AGENCY IMPLICATIONS OF CONNECTED AND AUTONOMOUS VEHICLES

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EXECUTIVE SUMMARY

This paper provides a brief summary of the roles and current activities undertaken by agencies from the national to local levels in relation to connected and autonomous vehicles (CAVs). Given the rapidly changing environment and technologies surrounding CAVs, the challenges of planning, prioritizing, constructing, maintaining, and operating transportation infrastructure will only become more complex. This paper identifies specific challenges posed for public agencies, and lays out immediate action items for transportation professionals so that they can start preparing now for the future.

INTRODUCTION

With the rapid advancement of connected and autonomous vehicle (CAV) technologies, transportation professionals are scrambling to stay ahead of the curve. Agency staff from local to national levels are wondering what they need to do today, tomorrow, and in the future to ensure for the safe and equitable movement of all users of the transportation network. This paper provides a brief summary of the current roles and activities of local, County, MPO, State, and Federal agencies across the US. Specifically, this paper lays out immediate action items for transportation professionals so that they can start preparing now for the future. The paper highlights tools and approaches utilized by the USDOT to plan at the national level; planning strategies being undertaken at the State, County, and MPO levels; and infrastructure needs and challenges being addressed at the local level to ensure safe movement for all users of their transportation infrastructure today, tomorrow, and into the future.

OVERVIEW OF CONNECTED/AUTONOMOUS VEHICLES

Before engaging in a discussion of connected and autonomous vehicles (CAVs), and the implications these vehicles present for agencies with a role in transportation, we must establish a baseline. For the purposes of this paper, the baseline will identify the current state-of-the-practice in terms of the levels of connectivity/automation for vehicles, the generally accepted benefits that are expected from vehicle connectivity/automation, the current anticipated timeframe for the deployment and integration of connected /automated vehicles into the existing fleet, and the general concepts for connectivity and communication.

Levels of Connectivity/Automation

This paper will use the Society of Automotive Engineers (SAE) recognized levels of autonomy, shown below:

Level 0 The human driver does everything.

Level 1 An automated system on the vehicle can sometimes assist the human driver conduct some parts of the driving task.

Level 2 An automated system on the vehicle can actually conduct some parts of the driving task, while the human continues to monitor the driving environment and performs the rest of the driving task.

Level 3 An automated system can both actually conduct some parts of the driving task and monitor the driving environment in some instances, but the human driver must be ready to take back control when the automated system requests.

Level 4 An automated system can conduct the driving task and monitor the driving environment, and the human need not take back control, but the automated system can operate only in certain environments and under certain conditions.

Level 5 The automated system can perform all driving tasks, under all conditions that a human driver could perform them.

Source: Federal Automated Vehicles Policy; https://one.nhtsa.gov/nhtsa/av/av-policy.html

The most critical distinction between Levels 4 and 5 is the presence of a steering wheel and other controls – in a Level 5 autonomous vehicle, and in some applications of Level 4, steering wheels and other controls are not necessary. A second critical distinction is the understanding of connectivity in regards to automation – at Levels 2 and above, the vehicle is “connected” to the outside world in some fashion, and uses that connectivity to make decisions and take actions on some or all of the driving activities. While on-board computer systems combined with sensor technology can allow a CAV to understand the world around it and take actions to respond, the connectivity is the key to ensuring that CAVs are receiving correct information and/or are correctly interpreting the world as the CAV sees it. This is particularly relevant in safety applications.

How Vehicles Are Connected

There are two generally accepted types of connectivity discussed in relation to CAVs: Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I). In the case of the former, CAVs communicate directly with other vehicles on the roadway, providing information on speed, the direction of travel, and anticipated maneuvers (e.g., turns). In the case of V2I connectivity, the CAVs communicate directly with the roadway infrastructure (e.g., signals, signs), and vice-versa. There is a third type of connectivity, and that is via an ad-hoc network of sensors and communication devices. This is referred to as V2X connectivity, and could refer to vehicle communicating with a pedestrians smart phone or wearable device, and vice-versa.

Expected Benefits

There are many reasons for connectivity and automation in vehicles, and one of the most frequently cited reasons is the expected benefits that connectivity and automation will deliver. It is estimated that human error accounts for more than 90% of all road collisions. In recent years the United States averages nearly 40,000 deaths per year from traffic collisions. It is expected that connectivity and automation will directly reduce the frequency and severity of traffic collisions, although this benefit will likely be proportional to the overall percentage of the vehicle fleet that is made up of CAVs.

A secondary benefit of CAVs is making auto travel more efficient, both in terms of roadway capacity and flows as well as productivity. It is estimated that Americans lose almost five billion hours per year due to congested traffic conditions. Delays in freight deliveries due to congestion result in costs of approximately $33 billion per year, and Americans burn almost two billion gallons of fuel per year due to congested travel. With the advent of CAVs, the levels of congestion could decrease due to improved operating efficiencies, and the time spent in vehicles could be better utilized, resulting in productivity gains.

Timeline for Deployment/Integration

Of course, it is important to use conditional statements when discussing the potential benefits of CAVs, since the amount of benefit will be proportional to the overall fleet mix on the roadways. Level 4 vehicles are available for purchase today, and many vehicles are currently on the roadway will levels of autonomy between Levels 1 and 3. The United States Department of Transportation (USDOT), via the National Highway Transportation Safety Administration (NHTSA), has issued guidelines regarding CAVs, and many states including California have provided legal and regulatory guidelines regarding the use of CAVs on public roads. The stage is set for the deployment and integration within the vehicle fleet; the question is what is the timeline? Estimates vary across the industry, although there appears to be some consensus that sometime between 2020 and 2030, possibly by 2025, Americans may see a significant market penetration (e.g., 15%) of CAVs within the general vehicle fleet. Given the recent experiences in the testing of autonomous for-hire vehicles, it is very likely that there will be further legislative and regulatory guidance on where Level 5 autonomous vehicles may operate versus Levels 1 through 4. It is the author's belief that Level 4 and 5 CAVs will most likely be authorized in specified geographic areas and/or dedicated facilities, where the vehicles may travel at low speeds with limited interaction with non-CAVs.

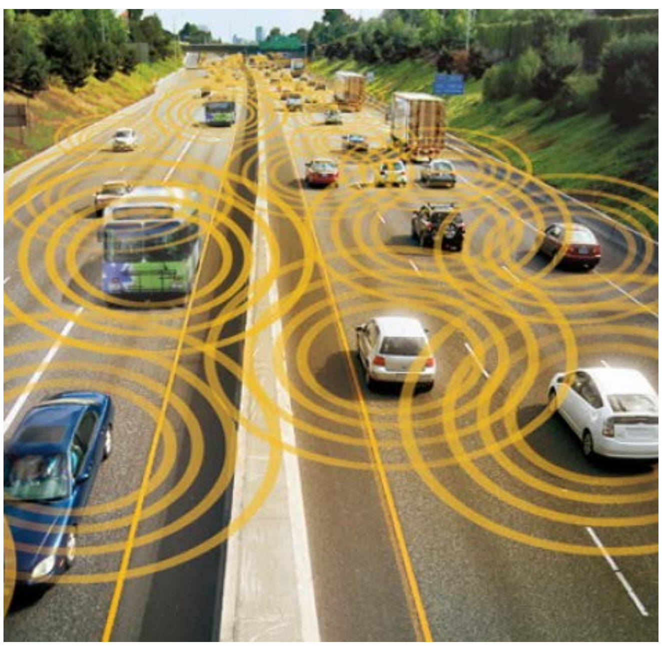
COMPLEXITIES/CONCERNS RELATED TO DEPLOYMENT/INTEGRATION

One of the most complex aspects of CAV technology is the ability for the vehicle to identify potential hazards and make split-second decisions on how to respond to those hazards in a safe manner. The complexity is increased by the density and variation of activity found on roadways – particularly in dense and active urban areas – compounded by the almost infinite variability of human responses and activities – bordering on Heisenberg uncertainty principle levels of complexity.

Take as an example the following scenarios as outlined by Dave Barnett of the United Kingdom's Transport Systems Catapult: A plastic bag drifts into the path of a moving vehicle. A human driver may see the bag, identify it as a non-threatening hazard, and simply drive forward while the bag drifts past the car (or more often than not gets lodged in the grill of the car). An autonomous vehicle, when presented with the same situation, would likely behave in a similar fashion. Now imagine if instead of a bag, it was a circular balloon. In this situation, both the human driver and AV would likely respond in the same way. Last, assume that instead of a circular balloon, the object is a soccer ball.

In this case, the human driver would recognize this not only as a soccer ball, but something that a human being (likely a child) had to kick in order for it to be in front of the vehicle; so the human driver would quickly look to find the human possibly chasing the soccer ball. In the case of an AV, this scenario presents a very complex situation. The soccer ball doesn't look that different from a circular balloon, and the trajectory of the circular balloon would be consistent with that of a plastic bag. How will the AVs algorithms be programmed so that in this case the response is not to continue to proceed straight, as the AV would have with the plastic bag or balloon, and rather to slow in anticipation of a human entering the roadway?

The example above is provided to highlight the complexities surrounding the correct identification of use cases that an AV has to handle. From the author's perspective, the complexities of public roads demand a solution greater than machine learning alone. Rather than waiting for AVs to experience every possible situation that one could experience driving on a road, and then having the AVs learn from those experiences, it is widely accepted that public agencies must play a role in ensuring that the infrastructure itself can help ensure for the safety of all users.



Uncertainty During the Transition Period

For precisely the reasons described previously – the complexities of non-CAV interaction with CAVs, as well as the complexities of active streetscapes in urban areas – the author believes we are entering a critical time in regards to roadway safety and the role of the public sector. With the deployment of CAVs onto public roadways, all roadway users will have to learn to respond to different situations; and the data is fairly clear regarding the limited abilities of motorists to respond to new and uncertain conditions. For all the expected benefits of CAVs, it is the uncertain behaviors and actions of human drivers that may present the greatest uncertainties and threats to safety during the transition period.

For example, in September 2016 a driverless car (operated by Google) was struck by a non-CAV. In this specific collision, the driverless vehicle was proceeding through an intersection after receiving a green signal indication. A van approached from the perpendicular direction, and although the van was approaching a red signal indication, the van proceeded through the intersection and struck the driverless vehicle. The public safety responders cited the human driver in the collision; however, this collision highlights the exact challenge facing the transition period of CAV integration into the vehicle fleet.

The remaining sections of this paper will discuss the roles of public agencies as they relate to CAVs, and how public agencies can leverage their roles to minimize the challenges associated with the transition period of CAV integration.

ROLES OF PUBLIC AGENCIES

All CAVs need transportation infrastructure to operate, and transportation infrastructure is almost exclusively the realm of the public sector. The federal government establishes national standards; develops national policies, guidelines, and regulations; provides funding; and supports implementation of transportation infrastructure and related components. State agencies play similar roles, at the statewide level, and have greater roles in the planning, implementation, operation, and maintenance of transportation infrastructure. Counties play nearly every role in transportation infrastructure, from the development of standards through operations and maintenance. At the Municipal Planning Organization (MPO) level – and for the purposes of this paper we will define an MPO as inclusive of agencies with planning, funding, and prioritization authority over multiple local agencies, which could include MPOs, County Transportation Commissions, Congestion Management Agencies, Port Authorities, etc. – the role of the MPO is generally in the planning, funding, and prioritization of transportation infrastructure. Last, local agencies play the most direct role in the implementation, operation, and maintenance of transportation infrastructure. The chart below presents a summary of agency roles. The following sections present a summary of some of the activities underway at each level in relation to the agency-specific role. Note that this discussion is limited to public agencies, and does not include Universities or other non-profit research entities.

Agency Roles in Relation to CAV Infrastructure & Operations

ROLE	AGENCY				
	Federal	State	County	MPO	Local
Standards	✓	✓	✓	✓	
Funding	✓	✓	✓	✓	✓
Planning Prioritization		✓	✓	✓	✓
Implementation	✓	✓	✓		✓
Operation Maintenance		✓	✓		✓

Current Agency Activities

Federal

At the Federal level, the USDOT has initiated efforts to establish standards, provide funding, and direct the implementation for CAVs. The Connected Vehicle Reference Infrastructure Architecture (CVRIA)[1] identifies standards for connected systems, and standardized communications for 97 unique applications. To further ensure the goals of the CVRIA are achieved, the USDOT has created the Systems Engineering Tool for Intelligent Transportation (SET-IT)[2]. This tool is freely available to agencies, and can be used to develop project architectures for pilots, test beds and early deployments of CAVs.

The USDOT has also provided direct grant funding to public agencies for the CAV pilot deployments. On September 1, 2016, the USDOT awarded three cooperative agreements collectively worth more than $45 million to initiate a Design/Build/Test phase of the CV Pilot Deployment Program in three sites: Wyoming, New York City, and Tampa.[3] The goals of this program are to encourage partnerships of multiple, deploy applications utilizing data captured from multiple sources across all elements of the surface transportation system, and to support improved system performance and enhanced performance-based management.[4]

In September 2016 NHTSA released its Federal Automated Vehicles Policy[5]. The policy addresses numerous topics related to vehicle performance and provides guidance in terms of deployment and operations. The policy provides a model state policy, for reference and use by states when developing their own specific CAV policies. One of the most interesting aspects of the policy, from the standpoint of the role of a federal agency, is in the discussion of NHTSA's current regulatory tools. The policy outlines the current tools available to NHTSA for regulating vehicle activities on public roads, and also outlines a number of new tools and authorities NHTSA may pursue in the future, to address potential future issues created by the deployment of CAVs.

One authority that should raise some concerns is in the area of software updates – NHTSA indicates a potential desire to approve software updates before public release, which could create a major hurdle in terms of quick fixes to software bugs.

State

At the state level, the approaches have varied. Many states, including ITE Western District states California, Nevada, and Utah, have recently updated Department of Motor Vehicle (DMV) guidelines and regulations to address CAVs. In September 2016 California released its first set of DMV regulations for CAVs, and at the time the regulations expressly restricted the testing of fully driver-less (Level 5) CAVs on public roads. In March 2017, the regulations were revised to allow for the testing of Level 5 CAVs, with specific requirements requiring the regular reporting of safety information and the presence of a human in the vehicle to take control if-needed.

Across the state of California, vehicle manufacturers, technology firms, and on-demand transportation providers have been testing CAVs on public roadways. These tests have generally been without incident; however, anecdotal reports circulate quickly on the internet regarding CAVs making improper turns and/or unsafe maneuvers. There have been a few documented collisions involving CAVs (operating at Level 4), including the collision in September 2016 as described earlier in this document.

MPOs

In California, a number of activities have been occurring at the MPO level, led by the pioneering efforts of the Contra Costa Transportation Authority (CCTA) in their acquisition of a decommissioned Naval facility and the creation of the GoMentum Station CAV testing facility. This was the first facility in the state to receive legislative approval (via AB 1592) to test Level 5 CAVs on public roads in California. The

[1] http://local.iteris.com/cvria/
[2] http://local.iteris.com/cvria/html/forms/setitform.php
[3] https://www.its.dot.gov/pilots/
[4] Ibid.
[5] https://one.nhtsa.gov/nhtsa/av/av-policy.html

5,000 acre facility has been in operation since 2015 and is testing CAVs under a variety of roadway conditions.

In 2016 the Metropolitan Transportation Commission of the San Francisco Bay Area (MTC) initiated its Future Mobility Research effort. This effort includes participation from the largest MPOs in California – the Sacramento Area Council of Governments (SACOG), the Southern California Association of Governments (SCAG), and the San Diego Association of Governments (SANDAG). The purpose of this research effort is to evaluate the potential impacts to MPOs related to CAVs and other new transportation technologies, and to provide guidance on how MPOs can adjust their planning, programming, and budgeting practices to better address CAVs and new transportation technologies.

Last, the Orange County Transportation Authority (OCTA) recently initiated a project to address V2I challenges. The purpose of this project will be to perform a technology review of connected vehicle technology, both V2V and V2I, with an emphasis on V2I technologies and requirements that may be incorporated into the Authority's signal synchronization program. A key goal is to determine OCTA's current and future roles (e.g., monitor, shape, or implement) related to V2I technologies, considering OCTA's current authority as a planning and funding agency for streets and highways.[6]

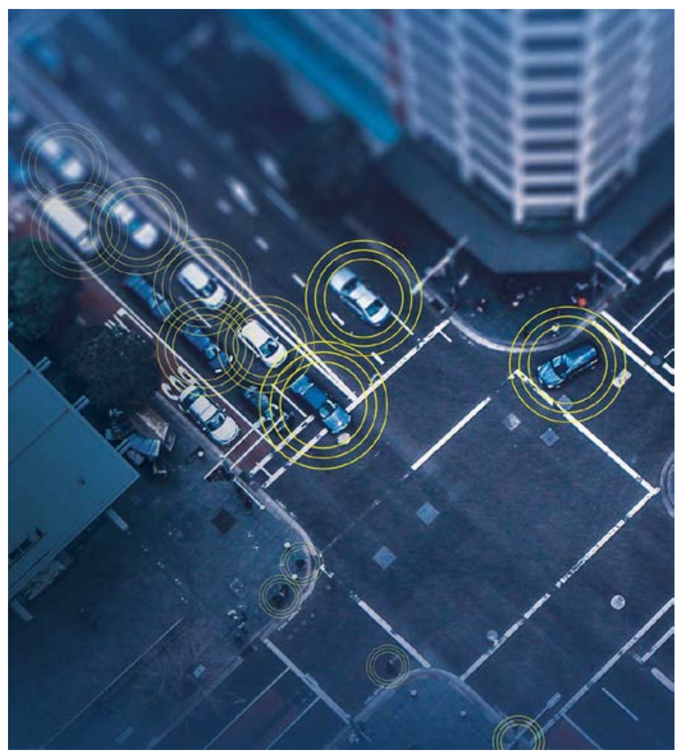
Local

U.S. Supreme Court Justice Louis Brandeis is attributed to have coined the term "laboratories of democracy," and this could be modified to say that "local government is the laboratory for new transportation technology." It is at the local level that the daily challenges of CAV integration will be most prevalent. In California a number of local agencies have identified CAVs and new transportation technology as potentially game changing, and are taking steps to proactively respond.

The City and County of San Francisco, via a grant awarded by the USDOT, is initiating its Advanced Transportation and Congestion Management Technologies Deployment Initiative (ATCMTD) program. This program is part of a broader Smart City initiative, and includes elements related to CAVs (as autonomous shuttles), tolling, signal synchronization, Vision Zero implementation (via improved metrics and new infrastructure), and an overall improvement in data collection and monitoring.[7]

The City of West Hollywood is initiating a Smart Cities Strategic Plan. The purpose of this plan will be to implement smart city technologies to enhance service delivery, improve municipal operations, improve residents' quality of life, and serve as a catalyst for accelerating the City's mobility and sustainability ambitions. This plan will address areas such as Sustainability, Mobility, Accessibility, Resiliency, and Transparency.[8]

Other Southern California cities are taking similar steps. The City of Los Angeles released its Transportation Technology Strategy in August of 2016, and is currently working on initial implementation steps. The City of Beverly Hills has openly declared its intention to develop and deploy a driverless taxi system and the City of Santa Monica has expressed a desire to develop CAV pilot deployments. As entities with control of both the public rights-of-way and associated transportation infrastructure, local agencies will literally be where the rubber hits the road in terms of CAV deployment.



[6] Request for Proposals (RFP) 7-1526, Vehicle-to-Infrastructure State of the Practice Review; January 26, 2017.
[7] City of San Francisco Advanced Transportation and Congestion Management Technologies Deployment Initiative (ATCMTD), Notice of Funding Opportunity #DTFH6116RA00012; September 2016.
[8] Request for Proposals; Smart City Strategic Plan; January 24, 2017.

INFRASTRUCTURE NEEDS AND CHALLENGES

With the various activities underway at all levels of public agencies, there are aspects of the transportation infrastructure in dire need of attention, in order to ensure that CAVs are safely integrated into local transportation networks.

CAV Infrastructure Requirements

As noted earlier, CAVs – particularly Level 4 and 5 vehicles – are outfitted with extensive sensor technology to view the world. These vehicles use any numbers of sensor technologies to map, measure, and assess what is occurring in real-time around the vehicle. In a closed system, with no other operators aside from the CAV, these sensor technologies would be sufficient to allow the CAV to safely navigate the world. In real-world settings, particularly in dense urban environments, CAV sensing technology is limited by what it sees and how it sees. In some cases, sensor technology is only as effective as the supporting infrastructure it is sensing. CAVs depend on clear signage and clear roadway markings to understand where to locate within a roadway and what to do at intersections and decision points. Like human drivers, CAVs generally depend on traffic signal indications for guidance on when to stop or proceed through an intersection. Lastly, CAVs require outside information to understand the nature of temporary road blockages and what their duration will be – for example, how to tell the difference between a large pothole and an excavation, or how to tell the difference between a collision and a planned closure for construction.

Infrastructure Needs

First and foremost, CAVs require infrastructure and traffic control devices that display clear messages and direction. Deteriorating pavement conditions (e.g., potholes) present hazards that CAVs must avoid. Roadway striping and markings let CAVs know where they should locate themselves within the roadway, and if those markings are not clearly visible, the CAVs will be challenged.

Most modern traffic signals operate using in-roadway or overhead sensors to detect the presence of vehicles. Most modern signal systems have communication capabilities to send and receive real-time information. Many City-wide connected signal systems, such as those used in the City of Los Angeles, include "system" detectors placed mid-block to determine average roadway speeds. With modest investment, traffic signal systems could be upgraded to provide real-time information to CAVs, on both the status of the signal and the movement of vehicles in opposing directions. This exact investment would prevent collisions like the one described earlier from September 2016, where a CAV was struck by a vehicle running a red light. Imagine if the signal system had detected a vehicle moving at a high rate of speed towards a red light – the system could alert the CAV and prevent the collision.

Temporary closures are a necessity for infrastructure maintenance, ongoing economic activities (e.g., deliveries, construction), as well as incident response. Agencies struggle with the monitoring and messaging of temporary closures, as anyone who has spent any time in a congested urban core can agree. Users of route planning applications like Waze are familiar with the routing dilemmas presented by unexpected roadway closures. Some agencies are partnering with Waze and/or other private sector firms to disseminate real-time information on temporary closures in addition to agency operated systems such as 511. This continues to be an area of active development.

Agency Challenges

Given the infrastructure needs described above, the largest challenge is funding. Agencies from the federal level down to the local level struggle with regular maintenance and maintaining a "state of good repair" for transportation infrastructure. Combined with the challenge of funding labor-intensive monitoring and enforcement activities; there is much work that needs to be done to elevate the importance of providing adequate budgets for maintenance and operations. Unfortunately; infrastructure maintenance doesn't have the political appeal of a ribbon cutting at a new park, or the announcement of the opening of a new homeless shelter.

Even if the underfunded maintenance gap can be filled, there will still be a need for investment in transportation infrastructure to support the mass deployment of CAVs. As mentioned previously, modest investments in traffic signal systems can create a communications and sensor backbone to support the safe interaction of CAVs with other roadway users. Agencies at all levels should understand the infrastructure investment needed, and take actions to ensure that they can make those investments to fulfill the responsibilities given their specific roles.

Agency Recommendations

The author recommends the following actions for planning and operational agencies, in order to support the safe integration of CAVs on the nation's transportation network.

AGENCY LEVEL	RECOMMENDATIONS	
	Near-term (0-5 Years)	**Long-term (5+ Years)**
State	• Ensure consistent infrastructure deployment via STIP programming, etc. • Integrate CAVs into statewide plans	• Ensure statewide standards for regulations and traffic control devices are consistent
County	• Complete inventory of all traffic signal, ITS, Signage, and Markings • Develop CAV Strategic Plan • Increase funding for maintenance and enforcement	• Upgrade all infrastructure equipment for standard communications
MPO	• Integrate CAVs into Regional Transportation Plans & modeling • Upgrade Congestion Monitoring Programs to utilize better data sources • Ensure standard infrastructure deployment via grant funding opportunities	• Coordinate planning activities across states/nation to ensure consistency
Local	• Complete inventory of all traffic signal, ITS, Signage, and Markings • Develop CAV Strategic Plan • Increase funding for maintenance and enforcement • Identify and deploy CAVs in designated areas where Level 5 CAVs can be supported with dedicated infrastructure	• Continue to identify and deploy CAVs in designated areas where Level 5 CAVs can be supported with dedicated infrastructure • Upgrade all infrastructure equipment for standard communications • Use data-driven approaches to identify new infrastructure needs

CONCLUSION

In conclusion, the advancement of CAV technology promises to change the landscape of public roadways. Although the long-term benefits of CAVs could be significant in terms of improved safety and efficiency, the near-term implications of a partially integrated fleet could present serious safety and operational challenges. These challenges will be faced on a daily basis by local agencies, who bear the majority of the responsibility for maintaining safe and efficient transportation networks across the US. Some activities are being carried out at the various agency levels, from Federal to local, and more needs to be done. At the MPO level, the author recommends that CAVs be incorporated immediately into Regional Transportation Planning and related processes, to ensure that funding can be programmed to ensure for consistent infrastructure deployment across an MPO. At the local level, the author recommends agencies recognize the need to elevate the priority of infrastructure maintenance and upgrade, and increase the funding allocated for basic infrastructure maintenance like signing, markings, and traffic signal maintenance. These activities should be addressed immediately, while also pursuing other activities related to CAV deployment - needs assessments, learning through pilot projects, and establishing the ability to collect and analyze data as the CAV infrastructure develops and expands.

ABOUT ITERIS, INC.

Iteris provides municipalities and government agencies around the world with the necessary design, real-time analytics and actionable informatics to improve mobility throughout our communities and ready our roadways for connected/autonomous vehicles and smart cities. We make communities more walkable, transit and bicycle friendly, and we enable mobility of people and goods across cities and states more safely and efficiently.

Iteris is the primary contractor for the Connected Vehicle Reference Implementation Architecture (CVRIA) for the United States Department of Transportation (USDOT), which is defining the framework for deployment of Vehicle-to-Infrastructure (V2I) technologies throughout the U.S., and as such provides the most informed perspective on V2I and accompanying Vehicle-to-Vehicle (V2V) activities within the industry. To help achieve this future vision, Iteris provides policy guidance, systems engineering, real-time data and analytics, and actionable informatics to improve mobility and safety within communities and prepare the transportation system within Smart Cities for the advent of V2I and V2V. For more information, visit www.iteris.com.