General Motors	-	V2V technology
2018	Nissan	2	Autonomously maneuver on multilane highways
	Tesla	4	Fully autonomous
	Google	4	Fully autonomous
2020	Ford	4 (SAE)	Highly autonomous
	Volvo	4	Fully autonomous
	General Motors, Mercedes-Benz, Audi, BMW, Renault, Tesla, and Google	3	Expect to be selling autonomous cars
	Nissan	4	Fully autonomous
	Toyota	3	Autonomous highway driving to the market
2024	Jaguar and Land Rover	4	Expects to release an autonomous car
2025	Daimler and Ford	4	Expect autonomous vehicles on the market
	General Motors	4	Fully autonomous and V2V technology
2030	Uber	4	Expects Uber's fleet to be driverless.

Related NCHRP Projects

Currently, there are several ongoing/planned National Cooperative Highway Research Program (NCHRP) research projects directly related to the impact of AV/CV on transportation infrastructure, and some will be completed in the next few years. The next section provides a summary of these projects, including their objective, timeframe, and budget assigned.

NCHRP 20-07: Research for AASTHO Standing Committee on Highways

This major project includes a research task (i.e., Task 322), which might be of interest to ATSSA members. The main objectives of Task 322 are to describe the current state of DSRC equipment capabilities, spectrum licensing, acquisition requirements, and the further development required to achieve vehicle-to-roadside communications.

NCHRP 20-102: Impacts of AV/CV on State and Local Transportation Agencies—Task-Order Support

The objectives of this project are to (1) identify critical issues associated with CV and AV that state and local transportation agencies and AASHTO will face; (2) conduct research to address those issues; and (3) conduct related technology transfer and information exchange activities. This project currently has 14 tasks defined, which are either active or anticipated. Task 6 under this project, titled "Road Markings for Machine Vision," is directly related to ATSSA members' businesses. The objective of this task is to obtain data that can be used to develop correlations between machine vision performance and pavement markings.

NCHRP 20-24(98): Connected/Automated Vehicle Research Roadmap for AASHTO

This project, completed in June 2015, aimed to develop an AV/CV research roadmap addressing the policy, planning, and implementation issues that state and local transportation agencies will face. The most important outcome of this project was a deliverable that proposes 23 projects to be defined by AASHTO related to AV/CV under the following four topics:

1. Institutional and Policy Issues
2. Infrastructure Design and Operations
3. Planning Issues
4. Modal Applications (transit, trucking)

Table 2.3 lists several specific related research tasks under the NCHRP 20-07 and 20-102 and several proposed related research projects by NCHRP 20-24(98). The outcomes of these research tasks will answer many unknown questions on the real impact of AV/CV on roadway infrastructure and traffic control devices. ■

Figure 2-1 Uber Self-Driving Taxi in Pittsburgh (Brewster 2016)

Table 2.3 Ongoing and Proposed NCHRP Research Topics

Projects	Research Tasks	Outcome	Estimated Budget/Duration
NCHRP 20-07: Research for AASHTO Standing Committee on Highways	State of Readiness of the Dedicated Short Range Communications (DSRC) Spectrum for Early Deployment of Connected Vehicle Transportation Systems	Description of the current state of DSRC equipment capabilities, spectrum licensing, acquisition requirements, and the further development required to achieve vehicle-to-roadside communications. In addition, this task will include the development of deployment, operating, and maintenance guidelines, including licensing approaches	$50K/(Ongoing)
NCHRP 20-102: Impacts of AV/CV on State and Local Transportation Agencies — Task-Order Support	Road Markings for Machine Vision	Develop correlation between machine vision performance and pavement marking. Factors to be considered in this study are pavement marking presence, contrast, retro-reflectivity, pavement uniformity, day and night condition, and vehicle speed	$200K/12 Months (Completion date: May 2017)
NCHRP 20-24(98): Connected/ Automated Vehicle Research Roadmap for AASHTO	Public Agency Actions to Facilitate AV/CV implementation	Recommended policy actions as well as their cost estimation and impact deployment on AV/CV technologies	$500K/12 months (Proposed)
	Lessons Learned from Safety Pilot and CV Pilot Deployments	A report on the findings from the CV pilot deployment projects to be shared with stakeholders	$250K/12 months (Proposed)
	Roadway Infrastructure Design Considerations for Operation of AV	A set of recommendations for infrastructure change to accommodate AV technologies	$750K/18 months (Proposed)
	Traffic Control Strategies with Consideration of AV	Recommendations for enhancing traffic control strategies applicable to AV technologies	$1.5M/36 months (Proposed)

Chapter 3: Impact of CAV Technologies on ATSSA Members' Businesses

This chapter gives a brief introduction about various CAV technologies at each level of automation and their implications on the safety and mobility of transportation systems. More importantly, a thorough market analysis of existing and emerging CAV technologies' impact on ATSSA members' business opportunity was conducted and findings are presented. Although some technologies do not have a direct impact on ATSSA members' businesses, they are introduced in this chapter to provide a broad overview of AV/CV/CAV technologies. All technologies are categorized into three different groups based on their impacts (high, medium, or low/no) on ATSSA members' businesses.

According to the new federal automated vehicle policy (NHTSA 2016), any technology utilized in creation of an AV system has a specific operational design domain (ODD) and object and event detection and response (OEDR) system. ODD defines the specific function performed by a technology within the automated system (NHTSA 2016). To efficiently cater to the needs of HAVs and other vehicles functioning at different levels of automation, the products manufactured by ATSSA members should have the capacity to simultaneously deal with different kinds of ODDs. For instance, a traffic signal head present at an intersection should be able to communicate the signal phase information to vehicles, detect vehicles violating the signal, and provide gap-assist to vehicles waiting to make turning maneuvers. Every HAV should have an OEDR system to detect and respond to speed limit changes, speed advisories, stop signs, yield signs, and temporary traffic control devices. If the automated driving system fails, then it should be able to take action to minimize risks. This is referred to as minimum risk condition (NHTSA 2016). Similarly, the remote units of an automated driving system, i.e., the roadside units, should also have a minimum risk condition. When the roadside units malfunction, they should have the capability to communicate their defect to concerned vehicles or have an auxiliary system that takes over when the primary system fails. It is recommended for ATSSA members to consider that their manufactured products should support a minimum risk condition.

The sections below contain brief definitions of CAV technologies, presented in Table 2.1 as well as a possible impact analysis per group.

High-Impact Technologies

1. **Lane Departure Warning (LDW):** LDW systems detect unindicated lane departure via a camera behind the rearview mirror and provide auditory and/or visual warnings to alert drivers. It operates at speeds above 35 mph (Flannagan, et al. 2016). Because the LDW systems alert the driver about imminent unintended lane departure, the implementation of this system is likely to considerably reduce lane departure crashes (Lee 2002, Yu, Zhang and Cai 2008). As a consequence, this should lessen the demand for roadside safety features such as rumble strips or other roadside countermeasures used to reduce lane departure crashes. However, the performance of LDW depends on the visibility of lane marking; as such, this system might require higher visibility of lane markings for proper functioning.

2. **Lane-Keeping Assist (LKA):** When a vehicle starts to drift away from the center of a travel lane without a lane change signal in use, the LKA system helps to bring the vehicle back to the lane center by applying mild steering torque. The LKA system consists of a camera-based lane recognition unit, a control unit, and electronic power steering (Ishida S, Gayko J E 2004). Such a system is likely to considerably reduce roadway/lane departure crashes. Therefore, there might be less demand for roadside safety equipment such as rumble strips or guardrails when LKA systems become widely available. However, the camera-based lane recognition unit in an LKA system captures images of lane markers to determine the lane positioning of a vehicle. Thus, highly visible lane markers will be required by this system for proper detection of lane positioning.

3. **Adaptive Cruise Control (ACC) with Lane-Keeping:** ACC with lane-keeping is a system where ACC integrates with lane-keeping assist (LKA). In this system, ACC and LKA operate simultaneously to adjust speed automatically based on the speed of preceding vehicles, maintain safe distance from the preceding vehicles, and help the driver stay on the lane center by applying mild steering torque in case the vehicle is drifting away from lane center. This system is likely to reduce rear-end and lane-departure crashes. ACC with lane-keeping will require more visible pavement marking for proper functioning of the LKA system.

4. **Adaptive Cruise Control (ACC) Including Stop and Go:** ACC assists drivers by automatically adjusting vehicle speed to maintain a safe distance from the preceding vehicle. While the conventional ACC only operates when the vehicle is traveling above a certain speed, ACC including Stop and Go is capable of operating at all speeds and bringing the vehicle to a complete stop (Naranjo, et al. 2006). In addition, ACC with Stop and Go is designed to assist in queuing scenarios by enabling the following vehicle to maintain a set distance behind slow-moving vehicles (Stanton, Dunoyer and Leatherland 2011). This system uses radar

to measure the gap and speed of the vehicle ahead (Naranjo, et al. 2006). ACC with Stop and Go systems can be integrated into smart work zone traffic control strategies to improve stop-and-go-type traffic control.

5. **Automatic Braking System:** Automatic braking system combines sensors (such as long-range radar) and brake controls to help prevent high-speed collisions. If an object is detected, the system can determine if the speed of the vehicle is greater than the speed of the object in front of it. A significant speed differential may indicate that a collision is likely to occur, in which case the system is capable of automatically activating the brakes. Experts stated that making automatic braking standard could potentially prevent 20% of accidents (Autodealio 2014). In addition to the direct measurement of sensor data, some automatic braking systems can also make use of GPS data. If a vehicle has an accurate GPS system and access to a database of stop signs and other information, it can activate its auto brakes if the driver accidentally fails to stop in time (Kurami 1994). Thus, the system demands on accurate GPS system and high-definition (HD) maps with detailed information on traffic control devices such as stop signs. This technology can also be applied to develop advanced work zone traffic control strategies.

6. **Emergency Brake or Autonomous Emergency Braking (AEB):** AEB is an AV safety system that employs sensors to monitor the traffic conditions ahead in addition to the proximity of vehicles in front and automatically brakes when the relative speed and distance between the vehicles suggest that a collision is imminent. Some manufacturers such as Volvo, Mazda, and Volkswagen offer the system as standard. However, almost all manufacturers have AEB systems available as an optional component. Similar to an automatic braking system, this technology can help reduce work zone-related crashes and may have an impact on work zone traffic control devices.

Figure 3-1 Autonomous Emergency Braking (Volkswagen 2011)

7. **Cooperative Adaptive Cruise Control (CACC):** Compared with conventional ACC, CACC reduces the amount of delay in responding to speed changes by preceding vehicles and shortens the minimum gap time in following the preceding vehicle; therefore, enabling vehicles to follow each other more accurately and in closer proximity (FHWA 2016). CACC-equipped vehicles communicate with other nearby equipped vehicles (V2V) and/or roadside equipment (V2I) to coordinate and adjust longitudinal control automatically through throttle and brake activations (Jones 2013). Such automation may improve safety by making rear-end crashes less likely, increase the road capacity, and decrease fuel consumption (Shladover, et al. 2014, Jones 2013). CACC can be implemented with either or both V2V and V2I communication, while V2V communication provides information about preceding vehicle/vehicles and V2I communication provides recommended speeds to vehicle speed control systems through TMC and roadside devices. Both V2V and V2I required for CACC systems can be achieved through DSRC communication (Shladover, et al. 2014). However, the communication range of DSRC is short; thus, a large number of DSRC-enabled roadside equipment (RSE) is required to cover longer roadway lengths. Cellular technology provides much greater coverage and could be used as a replacement to DSRC for disseminating information from the TMC (Parikh, et al. 2015, Shladover, et al. 2014). The CACC system will create demand for in-vehicle DSRC devices, DSRC-enabled RSEs, and/or cell towers. Additionally, a CACC system with local coordination requires infrastructure lane identification, which can be achieved through radio frequency identification (RFID) based lane identification, possibly from overhead gantries or from RFID chips embedded in the pavement of lane dividers (Shladover, et al. 2014). Therefore, a CACC system with local coordination will create demand for RFID.

8. **Front Collision Warning (FCW):** FCW reduces the possibility and/or severity of rear-end crashes by providing warnings to drivers when they approach too close to a preceding vehicle. The FCW system is capable of detecting vehicles within 197 feet ahead and operates at speeds above 25 mph (Flannagan, et al. 2016). The detection of a preceding vehicle is accomplished via a single forward-looking camera sensor located on the windshield in front of the rearview mirror. FCW systems warn drivers about imminent collision through a range of audio, visual, and/or tactile warning systems (Raphael, et al. 2011). FCW systems do not require additional traffic control devices or communications (V2I) for proper functioning. Because it helps reduce rear-end collisions and improves safety at work zones and intersections, FCW can be considered in developing traffic control strategies in the work zones. The FCW may help reduce negative safety impacts by technologies such as red light cameras (RLCs) or ramp meters that can increase rear-end crashes at intersections.

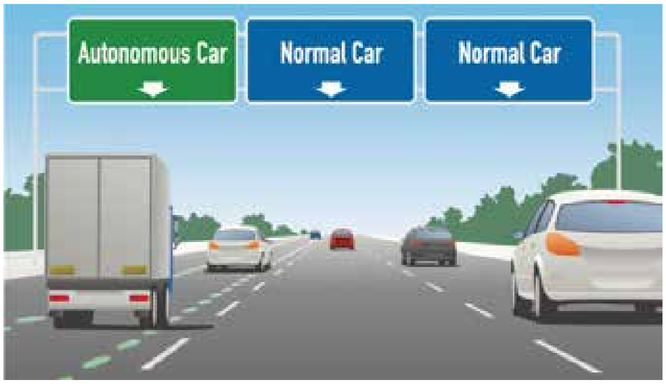


Figure 3-2 Dedicated Lane for Autonomous Vehicles (CBC News 2016)

9. **Highway Chauffeur:** This system uses the road markings to keep the vehicle on course and a high-precision GPS to find its route. The system handles all of the management-related tasks, securely overtaking, changing lanes, driving in tunnels, and tollbooths. The system lets the driver delegate driving on highways during long motorway journeys. Before exiting the highway, the vehicle warns the driver so the driver can be ready to take over. This technology only works for long-distance travel on freeways or expressways. It may require improving existing highways for AVs. A recent proposed plan to dedicate at least one lane for AV only on the I-5 from Seattle to Highway 99 in Richmond, B.C. in Figure 3-2 is an example for implementing this technology.

10. **Highway Auto-Pilot (Highway Convoy):** The highway auto-pilot technology was developed by electric car manufacturing company Tesla Motors. This technology is a collection of autonomous driving systems working in tandem. These systems depend on a variety of hardware components such as radars, cameras, ultrasonic sensors, GPS, and digitally controlled high-precision brakes to enable the highway auto-pilot (Tesla Motors 2015). Additionally, the auto-pilot utilizes its machine learning capabilities to learn from the mistakes made by other vehicles equipped with the same technology and continually improve its efficiency in self-driving. Tasks that can be performed by the auto-pilot include lane keeping, lane changing, speed management, automatic parallel parking, digital control of brakes, motor, and steering (Frankel 2016).The highway auto-pilot is by no means a fully autonomous driving technology. This technology needs clear or standard pavement markings to perform functions such as lane keeping and lane changing.

11. **Urban and Suburban Pilot:** Urban and suburban pilot makes piloted driving possible in city/urban settings. It uses millimeter-wave radar, laser scanners, an eight-way 360-degree-view camera system, high-speed computer processors, and a human-machine interface. The sensors and camera system scan the surroundings continuously to make self-driving possible in urban settings with various levels of traffic movement and is capable of driving at intersections, sharp curves, tight turns, and changing lanes (Nissan 2015). The anticipated urban and suburban pilot is fully dependent on the in-vehicle sensors, cameras, and processing units; thus, the commercial availability of this technology is unlikely to have any direct impact on ATSSA members' business opportunities. However, various signs and markings may need to be changed so that sensors and cameras can easily detect and understand the information conveyed by a particular sign or marking. Additionally, if urban and suburban pilot is integrated with V2I communication, it will require infrastructure development (e.g., DSRC, cell tower) to facilitate communications.

Medium-Impact Technologies

1. **Anti-Lock Brake System (ABS):** This system is designed to prevent skidding of vehicles and improve steering control when braking maneuvers are performed. ABS is especially useful to drivers while traveling on wet and slippery roads. ABS typically consists of an electronic control unit, wheel speed sensors, and hydraulic brake valves. By utilizing these components, ABS recognizes abnormal braking forces and compensates for them by repeatedly holding and releasing optimum braking pressure to each wheel of the vehicle. As a result, the wheels receive just enough braking pressure to make safe stops while the steering wheel retains its control over the vehicle (Burton 2004). ABS has the potential to decrease the risk of multiple-vehicle crashes and run-off-road crashes on wet and slippery surfaces by 18% and 35%, respectively (Burton 2004). However, while driving on gravel roads or on unpacked snow, ABS might have an opposite effect (NHTSA 1999). The functioning of ABS is not dependent on any traffic control devices nor does it make use of any roadside infrastructure. Its operation is entirely confined to the insides of the vehicle. Additionally, if and when this technology attains 100% market penetration, it might reduce the demand on the pavement friction improvement techniques such as high friction surfacing.

2. **Electronic Stability Control (ESC):** This technology limits the risk of skidding and loss of control over the vehicle in case of oversteering or understeering. ESC will be helpful to drivers while performing evasive maneuvers and while traveling on roads covered with gravel or snow. ESC is primarily a group of sensors that work in tandem with a control unit. Data regarding various aspects such as the steering wheel angle, wheel speeds, lateral acceleration, and vehicle rotation are

collected by sensors and fed into the control unit. The control unit analyzes the data and determines if there is a chance of control loss or skidding. If such risk is detected, the control unit separately applies brakes to individual wheels to counteract the potential skidding (Liebemann 2004). ESC has the potential to reduce fatal crashes by 43% (IIHS 2011) and SUV-related crashes by 67% (Dang 2004). All the information required by the ESC to perform its function is obtained using sensors present within the vehicle. Moreover, ESC does not communicate with traffic control devices in any way. The ESC technology combined with other automobile safety systems such as ABS has a potential impact on pavement friction improvement technologies.

3. **Stop Sign Gap Assist (SSGA):** This vehicle-to-infrastructure (V2I) safety technology involves changes to intersections in which minor and major roads meet and there is only a posted stop sign at the minor road. This system captures all sensor information for the major and minor roads and from medians to determine the dynamic state of the intersection (Iteris, Stop Sign Gap Assist 2016). It then issues warnings to drivers to alert them of unsafe gaps on the major road in order to prevent collisions from the misjudgment of distances. These warnings can be sent straight to CV or to roadway signage for the drivers of conventional vehicles. Safety infrastructure required for this application includes various roadway sensors and digital signage to alert drivers before full market penetration of CV. This technology could incorporate technologies already produced by ATSSA members who manufacture and sell digital message signs and other digital signage.

4. **Visual Pedestrian Detection and Pre-Collision Pedestrian Braking:** This technology involves detecting the presence of pedestrians in front of vehicles using an in-vehicle camera in order to mitigate crashes involving pedestrians. The system alerts the driver of a possible pedestrian in the vehicle's path with audible and visual messages in the vehicle. This system can also involve emergency application of the brakes if the driver does not respond with corrective movements when reaching the "point of unavoidable impact" (Mobileye 2016), called pre-collision pedestrian braking. As this application only involves changes to vehicle sensor and alert systems, it should not have any effect on ATSSA members' businesses. There may be potential effect on the quantity of pedestrian safety infrastructure required at intersections and crossings as vehicles become better at sensing and responding to pedestrians in roadways.

5. **Red Light Violation Warning (RLVW):** RLVW is a V2I safety technology, which is capable of communicating with the instrumented intersection signal controller to access information such as signal phase and timing (SPaT) and the geometry of the intersection. Based on the SPaT, geometry of the intersection, vehicle speed, and acceleration profile, RLVW determines if a driver is likely to commit a red light violation. When a red light violation is likely, the systems provide warning to drivers (Iteris 2016). Such a system is likely to reduce unintended red light violations and sudden stops to avoid red light running as drivers are informed about the likelihood of violations well ahead of time. Therefore, certain intersection-related crashes (e.g., right-angle, rear-end) will be reduced. RLVW requires communication with intersection signal controllers to determine the likelihood of violations. These communications can be accomplished through roadside DSRC. Additionally, intersection signal controllers should be upgraded to provide communication between roadside DSRC unit and signal controller.

6. **Real-Time Kinematic (RTK) GPS:** The real-time kinematic global positioning system (RTK-GPS) is an enhanced form of the existing GPS technology. RTK technology enables GPS to locate a point with centimeter-level accuracy (Stephenson, et al. 2011). The major components of RTK technology are the base station and the rover receiver. The base station receives carrier cycles (signals) from the satellites and sends out the corresponding corrected observations to the rover. Upon receiving these signals, the rover uses an ambiguity resolution algorithm to determine its own location (Wanninger 2004). RTK technology can be utilized to strengthen the vehicle localization capabilities. This will lead to greater performance in various ITS applications such as CACC, collision avoidance, and LDW (Stephenson, et al. 2011). In order to incorporate this technology into ITS, every vehicle in a transportation network should have the capability to act as a rover station. This capability allows vehicle communication with base stations, becoming a part of the roadside infrastructure, to accurately compute locations. In this scenario, ATSSA members might have a new business opportunity in the form of manufacturing base station equipment.

7. **Advanced Traveler Information System (ATIS):** This terminology is given to any system that obtains, analyzes, and presents travel-related information to travelers in real time. This information can be obtained through the other vehicles as well as traffic management centers. In order to better convey and provide faster information to travelers, there will be need for more variable message signs (VMS), DSRC, and 5G cell towers.

Figure 3-3 Collision Detection Braking of Ford (Ford 2016)

8. **Collision Detection Braking:** Collision detection braking helps reduce the likelihood and severity of a frontal collision. The system uses sensors in the front of the vehicle to detect vehicles traveling in the same direction and warns the driver when a vehicle is rapidly approaching. If the driver does not react to it, the vehicle will pre-charge and increase brake-assist sensitivity to provide full responsiveness when braking. Once the brake has been pre-charged, it will automatically apply a harder force to stop the vehicle quickly. The system does not activate the brakes automatically, and the driver remains responsible for safely operating the vehicle and avoiding collisions (Ford 2016, Honda 2016). Thus, more high-quality sensors need to be developed for the system.

9. **Automatic Parking:** Automatic parking is an autonomous car-maneuvering system that moves a vehicle from a traffic lane into a parking spot to perform parallel, perpendicular, or angle parking. The parking maneuver is achieved by means of coordinated control of the steering angle and speed, which takes into account the actual situation in the environment to ensure collision-free motion within the available space (Paromtchik and Laugier 1996). Therefore, a more accurate parking lot mapping system is needed in the future. Additionally, the automatic parking system requires less human interaction, which may place demands on the electronic parking-fee collection system (Rashid, et al. 2012).

10. **Automatic Lane Change:** Automatic lane change technology depends on a system of cameras, radars, ultrasonic sensors, and stored data (Tesla 2016). The system processes information, including the surrounding vehicles and the lane markings to determine when it is safe to make a lane change (Lavrinc 2014). The automatic steering then makes the change without driver input. This system requires clear lane markings that are readable to the car's sensors.

11. **Pedestrian in Signalized Crosswalk Warning:** Pedestrian in signalized crosswalk warning is a V2I safety application, which indicates the possibility of pedestrian presence in the signalized crosswalks. This application provides a warning to the driver when the communication between pedestrian sensors or pedestrian-activated call buttons indicates the presence of a pedestrian in the crosswalk. Such a system is likely to reduce the number of collisions between vehicle and pedestrian/bicyclist (CVRIA 2016). Signalized crosswalk warnings will require more pedestrian sensors and call buttons. Additionally, roadside DSRC units will be required to facilitate the communication between sensors/call buttons and the vehicles.

12. **Gap Assist at Signalized and Unsignalized Intersections:** At unsignalized intersections, drivers may find it difficult to estimate the availability of safe gaps to make turns. This situation arises due to lack of adequate sight distances. Gap assist technology at unsignalized intersections will help drivers entering major roads from stop- or yield-controlled approaches in accurately judging the availability of safe gaps to make turns. The major difference between this technology and SSGA is that here warnings are provided to drivers on both major and minor approaches, whereas in SSGA, only the drivers on minor approaches are warned. Gap assist at unsignalized intersections technology makes use of loop detectors, flashing lights, and real-time computer-controlled systems (NCHRP 2003). The roadside equipment (RSE) component of this technology is the flashing lights; therefore, ATSSA members who manufacture this kind of equipment might find it worthy to explore the market relevant to this technology. At signalized intersections, the objective of gap assist technology is to enhance driver ability in traffic detection and subsequently help the driver to properly judge safe gaps. This technology provides information related to the presence of oncoming vehicles to drivers. The information includes proximity of approaching vehicle and size of available gap. The gap assist system at signalized intersections consists of both onboard and RSE elements. The system collects information regarding the locations and speeds of vehicles approaching the intersection as well as the distance between them. In order to do this, the gap assist system relies on a cohort of sensors, DSRC, and message display units present in vehicles and in RSE (Misner, et al. 2010). A study conducted by FHWA (Richard, et al. 2015) indicated that using message signs at intersections to display unsafe gap warnings will be a more effective way to enhance safety. This arrangement will help drivers to remain attentive about the road environment and be aware of the unsafe gaps at the same time. Because the facilitation of the gap assist system involves setting up relevant roadside infrastructure to house the sensors and warning message display signs, ATSSA members can turn manufacturing such infrastructure into a business opportunity.

Low/No-Impact Technologies

1. **Lane Change Assist (LCA):** This technology monitors the areas to the rear of the vehicle and the blind spots on both sides of the vehicle. If a vehicle is detected in those zones while a driver is about to change lanes, a visual warning in the exterior mirror will be displayed. This technology may require more visible pavement marking to accurately assess the position of the subject vehicle.

2. **Park Distance Control (PDC):** PDC lets drivers enter or leave the tightest parking space more safely. An acoustic warning signal allows the driver to keep track of how close a vehicle is to other objects or vehicles. Ultrasound sensors integrated into the bumper at both the front and rear of vehicle measure the distance to the nearest large object beside the vehicle (BMW 2016). PDC can contribute to narrowing the space of the parking lot and reducing minor property damage crashes at parking lots.

3. **Dynamic Steering Response (DSR):** This Volvo-patented technology, available on large trucks, combines an electric motor that is fitted to the steering gear with hydraulic power steering in order to correct any unintentional steering movements and provide assistive steering torque when necessary using "torque-overlay" (Volvo 2016). The electrical control unit (ECU) processes inputs from sensors to determine the driver's directional intention and provides correction. This technology assists by providing correction to steering at high speeds and extra steering torque at lower speeds, allowing a looser grip on the steering wheel by the driver. As this technology relies on internal sensors from the vehicle, no infrastructure changes are required, and it should not affect the businesses of ATSSA members. However, high friction surface may contribute to the better performance of this technology.

4. **Blind-Spot Warning:** A typical blind-spot warning system uses some kind of electronic detection device(s) mounted on the sides of the car that sends out either electronic electromagnetic waves (usually in the radar wavelengths) or takes computer-processed images with a digital camera and analyzes them. If a driver turns on the signal while a vehicle is in the blind spot, the monitors will send an urgent warning to let the driver know it is not the right time to make a lane change. Warnings can be visual, audible, vibrating, or tactile (Demuro 2014, Inifiniti 2016). It may require high-quality sensors and cameras.

5. **Park Assist:** Park assist is a semiautomatic system based on sensors or cameras that provide assistance when parallel parking by measuring the parking space and turning the steering wheel (Volvo 2016). It then expertly steers the car into the space while the driver controls the brakes and gear selection. Parking space markings will need to be more visible to be detected by the sensors or cameras. This technology could narrow space required for parking lots.

6. **Pre-Collision Pedestrian Braking:** This system can detect imminent front collisions involving pedestrians, provide auditory and visual warnings to drivers, and apply brakes to slow down or stop the vehicle completely. The pre-collision pedestrian braking system uses radar and camera-based sensors to detect the presence of a pedestrian (Gandhi 2007, Ford 2014). Such a system has the potential to reduce the severity and/or frequency of frontal collisions involving pedestrians. This system is solely dependent on the in-vehicle sensors; therefore, it is unlikely to have any impact on ATSSA members' businesses. However, more road visibility through proper street lighting might be desirable for proper functioning of this technology.

7. **Parking Garage Pilot:** The basic function of this technology is to automate parking maneuvers. This technology was originally conceived by Audi, and a working prototype was demonstrated to the public in November 2015 (Crucchiola 2015). The major components required for functioning of this technology include ultrasonic sensors, cameras, a group of lasers, and a central computer (Youngs 2013). The sensors and cameras are mounted in the vehicle, while the lasers and the computer unit are present in the parking facility. Using the sensors and cameras, the vehicle can drive autonomously to the parking facility. The parking facility's computer uses the lasers to map the empty spaces inside the facility and also to record the movements of the vehicles within it. Once the vehicle is inside the facility, it communicates with the facility's computer unit to obtain information on availability of empty parking spaces. Then, it travels to the nearest available parking space and parks itself. At present, this technology is entirely controlled by Audi. Due to this reason, ATSSA members will have no business opportunities with regards to this technology in the next 15 years. However, this scenario will change in the future. Audi announced that it plans to make this technology available in the broader market by 2030 (Youngs 2013). This technology may require innovative parking lot design for better performance.

Summary of AV/CV/CAV Technologies' Impact on ATSSA Member Business

Table 3.1 summarizes all impacts and presents them in an easy-to-understand manner.

Table 3.1 Impact of AV/CV/CAV technologies on ATSSA members' business opportunities

Level of Impact	AV/CV/CAV Technologies	Potential Impact on ATSSA Member Business	Affected ATSSA Members' Business Area
High-Impact Technologies	Lane Departure Warning (LDW)	More visible lane markings; less demand for roadside safety equipment such as guardrails, rumble strips	Pavement Marking; RSE[3]
	Lane-Keeping Assist (LKA)	More visible lane markings; less demand for roadside safety equipment such as guardrails, rumble strips	Pavement Marking; RSE
	Adaptive Cruise Control (ACC) with Lane-Keeping	More visible lane markings; less demand for roadside safety equipment such as guardrails, rumble strips	Pavement Marking
	Adaptive Cruise Control (ACC) Including Stop & Go	Less demand for speed cameras and speed limit signs; may change work zone traffic control strategies	Sign; Work Zone Traffic Control
	Automatic Braking System	Less demand for intersection rumble strip and stop sign	Sign; Work Zone Traffic Control
	Emergency Brake or Autonomous Emergency Braking (AEB)	Temporary traffic control	Work Zone Traffic Control
	Cooperative Adaptive Cruise Control (CACC)	Need for infrastructure lane identification, e.g., RFID chips embedded in the pavement; DSRC; cell tower; less demand for speed cameras and speed limit signs; may change work zone traffic control strategies	RSE; Sign; Work Zone Traffic Control
	Front Collision Warning (FCW)	Temporary traffic control strategies; high friction surface with colored lane demarcation	Work Zone Traffic Control; High Friction Surface; Pavement Marking
	Highway Chauffeur	More visible pavement marking	Pavement Marking
	Highway Auto Pilot (Highway Convoy)	Standardize the traffic sign and pavement marking on highway	Standard Traffic Control on Highway
	Urban and Suburban Pilot	Standardize the traffic sign and pavement marking on urban streets	Standard Traffic Control on Urban Streets
Medium-Impact Technologies	Anti-Lock Brake System (ABS)	Pavement surface friction requirement	High Friction Pavement Surface
	Electronic Stability Control (ESC)	Pavement surface friction requirement	High Friction Pavement Surface
	Stop Sign Gap Assist (SSGA)	LED icon-based sign; smart intersections; DSRC; 5G Cell Tower	Sign; Signal; RSE
	Visual Pedestrian Detection	Less demand on pedestrian crossings	Pavement Marking; Signal
	Red Light Violation Warning (RLVW)	Need for virtual signal; DSRC	Signal; RSE
	Real-Time Kinematic (RTK) GPS	Base station for RTK GPS	RSE
	Advanced Traveler Information System (ATIS)	Need for variable-message signs; DSRC; 5G Cell Tower	Sign; RSE

3 - Roadside Equipment

Level of Impact	AV/CV/CAV Technologies	Potential Impact on ATSSA Member Business	Affected ATSSA Members' Business Area
Medium-Impact Technologies	Collision Detection Braking	Demands of high-quality sensors such as long-range radars	Work Zone Traffic Control; Sensors (radars)
	Automatic Parking	Need for Internet-connected parking meters; better parking markings; RFIDs for localization	Pavement Marking
	Automatic Lane Change	More visible pavement marking	Pavement Marking
	Pedestrian in Signalized Crosswalk Warning	More demand for pedestrian call button and sensors	RSE
	Gap Assist at Signalized and Unsignalized Intersections	Loop detectors; DMS; DSRC	Sign; RSE
Low/No-Impact Technologies	Lane Change Assist (LCA)	More visible pavement marking	Pavement Marking
	Park Distance Control (PDC)	Narrowed space of parking lot	Parking Lot Design
	Dynamic Steering Response (DSR)	Pavement surface friction requirement	High Friction Pavement Surface
	Blind-Spot Warning	Demands of high-quality sensors or cameras	Sensors or Cameras
	Park Assist	Improved parking space markings	Pavement Marking
	Pre-Collision Pedestrian Braking	More road visibility	Street Light
	Parking Garage Pilot	Parking lot	Parking Lot Design

Impacts on ATSSA Member Business Opportunities Based on Interviews with OEMs

Other areas of manufacturing also have been contributing to AV for a long time. Interviews were conducted with Velodyne lidar, nVIDIA, and Civil Maps for comments based on their specific perspectives toward bridging the gap between AVs and highway infrastructure.

Velodyne Lidar

Velodyne lidar provides sensors for several automakers (e.g., Google self-driving cars, Volvo, Ford). It believes that vehicles will eventually use localizing ground-penetrating radar (LGPR) technology where an underground map will be generated to help localizing AVs on the roadway. It suggested that lidar may replace camera-based computer vision altogether. High-reflective characteristics will help lidar see visual cues more easily, although lidar has no trouble identifying the existing infrastructure. This, in turn, creates a lesser need for dynamic message signs (DMS) and traffic signals and is solved easily with Bluetooth or similar wireless technology.

nVIDIA

nVIDIA offers graphics processing units (GPUs), which are revolutionary processors that advance artificial intelligence (AI) and autonomous vehicles. nVIDIA indicated that AI is the best way to enable autonomy and to handle situations with superhuman ability. The company improved force power of GPU to augment the deep machine learning ability of the software, which would have an impact on the behavior of the intelligence vehicles. For the effects of CAV on future traffic infrastructure, it suggested that there will be more traffic cameras used for real time in addition to analyzing and making predictions. nVIDIA is developing its systems independently. nVIDIA further noted that it is impossible to prove the AV/CV to be 100% reliable, and there is debate as to when these vehicles will be in use. At that time, there may be special lanes or areas for AVs only.

Civil Maps

Civil Maps is creating a new generation of maps that enable HAVs to traverse any road safely and comfortably without any human intervention. For impacts of CAV on future transportation infrastructure, Civil Maps stated that changing the infrastructure is not helpful. One of Civil Maps' goals is to enable an alternative future where local governments or road maintenance agencies do not have to change much, but proper maintenance will be required. Civil Maps also predicted that HD maps might be available at areas where only HAVs are allowed.

OEMs from different areas agreed that if more AVs appear, there will be less need for traffic signals and signs, but standardization of roadway features will be of utmost importance after AV/CV/CAV become ubiquitous. ■

Chapter 4: Recommendations

The transportation system is on the verge of a major revolution. In 2015, a total of 35,092 people died on the U.S. roadways, and 94% of the crashes were potentially tied to a human choice or error (NHTSA 2016). Automated vehicles have the potential to save thousands of lives each year and to provide alternative transportation for many senior citizens and Americans with disabilities. To accommodate new AV/CV/CAV technologies, significant changes in roadway infrastructure (e.g., highway design, pavement markings, signs, and other traffic control devices) may be required to support proper operation and achieve maximum benefits. Given that the HAVs are still a new concept to most drivers, little is known about the required infrastructure changes. The main focus of this document was to conduct a thorough market analysis of CAV technologies and portray the potential changes in roadway infrastructure that might affect the business opportunities of ATSSA members.

In recent years, the federal government and more than 14 state DOTs have invested in developing AV/CV/CAV-related projects. For instance, the federal government pledged to invest $4 billion in self-driving cars at the beginning of 2016. Additionally, Faraday Future, an electric car company, plans to invest $1 billion in Nevada to transform the state into a major manufacturing hub for the next generation of electric and autonomous cars (Zolfagharifard 2016). Various auto manufacturers and OEMs are rapidly improving AV technologies. Tesla and Google are expected to release fully autonomous car technology in 2018; thus AV/CV/CAV will soon have a broad market prospect. Additionally, interview results indicated that many state DOTs have plans for CV deployment; however, they did not receive funding from the Wave-I of the federal CV pilot deployment program. They are currently working to find funding to support these plans. DOTs are mainly focusing on infrastructure adaptations for AV/CV/CAV, including applications for transit/freight/snow plow signal priority, test beds with groupings of intersections equipped with DSRC for testing vehicles, queue warning to vehicles in work zones, alerts of changing work zone conditions, and the gathering of weather data. These adaptions primarily involve updating striping/signage for clear reading by AV, highly accurate signalized intersections that include accurate signal phase and timing, a highly accurate map, and the installation of roadside DSRC units.

Meanwhile, automakers and OEMs are working toward developing AV technologies that can operate safely even in the poorest road conditions. Their goal is to design AV technologies that will require very little to no infrastructure changes.

The impact of CAV technologies was analyzed based on an extensive literature review, understanding of the technologies, interviews with experts (e.g., state DOT officials, ATSSA members, OEM managers, and researchers), investigation of current policy/guidelines, and analysis of the published/online sources. Based on these findings, the following is a list of key potential impacts of CAV technologies on ATSSA members' business opportunities.

1. **Pavement Markings:** Deployment of CAV technologies will probably have the highest impact on pavement markings. Current practices for pavement markings may significantly change for proper operation of CAV technologies as many of these technologies (e.g., ***lane change assist, lane departure warning, visual pedestrian detection, parking assist, lane-keeping assist, automatic parking, automatic lane change, adaptive cruise control with lane-keeping, highway chauffeur, highway auto pilot, urban and suburban pilot***) detect pavement markings using machine vision to perform their function. However, it is unclear which qualities of pavement markings (e.g., width, luminosity, retroreflectivity) will need to be adapted so that machine vision is capable of detecting the markings with perfection. Researchers are working on determining connections between pavement marking and machine vision performance. Particularly, a NCHRP research task titled "Road Markings for Machine Vision" may provide useful information. The Texas Transportation Institute (TTI) is conducting this research task, with an expected completion date of May 2017. The anticipated outcome is to develop correlation between machine vision performance and pavement marking. Factors to be considered in this study are pavement marking presence, contrast, retroreflectivity, pavement uniformity, day and night condition, and vehicle speed. ATSSA members are recommended to monitor the outcome of this research task to determine specific guidance about pavement markings for CAV technologies.

2. **DSRC:** Deployment of DSRC is another major change in roadway infrastructure that will likely occur. Many CAV technologies (e.g., ***stop sign gap assist, red light violation warning, advanced traveler information system, cooperative adaptive cruise control***) may need a roadside DSRC unit for required communications. Additionally, the U.S. DOT estimated that DSRC will be deployed on more than 80% of traffic signals by 2040 for facilitating V2I communications (U.S. DOT 2014). AASHTO's "National Connected Vehicle

Field Infrastructure Footprint Analyses" reported that the deployment of DSRC can be completed in a similar fashion to the deployment of the 511 system with the introduction of ITS.

3. **Temporary Traffic Control Devices:** New CAV technologies (e.g., ***front collision warning, adaptive cruise control including stop and go, emergency brake***) can be integrated into the advanced temporary traffic control strategies in work zones. For instance, several interviewed state DOTs are focusing on application of CV in work zones by sending signals for end-of-queue warning to vehicles, and alerting to changing work zone conditions.

4. **Standardization of Traffic Control Devices:** Road infrastructure, including signs, traffic signals, and pavement markings, may need to be standardized nationwide to support the safe operation of CAV and also to ensure the safety of human drivers who will operate the vehicles. The Manual of Uniform Traffic Control Devices (MUTCD) ensures a certain level of uniformity for traffic control devices mostly for human drivers. Some OEMs stated that standardization of roadway features will be of utmost importance after CAVs become ubiquitous although most AVs are designed for the existing infrastructure conditions.

5. **Dedicated Lanes for HAVs:** There may be demands for special lanes, such as HAV lanes or areas with AV/CV/CAV only. For example, recently some high-tech entrepreneurs proposed to build a driverless highway from Vancouver to Seattle, and an HOV lane would be dedicated exclusively to AVs when they became more popular (CBC News 2016).

6. **Signal Controller Upgrades:** As the U.S. DOT estimated widespread deployment of DSRC at traffic signals, the signal controller at these intersections may need to be upgraded as well to facilitate required V2I communications. For instance, advanced signal controllers, capable of transmitting SPaT data (e.g., signal phase and the amount of time remaining until the change of the phase for each direction), are expected to enable future integration of CAV system (CAR and Parsons Brinckerhoff 2012). Therefore, the demand for such advanced signal controllers may increase as CAV emerges. Researchers from Carnegie Mellon University in collaboration with the Pennsylvania DOT have installed DSRC at 11 traffic signals in Cranberry Township and 24 traffic signals in Pittsburgh. The final report of this project is expected to provide more guidance on what changes may be required in the traffic signal system to be interoperable with DSRC (Kopko 2015, Chris Hendrickson 2014).

7. **New Signs:** The CAV technologies such as stop sign gap assist may increase the need for some novel signs. New business opportunities for this application may include new roadway sensors, digital signage, and communication system between them. This application could incorporate technologies already produced from ATSSA members who manufacture and sell digital message signs and other digital signage. At the same time, technologies such as ACC including stop and go is likely to reduce the demand for speed limit signs and speed cameras.

8. **New Roadside Equipment (RSE):** New RSE may need to be introduced for RFID-based lane identification technology.

9. **Pavement Maintenance:** There may be an increased demand for pavement maintenance on specific areas of tracks. Automated vehicles moving along the same exact route may cause compression dips in the pavement. At present, car positions are more random; however, if vehicle position is in the exact same spot due to deployment CAV technologies, it could result in more wear in specific areas of the pavement.

10. **Innovative Parking Lot Design:** Due to the deployment of technologies such as park distance control and parking garage pilot, innovative parking lot design may need to be adopted, as conventional parking lots are not equipped with all the required features.

11. **High Friction Pavement Surface:** New AV technologies (e.g., ***anti-lock brake system, electronic stability control, dynamic steering response***) are likely to require a less high-friction pavement surface for achieving their full performance because the vehicle technology can monitor pavement friction and make adjustments in braking to account for varying friction.

What is interesting to think about now is what you can do to design your products to make them more accommodating for upcoming HAVs. It is also important to note that the human element can never be eliminated from the driving task. In the case of malfunctioning HAVs, human drivers are needed to take control of the vehicle. Similarly, the concept of recreational driving, i.e., driving for pleasure, will continue to exist. In such cases, humans will want to drive vehicles despite the availability of HAVs. The recent federal automated vehicle policy states that, for scenarios like these, the human-machine interface (HMI) aspect of HAVs should be given due attention (NHTSA 2016). The same holds true for roadside infrastructure as well. This implies that all the signs, signals, and pavement markings are designed not only for HAVs but also for comprehension of human drivers. The standardization of road infrastructure has a good chance of materializing in the near future. These chances are bolstered after the issuance of the U.S. DOT's guidance on HAVs. The guidance document encourages state DOTs to collaborate in standardizing and maintaining road infrastructure, including signs, signals, lights, and pavement markings (NHTSA 2016).

It should be noted that there are certain limitations of these results on the impact to ATSSA members' businesses. The outcome of related ongoing/proposed NCHRP projects (refer to Table 2.3) will likely provide more specific guidance/requirement of roadway infrastructure changes for AV/CV/CAV technologies. ATSSA members will need to monitor these projects on a regular basis to stay up to date. Additionally, ATSSA members are recommended to follow-up with the other U.S. DOT AV research activities. U.S. DOT maintains a website to keep record of recent AV research activities (http://ops.fhwa.dot.gov/regulationpolicy/avpolicyactivities/index.htm). ■

Bibliography

Autodealio. 2014. *Honda City Brake Assist System*. http://autodealio.com/honda-city-brake-assist-system/.

Automotive-fleet. 2015. *NYC Receives $20M for Connected-Vehicle Project.* http://www.automotive-fleet.com/news/story/2015/09/nyc-receives-20m-for-connected-vehicle-project.aspx.

BMW. 2016. *Park Distance Control.* http://www.bmw.com/com/en/insights/technology/technology_guide/articles/park_distance_control.html.

Bomey, Nathan. 2016. *Self-driving car leaders ask for national laws.* March 15. Accessed Oct. 27, 2016. http://www.usatoday.com/story/money/cars/2016/03/15/google-alphabet-general-motors-lyft-senate-commerce-self-driving-cars/81818812/.

Brewster, S. 2016. "Uber starts self-driving car pickups in Pittsburgh." *Techcrunch.* 09 14. Accessed 10 6, 2016. https://techcrunch.com/2016/09/14/1386711/.

Burton, David, A. Delaney, S. Newstead, D. Logan, and B. Fildes. 2004. "Evaluation of anti-lock braking systems effectiveness." Research Report.

CaliforniaDOT. 2015. "One California Project." *California Department of Transportation*. http://www.dot.ca.gov/research/operations/one_california/docs/DR1_OneCalifornia_Vol_I_Part_I.pdf.

CAR and Parsons Brinckerhoff. 2012. *Connected Vehicle Infostructure Plan*. Michigan Department of Transportation.

CBC News. 2016. "Driverless highway from Vancouver to Seattle proposed."

"Driverless Highway from Vancouver to Seattle Proposed." Sept. 20. Accessed Oct. 06, 2016. Driverless highway from Vancouver to Seattle proposed.

CBCNews. 2016. "Driverless highway from Vancouver to Seattle proposed."

"Center for Advanced Automotive Technology." 2016. http://autocaat.org/Technologies/Automated_and_Connected_Vehicles/.

Chris Hendrickson, Allen Biehler, Yeganeh Mashayekh. 2014. *Connected and Autonomous Vehicles 2040 Vision*. PennDOT.

Colorado DOT. 2016. "Colorado's Vision 2016." *Colorado Department of Transportation website*. https://www.codot.gov/programs/roads/roadx-vision.

Crucchiola, Jordan. 2015. *Audi Will Unleash Self-Parking Cars in a Bid to Fix Urban Gridlock*. Nov. 27. https://www.wired.com/2015/11/audi-will-unleash-self-parking-cars-in-a-bid-to-fix-urban-gridlock/.

CVRIA, Connected Vehicle Reference Implemention Architecture. 2016. *Pedestrian in Signalized Crosswalk Warning*. May 5. https://www.iteris.com/cvria/html/applications/app51.html#tab-5.

Dang, Jennifer N. 2004. "Preliminary results analyzing the effectiveness of electronic stability control (ESC) systems." *U.S. Department of Transportation, National Highway Traffic Safety Administration* No. HS-809 790.

Davidson, Lee. 2015. *Cars talking to cars? UDOT about to launch tests to help development*. May 03. Accessed 2016. http://www.sltrib.com/news/2413155-155/cars-talking-to-cars-udot-about?fullpage=1.

Demuro. 2014. *Are Blind Spot Monitors Worth the Extra Money?* http://www.autotrader.com/car-news/are-blind-spot-monitors-worth-the-extra-money-225249.

Driverless Car Market Watch. 2016. *Autonomous Car Forecasts*. http://www.driverless-future.com/?page_id=384.

Duncan, M., N. Charness, T. Chapin, M. Horner, L. Stevens, A. Richard, D. Souders, J. Crute, A. Riemondy, and D. Morgan. 2015. "Enhanced Mobility for Aging Populations Using Automated Vehicles." Florida Department of Transportation, Tallahassee, FL 32399.

Dwoskin, E., and B. Fung. 2016. “For Some Safety Experts, Uber’s Self-driving Taxi Test isn’t Something to Hail.” *The Washington Post.* 09 11. Accessed 10 6, 2016. https://www.washingtonpost.com/business/economy/for-some-safety-experts-ubers-self-driving-taxi-test-isnt-something-to-hail/2016/09/11/375f980a-769a-11e6-be4f-3f42f2e5a49e_story.html.

FDOT. 2014. “2014 Florida Automated vehicles.” *Florida DOT Website*. http://www.dot.state.fl.us/planning/statistics/fav/Hutchinson-FAVInitiative.pdf.

FDOT. 2014. *Florida’s Intelligent Transportation Systems Strategic Plan: Version*. Intelligent Transportation Systems Program, Florida Department of Transportation.

FHWA. 2016. “Cooperative Adaptive Cruise Control: Taking Cruise Control to the Next Level.” Exploratory Advanced Research Program, McLean, VA 22101-2296 United States.

“Vehicle-to-Infrastructure (V2I) Safety Applications, Performance Requirements, Vol. 7, Stop Sign Gap Assist (SSGA).” August. http://ntl.bts.gov/lib/58000/58000/58014/FHWA-JPO-16-254.pdf.

Flannagan, C., D. LeBlanc, S. Bogard, K. Nobukawa, P. Narayanaswamy, A. Leslie, R. Kiefer, R. Marchione, C. Beck, and K. Lobes. 2016. “Large-Scale Field Test of Forward Collision Alert and Lane Departure Warning Systems.” National Highway Traffic Safety Administration, Washington, DC 20590.

FDOT. 2016. “Automated Vehicles Technology - Our Future.” August. https://www.pinellascounty.org/mpo/agendas/MPO_Meeting/2016/Automated%20Vehicles%20Presentation%20by%20FDOT.pdf.

Ford. 2014. https://media.ford.com/content/fordmedia/fna/us/en/news/2014/10/23/new-ford-pre-collision-assist-with-pedestrian-detection.html.

“Collision warning with brake support.’ 2016. https://owner.ford.com/how-tos/vehicle-features/brakes/collision-warning-with-brake-support.html.

Frankel, Todd C. 2016. *What it feels like to drive a Tesla on autopilot.* Feb. 1. https://www.washingtonpost.com/news/the-switch/wp/2016/02/01/what-it-feels-like-to-drive-a-tesla-on-autopilot/#comments.

Gandhi, Tarak, and Mohan Manubhai Trivedi. 2007. “Pedestrian protection systems: Issues, survey, and challenges.” *IEEE Transactions on Intelligent Transportation Systems 8* 3: 413-430.

Gustafson, D.H. 2016. “Connected and Automated Vehicle Program Plan.” *Virgina DOT*. Feb. 10. http://www.virginiadot.org/projects/resources/2016PlanningProgramming/6_VDOT’s_Connected_Vehicle_Program_Plan.pdf.

Hendrickson, C., A. Biehler, and Y. Mashayekh. 2014. *Connected and Autonomous Vehicles 2040 Vision*. Pittsburgh: Pennsylvania Department of Transportation.

Honda. 2016. *Collision Mitigation Braking System.* http://owners.honda.com/vehicles/information/2016/Civic-Sedan/features/Collision-Mitigation-Braking-System.

IEEE. 2012. https://www.ieee.org/about/news/2012/5september_2_2012.html.

IIHS. 2011. *Electronic stability control could prevent nearly one-third of all fatal crashes and reduce rollover risk by as much as 80%; effect is found on single- and multiple-vehicle crashes.* http://www.iihs.org/iihs/news/desktopnews/electronic-stability-control-could-prevent-nearly-one-third-of-all-fatal-crashes-and-reduce-rollover-risk-by-as-much-as-80-effect-is-found-on-single-and-multiple-vehicle-crashes.

Inifiniti. 2016. *Blind Spot Warning.* http://www.infinitiusa.com/now/technology/blind-spot-warning.html.

Ishida, S., J.E. Gayko 2004. “Evaluation and introduction of a lane keeping assistance system.” *Intelligent Vehicles Symposium IEEE* 943-944.

Ishida, S., and E. Gayko. 2004. “Development, Evaluation and Introduction of a Lane Keeping Assistance System.” *IEEE Intelligent Vehicles Symposium.* Parma, Italy. 943-944.

Iteris. 2016. *Red Light Violation Warning.* May 5. https://www.iteris.com/cvria/html/applications/app57.html#tab-5.

Stop Sign Gap Assist. https://www.iteris.com/cvria/html/applications/app70.html#tab-5.2016.

Johnson, C., B. Scott, S. Shogan. 2016. “ Minnesota Connected Vehicle Pilot Deployment Project.” *Minnesota State DOT website.* http://www.dot.state.mn.us/its/connectedvehicle/connectedvehicleproposal.pdf.

Jones, S. 2013. “Cooperative Adaptive Cruise Control: Human Factors Analysis.” Office of Safety Research and Development, Federal Highway Administration, McLean, VA 22101-2296.

Kopko, M. 2015. *Connected and Automated Vehicles.* ITS Pennsylvania.

Kurami, Lizuka 1994. *Automatic braking system with proximity detection to a preceding vehicle*. https://www.google.com/patents/US5278764.

Kusano, K.D., and H.C. Gabler. 2012. “Safety Benefits of Forward Collision Warning, Brake Assist, and Autonomous Braking Systems in Rear-End Collisions.” *IEEE Transactions on Intelligent Transportation Systems* 13 (4): 1546-1555.

Lavrinc. 2014. *Tesla Model S Auto Pilot Does Lane Changes For You*. http://jalopnik.com/tesla-model-s-auto-pilot-does-lane-changes-for-you-1644644652.

Lee, J.W. 2002. “A Machine Vision System for Lane-Departure Detection.” *Computer Vision and Image Understanding* 86: 52-78.

Liebemann, E.K., K. Meder, J. Schuh, and G. Nenninger. 2004. “Safety and performance enhancement: The Bosch electronic stability control (ESP).” *SAE Paper 20004* 21-0060.

Litman, T. 2015. “Autonomous Vehicle Implementation Predictions: Implications for Transport Planning.” *Transportation Research Board 94th Annual Meeting*. Washington, DC, U.S. 15p.

Maricopa County DOT. 2012. “SMART Drive Program.” http://www.aztech.org/TravInfo/Connected%20Vehicle%20Application/MCDOT_SMARTDrive_Handout_April2012.pdf.

Mass DOT. 2013. “Intelligent Transportation Systems Strategic Plan.” https://www.massdot.state.ma.us/Portals/17/docs/ITS/StrategicPlanRev_07-30-14.pdf.

Misner, J., Ching-Yao Chan, S. Dickey, T. Kuhn, T. Lian, D. Nelson, Ashkan, Shaldover, S. Sharafsaleh, and J. Spring. 2010. *Cooperative Intersection Collision Avoidance System (CICAS): Signalized Left Turn Assist and Traffic Signal Adaptation.* Richmond, CA: University of California, Berkeley.

Mobileye. 2016. *Pedestrian Detection.* http://www.mobileye.com/technology/applications/pedestrian-detection/.

Muller, P. 2016. *Automated Transit: Future Impacts on the Built Environment.* May. http://onlinepubs.trb.org/Onlinepubs/webinars/160527.pdf.

Naranjo, J.E., C. Gonzalez, R. Garcia, and T. De Pedro. 2006. “ACC+Stop&Go Maneuvers With Throttle and Brake Fuzzy Control.” *IEEE Transactions on Intelligent Transportation Systems 7* (2): 213-225.

NCHRP. 2003. *Guidance for Implementation of the AASHTO Strategic Highway Safety Plan.* Technical report, Washington, D.C.: Transportation Research Board.

Nebraska DOT. 2016. “The Smart City Challenge.” *City of Lincoln Website.* Feb. 1. https://lincoln.ne.gov/city/pworks/docs/pdf/smart-city-challenge.pdf.

New Mexico DOT. 2015. “The New Mexico 2040 Plan: NMDOT’s Long Range, Multi-Modal Transportation Plan.”

NHTSA. 2016. “2015 Motor Vehicle Crashes: Overview.” Research Note, U.S. Department of Transportation, National Highway Traffic Safety Administration (NHTSA). https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812318.

Antilock Brake Systems (ABS). 1999. http://www.nhtsa.gov/cars/problems/Equipment/absbrakes/page1-doom-04-26-2013.html.

NHTSA. 2016. “Federal Automated Vehicles Policy: Accelerating the Next Revolution In Roadway Safety.” Federal Highway Administration, Washington, D.C.

NHTSA. 2016. *Federal Automated Vehicles Policy: Accelerating the Next Revolution In Roadway Safety.* Washington, D.C.: FHWA.

Nissan. 2015. “Official Media Newsroom.” *Nissan News.* October 29. Accessed Sept. 21, 2016. http://nissannews.com/en-US/nissan/usa/releases/nissan-conducts-first-on-road-test-of-prototype-vehicle-featuring-piloted-drive-on-highway-and-city-urban-roads.

ODOT. 2015. “Connected and Automated Vehicles Strategic Framework.” *Oregon DOT*. https://www.oregon.gov/ODOT/Documents/Final_CAV_Report_9_29.pdf.

Parikh, J., O. Abuchaar, E. Haidar, A. Kailas, H. Krishnan, H. Nakajima, M. Maile, et al. 2015. “Cooperative Adaptive Cruise Control (CACC): Final Report.” Crash Avoidance Metrics Partners LLC on behalf of the Vehicle-to-Infrastructure Consortium, Intelligent Transportation Systems Joint Program Office: U.S. Department of Transportation, Washington, DC 20590.

Paromtchik, Igor, and Christian Laugier. 1996. “Motion Generation and Control for Parking an Autonomous Vehicle.” *Proceedings of the IEEE International Conference on Robotics and Automation* 3117–3122.

Raphael, E., R. Kiefer, P. Reisman, and G. Hayon. 2011. “Development of a Camera-Based Forward Collision Alert System.” *SAE International*.

Rashid M.M., A. Musa, M.A. Rahman, et al. 2012. “Automatic parking management system and parking fee collection based on number plate recognition.” *International Journal of Machine Learning and Computing 2*(2): 94.

Richard, C.M., J.F. Morgan, L.B. Paige, J.S. Graving, G. Divekar, and M.G. Lichty. 2015. *Multiple Sources of Safety Information from V2V and V2I: Redundancy, decision making and Trust - Safety Message Design Report.* Interim Report, McLean, VA: FHWA.

SAE. 2014. *Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems.* http://www.sae.org/misc/pdfs/automated_driving.pdf.

Sawyer, J. 2016. “Connected Vehicles Safety Pilot.” *UMTRI Website.* http://www.ssti.us/wp/wp-content/uploads/2012/05/Jim_Sayer_SPMD_overview_042412.pdf.

Seymour, E., B. Kuhn, K. Balke, N. Chaudhary, D. Jasek, R. Rajbhandari, T. Voigt, K. Miller, T. Geiselbrecht, and S. Venglar. 2014. *TXDOT ITS STRATEGIC PLAN 2013*. Technician Report, Austin: Texas Department of Transportation.

Shladover, S.E., C. Nowakowski, Xiao-Yun Lu, and R. Hoogendoorn. 2014. “Using Cooperative Adaptive Cruise Control (CACC) to Form High-Performance Vehicle Streams.” California PATH Program: Institute of Transportation Studies, University of California, Berkley.

Stanton, N.A., A. Dunoyer, and A. Leatherland. 2011. “Detection of New In-path Targets by Drivers Using Stop & Go Adaptive Cruise Control.” *Applied Ergonomics* 562-601.

Stephenson, S., X. Meng, T. Moore, A. Baxendale, and T. Edwards. 2011. “Precision of Network Real Time Kinematic Positioning for Intelligent Transport Systems.” *European Navigation Conference*.

Tennessee DOT. 2016. *Integrated ITS SmartWay Systems.* https://www.tn.gov/tdot/topic/its-integrated-smartway-systems.

Tesla. 2016. *Model S Software Version 7.0*. https://www.tesla.com/presskit/autopilot.

Tesla Motors. *Your Autopilot has arrived*. Oct. 14, 2015. https://www.tesla.com/blog/your-autopilot-has-arrived.

The City of Lincoln, Nebraska. 2016. *Beyond Traffic: The Smart City Challenge*. Lincoln: U.S. DOT, FHWA. https://lincoln.ne.gov/city/pworks/docs/pdf/smart-city-challenge.pdf.

U.S. DOT. 2016. *CV Pilot Deployment Program.* http://www.its.dot.gov/pilots/wave1.htm.

U.S. DOT. 2014. *National Connected Vehicle Field Infrastructure Footprint Analysis*. American Association of State Highway and Transportation Officials (AASHTO).

“Office of Operations.” June. Accessed Sept. 28, 2016. http://ops.fhwa.dot.gov/regulationpolicy/avpolicyactivities/index.htm.

“U.S. Department of Transportation Announces up to $42 Million in Next Generation Connected Vehicle Technologies.” 2015. http://www.its.dot.gov/press/2015/ngv_tech_announcement.htm.

"U.S. Department of Transportation Releases Policy on Automated Vehicle Development." May 20, 2015. http://www.nhtsa.gov/About+NHTSA/Press+Releases/U.S.+Department+of+Transportation+Releases+Policy+on+Automated+Vehicle+Development.

"U.S. DOT Automation Program." *Office of the Assistant Secretary for Research and Technology, U.S. Department of Transportation.* July 23, 2015. Accessed Oct. 26, 2016. http://www.its.dot.gov/presentations/AVS2015/AVS15_Dopart.pdf.

Volkswagen. 2011. *Volkswagen City Emergency Brake, Euro NCAP Advanced.* http://www.euroncap.com/en/ratings-rewards/euro-ncap-advanced-rewards/2011-volkswagen-city-emergency-brake/.

Volvo. 2016. *Dynamic Steering Response.* http://www.volvotrucks.co.uk/en-gb/trucks/volvo-fm/features/volvo-dynamic-steering.html#sthash.kiPipPmP.dpuf.

Park Assist Pilot (PAP), 2016. http://support.volvocars.com/en-CA/cars/Pages/owners-manual.aspx?mc=V423&my=2016&sw=15w46&article=b290155706304e6ac0a801e800eac367.

Wanninger, L. 2004. "Introduction to network RTK." *International Association to Geodesy meeting* vol. 4, no. 1.

WSDOT. 2009. *Plan, WSDOT Statewide ITS*. WSDOT.

Youngs, Jeff. 2013. *Audi's Piloted Parking Technology Wins Acclaim*. Feb. 04. http://www.jdpower.com/cars/articles/car-news/audis-piloted-parking-technology-wins-acclaim.

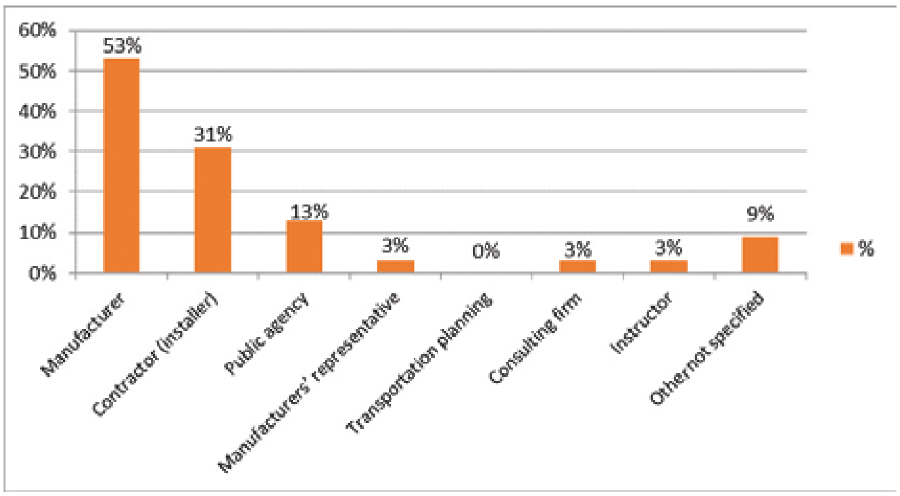
Yu, B., W. Zhang, and Y. Cai. 2008. "A Lane Departure Warning System based on Machine Vision." *IEEE Pacific-Asia Workshop on Computational Intelligence and Industrial Application* 197-201.

Zolfagharifard, E. 2016. *Faraday Future reveals the Nevada megafactory it hopes will topple Tesla: $1billion facility will build mystery electric car in 2018*. April 14. http://www.dailymail.co.uk/sciencetech/article-3540360/Faraday-Future-reveals-Nevada-megafactory-hopes-topple-Tesla-1billion-facility-build-mystery-electric-car-2018.html. ■

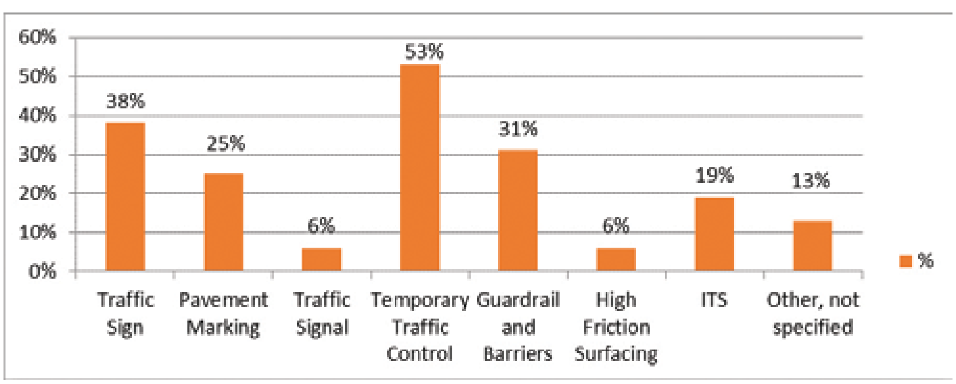
Appendix A: Online Survey Questionnaire and Results for ATSSA Members

General Questions

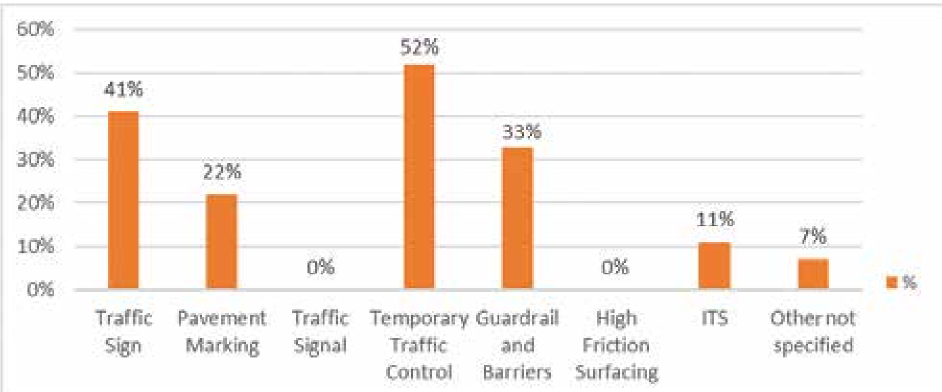
1. Please specify your ATSSA membership category/categories:
   - ◻ Manufacturer
   - ◻ Contractor (installer)
   - ◻ Public agency
   - ◻ Manufacturers' representative
   - ◻ Transportation planning
   - ◻ Consulting firm
   - ◻ Instructor



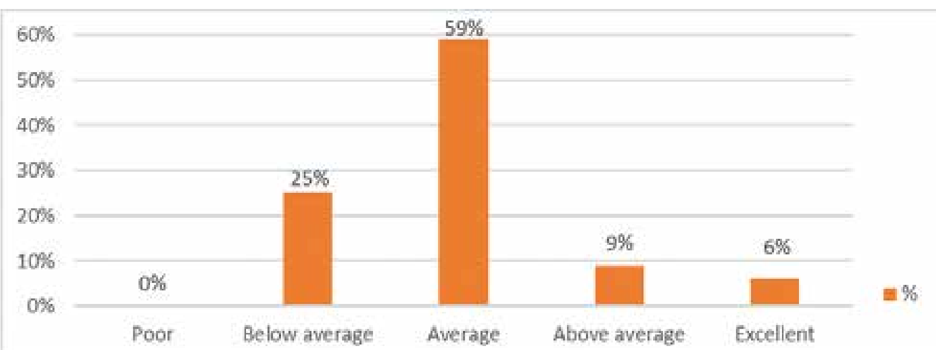
2. In which area(s) does your agency do business?
   - ◻ Traffic sign
   - ◻ Pavement marking
   - ◻ Traffic signal
   - ◻ Temporary traffic control
   - ◻ Guardrail and barriers
   - ◻ High friction surfacing
   - ◻ ITS
   - ◻ Other, please specify: _________________



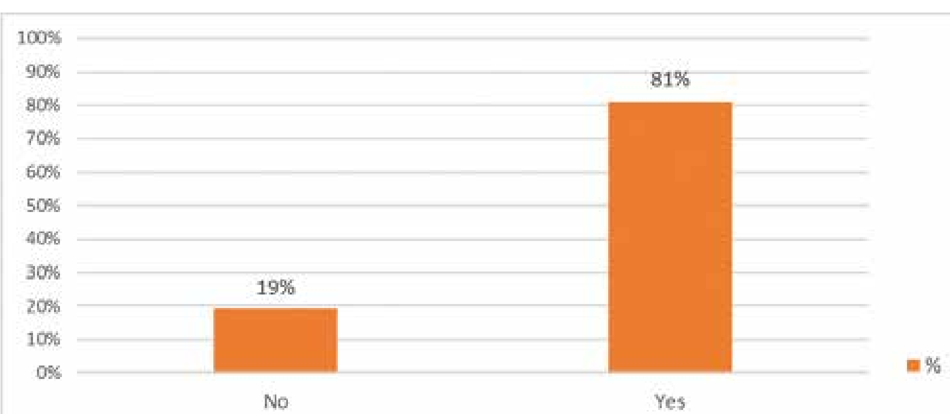
3. What are your areas of focus within your company/agency?
   - □ Traffic sign
   - □ Pavement marking
   - □ Traffic signal
   - □ Temporary traffic control
   - □ Guardrail and barriers
   - □ High friction surfacing
   - □ ITS
   - □ Other, please specify: ________________



4. Please rank your knowledge of AV/CV technologies.
   - O Poor
   - O Below averge
   - O Average
   - O Above average
   - O Excellent



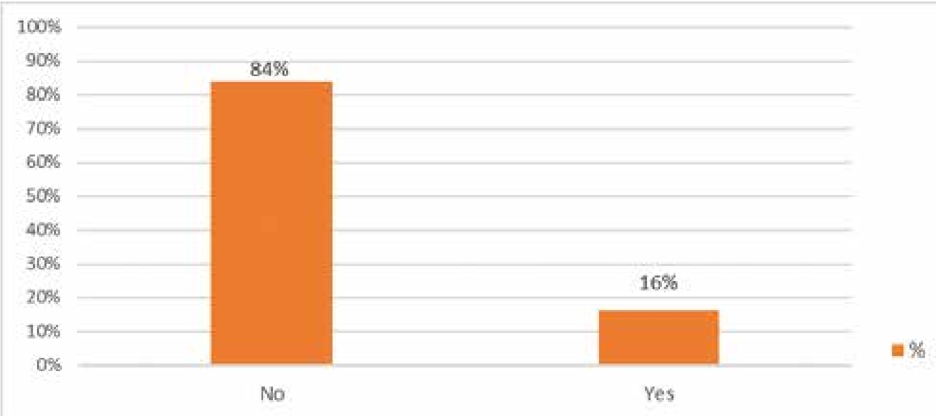
5. Is your company or agency interested in doing work with AV/CV technologies?
   - O No
   - O Yes



6. Have you ever worked with any state or federal agencies on new AV/CV-related products?

O No

O Yes, please explain briefly: ____________________

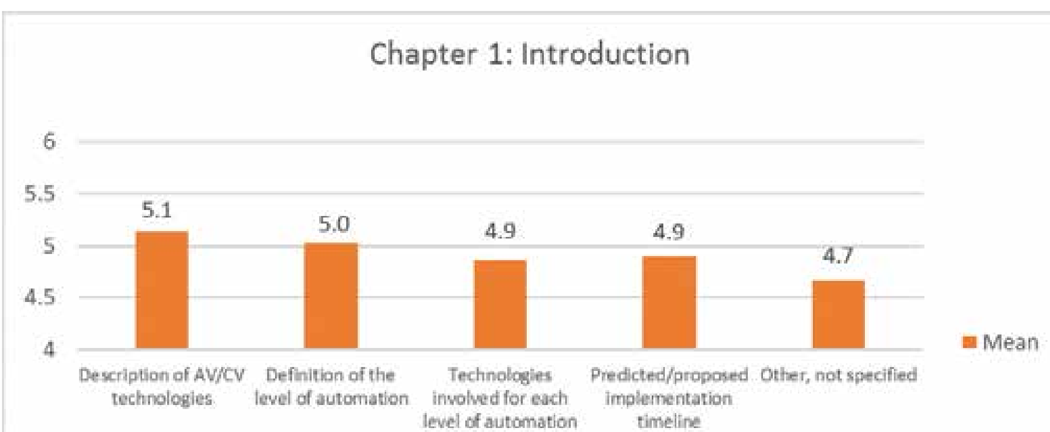


Specific Questions About the Contents of the Document

For the following questions under this section, please specify your interest in the topics to be covered in the final document by ranking on a scale of 0 (Not at all Important) to 5 (Very Important).

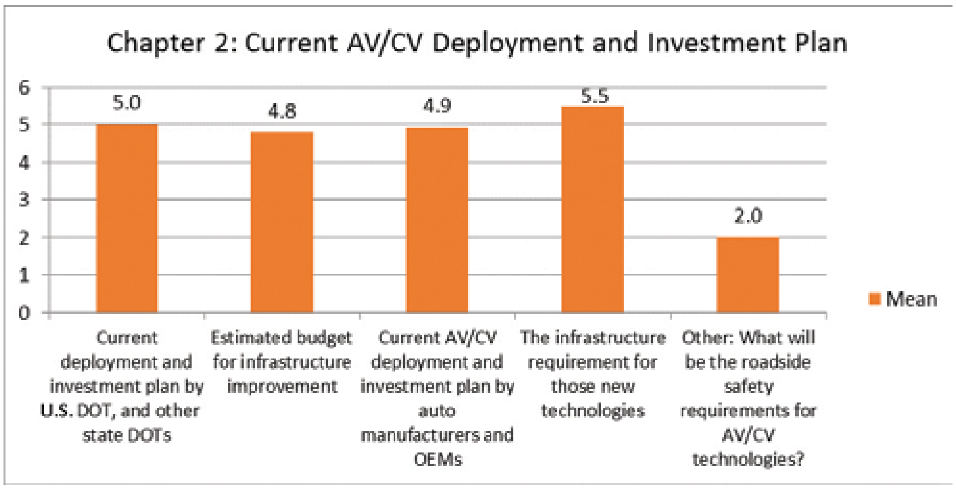
7. Proposed contents to be covered in Chapter 1: Introduction

Proposed Topic	Level of Importance					
	0	1	2	3	4	5
Description of AV/CV technologies	O	O	O	O	O	O
Definition of the level of automation	O	O	O	O	O	O
Technologies involved for each level of automation	O	O	O	O	O	O
Predicted/proposed implementation timeline	O	O	O	O	O	O
Other 1: ______________________	O	O	O	O	O	O
Other 2: ______________________	O	O	O	O	O	O
Other 3: ______________________	O	O	O	O	O	O



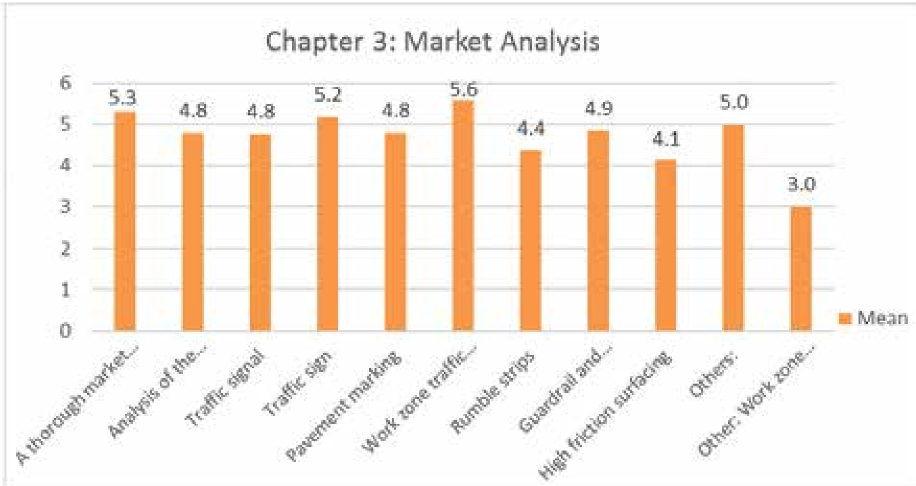
8. Proposed contents to be covered in Chapter 2: Current AV/CV Deployment and Investment Plan

Proposed Topic	**Level of Importance**					
	0	**1**	**2**	**3**	**4**	**5**
Current deployment and investment plan by U.S. DOT and other state DOTs	O	O	O	O	O	O
Estimated budget for infrastructure improvement	O	O	O	O	O	O
Current AV/CV deployment and investment plan by auto manufacturers and OEMs	O	O	O	O	O	O
The infrastructure requirement for those new technologies	O	O	O	O	O	O
Other 1: ______________________	O	O	O	O	O	O
Other 2: ______________________	O	O	O	O	O	O
Other 3: ______________________	O	O	O	O	O	O



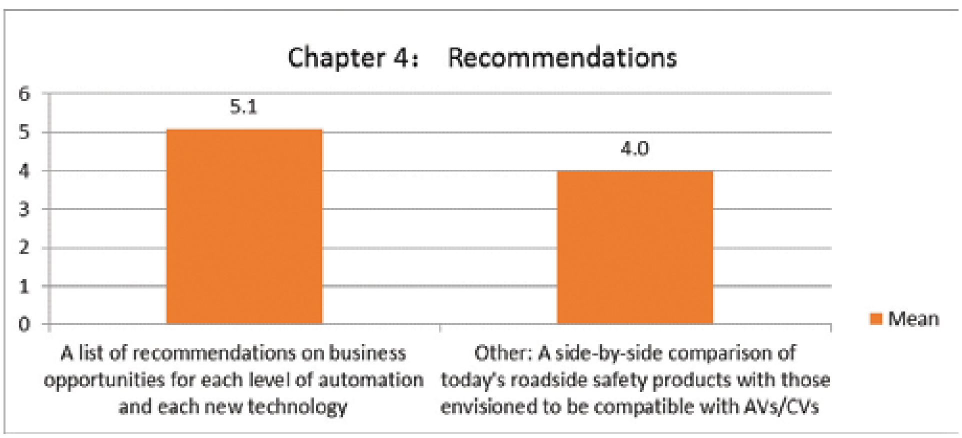
9. Proposed contents to be covered in Chapter 3: Market Analysis of New AV/CV Technology's Impact on ATSSA Business Opportunity

Proposed Topic	**Level of Importance**					
	0	**1**	**2**	**3**	**4**	**5**
A thorough market analysis of new AV/CV technologies' impact on ATSSA member business opportunity based on three survey results (ATSSA members, DOTs, and OEMs)	O	O	O	O	O	O
Analysis of the impact of AV/CV technologies on each of the following categories:						
Traffic signal	O	O	O	O	O	O
Traffic sign	O	O	O	O	O	O
Pavement marking	O	O	O	O	O	O
Work zone traffic control devices	O	O	O	O	O	O
Rumble strips	O	O	O	O	O	O
Guardrail and barriers	O	O	O	O	O	O
High friction surfacing	O	O	O	O	O	O
Other 1: ______________________	O	O	O	O	O	O
Other 2: ______________________	O	O	O	O	O	O
Other 3: ______________________	O	O	O	O	O	O



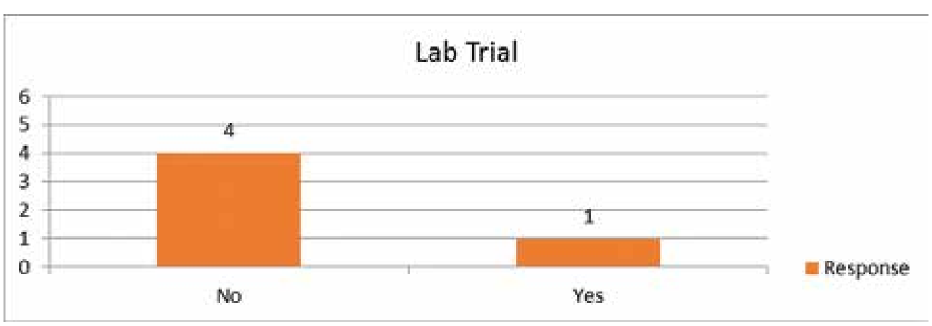
10. Proposed contents to be covered in Chapter 4: Recommendations

Proposed Topic	Level of Importance					
	0	1	2	3	4	5
A list of recommendations on business opportunities for each level of automation and each new technology	O	O	O	O	O	O
Other 1: ____________________	O	O	O	O	O	O
Other 2: ____________________	O	O	O	O	O	O
Other 3: ____________________	O	O	O	O	O	O



Lab Trial Opportunity for Potential Products

11. If your organization has any new product with potential benefits for the AV/CV technologies, please contact us, as we can help you conduct a lab trial to further explore the effectiveness.



Appendix B: Phone Interview Questions for State DOTs

Basic Information of State DOTs			
DOT	**Interviewee**	**Interviewee Position**	**Contacting Information**
California	Greg Larson	Chief, Office of Traffic Operations Research, Caltrans Division of Research, Innovation and System Information	greg.larson@dot.ca.gov 916-657-4369
Iowa	Sandra Larson	Systems Operations Bureau Director, Highway Division	sandra.larson@dot.iowa.gov 515-239-1205
Maricopa County	Faisal Saleem	ITS Branch Manager	faisalsaleem@mail.maricopa.gov 602-506-1241
Arizona	Reza Karimvand	Assistant State Engineer	rkarimvand@azdot.gov
Michigan	Collin Castle	Connected Vehicle Specialist	castlec@michigan.gov 517-636-0715
Minnesota	Michael J. Kronzer	ITS Project Manager	michael.kronzer@state.mn.us 651-234-7064
Nevada	Denise M. Inda	Chief Traffic Operations Engineer	dinda@dot.state.nv.us 775-888-7867
Pennsylvania	Mark Kopko	Manager, Traveler Information & Advanced Vehicle Technology Bureau of Maintenance and Operations	markopko@pa.gov 717-783-1903

Questions	Responses from State DOT Interviewees
How is the Department of Transportation planning for the use of connected and autonomous vehicles?	DOT submitted a proposal to the FHWA for the WAVE 1 of the CV Pilot Deployment Project and was not selected. It has a test bed of 11 connected intersections it hopes to extend into a two-mile corridor. It is working with a local transit authority to begin a project involving bus/transit signal priority.
	Focused on its autonomous vehicles technologies project with a local university, which involves high-definition mapping, predictive traffic modeling, and the demonstration of an actual vehicle.
	Partnership between state and county DOT on a project that began as a test bed of connected intersections focusing on emergency response priority at traffic signals. Developing into a freeway system connected to the arterials that will flush out the queue on the ramp and allow emergency vehicles to pass. The test bed is currently live and will integrate freeways when funding is received.
	Have been testing CV infrastructure over the past five to seven years and have deployed test beds with it supporting infrastructure. The DOT CV deployment plan has a five-year timeline with 350 roadway miles of infrastructure. Have recently invested in AV research activity over the past two to three years.
	In the beginning stages of planning proposals in research rather than implementation. Focus on installing DSRC in maintenance vehicles and snowplows to communicate to digital message signs and eventually cabs of connected vehicles. Eventual use for navigation of work zones, end-of-queue warnings, and alerts of changing work zone conditions.
	For the past five years, it has been part of the pilot program through the FHWA Connected Vehicles initiative. Monitoring weather-related data from vehicles, determining real-time weather conditions such as rain, snow, and any summertime maintenance data. It does not have any specific plan in place for its own statewide implementation funded through the DOT. Mostly focusing on gathering data and measuring viability of statewide implementation.
	Partnering with local university on a CV initiative, studying for the effects on drivers licensing and freight movement. It has test beds that are funded through local municipalities and a federal grant. It is passing legislation involving Level 4 automation.

Questions	Responses from State DOT Interviewees
What type of autonomous or connected technology is being planned for?	Planning for DSRC, focusing mostly on transit and freight signal priority applications.
	Focusing on autonomous vehicles that rely on the 3-D mapping of infrastructure.
	Using DSRC and a smartphone app for pedestrians.
	Planning to implement DSRC roadside units with the back office infrastructure to collect and send out data.
	Near-future goal is to integrate DSRC into signals in metropolitan areas and eventually have full metro DSRC coverage.
	Phasing out the use of 800 MHz radios and cell phones. DSRC is installed in a smaller corridor and is working very well; it is currently experimenting with spacing to a point that a car can go in and out of range.
	Data are not as real time but saves money on infrastructure and is still effective especially in more rural areas.
	DSRC equipped signals.
Are any specific OEM's technology being planned for over others?	No, just focusing on the DSRC technology.
	Focusing on Volvo's autonomous technology, which used the paint to center itself.
	No.
	No, focusing on industry best practice.
	No.
	No, just focusing on the DSRC technology.
	No.
For what level of automation are plans being created?	N.A.
	N.A.
	N.A.
	N.A.
	N.A.
	N.A.
	Passing legislation for Level 4 Automation.
What infrastructure adaptations are planned for to support these vehicles? Focusing on safety devices. • Pavement markings • Signs • Rumble strips • Pavement surface • Guardrail • Temporary traffic control zone and • Work zones • Traffic signals • Other roadside hardware?	Changes in safety devices are not being planned, just the installation of DSRC radios at intersections.
	3-D model of all the currently implemented roadway infrastructure. They are keeping all paint up to date in preparation.
	Focusing on equipping traffic signals with DSRC for transit priority. Have future plans to install and link freeway DSRC as well.
	It is paying attention to what the auto industry is saying with regards to signage and striping. Require better lane marking and highly accurate signalized intersection that includes GPS and 3-D mapping of intersection, how the signal heads apply to lanes, highly accurate map, and signal phase and timing.
	Right now no plans to change infrastructure; will most likely be more reactive to automotive manufacturing plans.
	No change in safety devices, installing DSRC radios.
	N.A.

Questions	Responses from State DOT Interviewees
How does the market penetration rate affect plans for infrastructure? (20%, 50%, 100%)	N.A.
	N.A.
	N.A.
	N.A.
	N.A.
	N.A.
	N.A.
What is a likely timetable for the deployment of these systems?	Dependent on funding, it can complete the local transit authority projects in the next 1.5 years.
	No set timeline for project tasks. Very young project; only focusing on the next year.
	Mostly focusing on V2I; thinks V2V will be available for public purchase 2020 to 2022. Have its test bed up and running, but is waiting on funding for freeway application.
	It has a five-year timeline for CV implementation.
	DSRC signals in metro areas have a four- to five-year timeline of deployment, which is dependent on the receipt of federal funding.
	Have been working on the FHWA pilot project for the past five years but do not have a solid plan or timeline of statewide deployment.
	N.A.
What is an estimated budget for the planned infrastructure changes?	Plan on equipping 135 intersections at a cost of $50,000 per intersection. Possible sources of funding include a grant from the federal government and “cap and trade” programs with air quality agencies.
	Noted only it would be state funded.
	It participated in the pilot programs for the scope implementation but did not receive funding for the CV plan that it developed. It was on the “maybe” list if more funding came, but it did not.
	It is funded through a statewide ITS template with a shift toward CV and air quality organizations.
	Proposal for federal funding, if awarded $23 million over four years planned for V2I and CV projects.
	It received $500,000 in federal funding for the current project.
	N.A.

Appendix C: Phone Interview Questions for OEMs

Basic Information of OEMs					
Area of Manufacture	**OEM**	**Interviewee**	**Interviewee Position**	**Contacting Information**	**Interview Results**
Lidar	Velodyne	Frank Bertini	Account Manager, East Coast	fbertini@velodyne.com	See below
	PointGrey	Louisa Ng	Sales Representative	louisa.ng@ptgrey.com	Reject Interview
GPU	nVIDIA	Danny Shapiro	Supervisor, Senior Director of Automotive	dashapiro@nvidia.com	See below
Communications	Denso	Roger Berg	Vice President	roger_berg@denso-diam.com	No reply
Maps	Civil Maps	Sravan Puttagunta	CEO	sravan@civilmaps.com	See below

Interview of Velodyne

Questions	Responses from Interviewee
What aspects of below roadway features hamper the usage of Velodyne lidar?	Lidar has no trouble identifying the below physical features of roadways. Lidar can read large street signs if they are constructed with retroreflective tape. With the right software, roadside and overhead signage can be read by lidar plus software if it is constructed with the right reflectivity characteristics. Velodyne's lidar has a feature called dual returns, which allows it to function well in rain and snow conditions. If the weather condition is a complete whiteout or 5 feet visibility fog, the sensor will not perform well.
Which traffic control devices (TCDs) are the least useful for lidar in AV as compared with human-operated vehicles?	DMS and traffic lights. This can be solved easily with other CHEAP technologies such as a local wireless switching signal sent to the car.
What are some difficulties associated with the way in which road work is performed as they relate to lidar?	Nothing. Mapping programs can already reroute around this.
Do you have any suggestions for altering the design of the roadway features to increase the reliability and effectiveness of lidar?	DMS: Push message via cellular technology. Traffic signals: Explore Bluetooth or similar wireless technology. Lane markings: Paint with high-reflectivity crystals in it. Pavement surfaces: Blank pavement is fine, don't change it. Rumble strips: Reflective tape on the edge of the strip. Raised lane dividers (both high- and low-reflectivity): Velodyne lidar can see both, but more reflectivity is always better. Road edges: Reflective, similar to lane markings. Not really necessary. Guardrail: Reflectivity is always better but not necessary. Pedestrian/cyclist/large animal crossings: Programmed into the global street map libraries.
Locales across the U.S. vary greatly in terms of roadway features. What effects does this have upon lidar? How might standardizing roadway features benefit lidar?	Velodyne lidar is designed to see everything all of the time. It can operate in virtually any roadway already. Standardizing and optimizing road features and signage could potentially help AV see visual cues more easily.

Questions	Responses from Interviewee
What are the standard requirements of lidar to AV?	No standard requirements right now.
How do you predict future lidar usage in AV with ideal technologies and traffic environment? Please describe the ideal technologies and traffic environment?	Lidar has the capacity to potentially replace camera-based computer vision altogether. GPS and IMU sensors will usually be associated with any mobile autonomous system. Cars will also eventually use technology called localizing ground penetrating radar (LGPR). With this technology, you can create an underground map, which can help to localize autonomous vehicles on the roadway.
Any other comments?	As people become more comfortable with handing control off to a computer, the scope of the features will increase. The trade-off will turn from 5% automation and 95% manual, to 50–50, and then eventually closer to 95% automation and ultimately full autonomy. An autonomous taxi could easily generate over $1 million in revenue if it operates 24/7/365 for 10 years.

Interview of nVIDIA

Questions	Responses from Interviewee
What are nVIDIA's long-term goals in the automotive sector?	NVIDIA software is taking all the sensor data and being able to process that, analyze it, understand it, and then enable the car to talk on its own. Through a variety of different means, artificial intelligence (AI) is the way to enable all that autonomy.
How do you believe that increases in onboard computing power will have an impact on the behavior of intelligent vehicles?	Our customers also request for increasing the force power, and we improved force power of the GPU to 10 times more performance on January this year for deep machine learning and training.
How do you believe that disparities in onboard computing power will affect interaction between vehicles?	Different inputs such as sensor fusing, camera, lidar, and radar combined increases competences and accuracy and also can strength the weakness. No way to program for all the potential scenarios. AI is becoming useful to handle situations with superhuman ability. We will see more traffic cameras used for real time in addition to being able to analyze, log, and make predictions from the data. There is not a lot infrastructure space today (V2V and V2I), we are developing their systems independent of that.
Is nVIDIA working with anyone in that field right now? Are you working with anyone as far as selling GPUs, and giving them support?	We are working with several smart city entrances and selling GPU to them. There are a lot of frameworks people are building on. We don't write the apps, but a lot of other folks are doing the work to be able to write the apps to be able to do all kinds of data analytics on the GPU. Consulting firms are playing in AV sphere.
How can highway infrastructure best facilitate distributed computing in connected vehicles?	There would be benefits in both directions. With CV, it would be the information first and foremost, and I think if there could be basic types of information that could be locally communicate.
What do you think will be the scheduling as far as this technology being adopted? What improvements could be made?	This technology is on the road already. Within 12 months we will see AV on the road in some levels. We have Audi bringing out traffic jam assist with us next year. I think the long delaying factor will be regulation, whether it is infrastructure or states and federal governments saying it is okay to drive.
What TCD do you think will become obsolete as we get more Level 4 vehicles?	In the future, maybe no streetlights, stop lights, or stop signs. And then, once you get to that point, you can't have any human driven cars at that point. May have special lanes or area with autonomous cars only.

Questions	Responses from Interviewee
What current approaches to traffic safety do you believe will remain vital after AV have become ubiquitous?	Short-term, maybe restricted regions with just AV. There is need for smarter streetlights and sensors on the road to understand traffic flow. Maybe also a standardized system to enable temporary infrastructure to communicate temporary changes to environment (like ok, this lane is closed). There will be many new approaches and apps in the car that we have not thought about. For example, we take the video from front-facing cameras in and map it to the steering wheel and teach the car how to drive in a more holistic manner. If the lane markings disappeared, the system did not care because it was looking at the entire scene, not just lane markings.
The only way to get information is through so many hours of simulation. At what point is it reliable? At what point can we call it “safe”?	The simulation is key because how many times do you get to test how good your car is in emergency situations. We will need to see government regulatory bodies come up with a broad test for automakers to be able to pass to show their systems are robust. Can we ever prove 100%? I don’t really think that is possible. And that will be a debate of when they can be in use.

Interview of Civil Maps

Questions	Responses from Interviewee
Could you give a brief introduction of Civil Maps?	We are creating a new generation of maps that enable fully AV to traverse any road safely and comfortably without any human intervention. We convert depth data (camera/lidar) into vector maps, and the data can come from lidar and sensors.
Locales across the U.S. vary greatly in terms of roadway features. What effects does this have upon building and using HD maps? How might improving standardization of roadway features benefit the efficacy of HD maps?	Mapping needs to have stringent certification procedures such as safety-critical systems. Standards need to be put in place. To use lidar more than cameras for sign detection and use cameras to determine regulatory information from a sign once the sign is identified lidar DNN (most ML focuses on camera).
How does municipal handling of inclement weather have an impact on the usability of HD road maps? What improvements could be made?	It synthetically creates snow/rain in simulation to train road map to deal with weather. We will focus on testing in as many scenarios as possible, rather than a lot of time in a low set of scenarios
How do you predict the availability of HD maps will spread over the next 5–25 years, in terms of coverage area?	Possibly HD maps will have areas where only AV is allowed.
How might highway infrastructure be improved to reduce the post-processing burden of building HD maps.	Changing the infrastructure is not even helpful, just maintain the existing infrastructure. One of our goals is to enable an alternative future where the local governments or the road maintenance agencies don’t really have to change much. They just have to make sure the existing assets are maintained properly.
How might highway infrastructure be changed to improve the real-time usage/refinement of HD maps?	

SAFER ROADS SAVE LIVES

American Traffic Safety Services Association
15 Riverside Parkway, Suite 100
Fredericksburg, VA 22406
800-272-8772 • www.atssa.com