Title
Caltrans Connected and Automated Vehicle Strategic Plan

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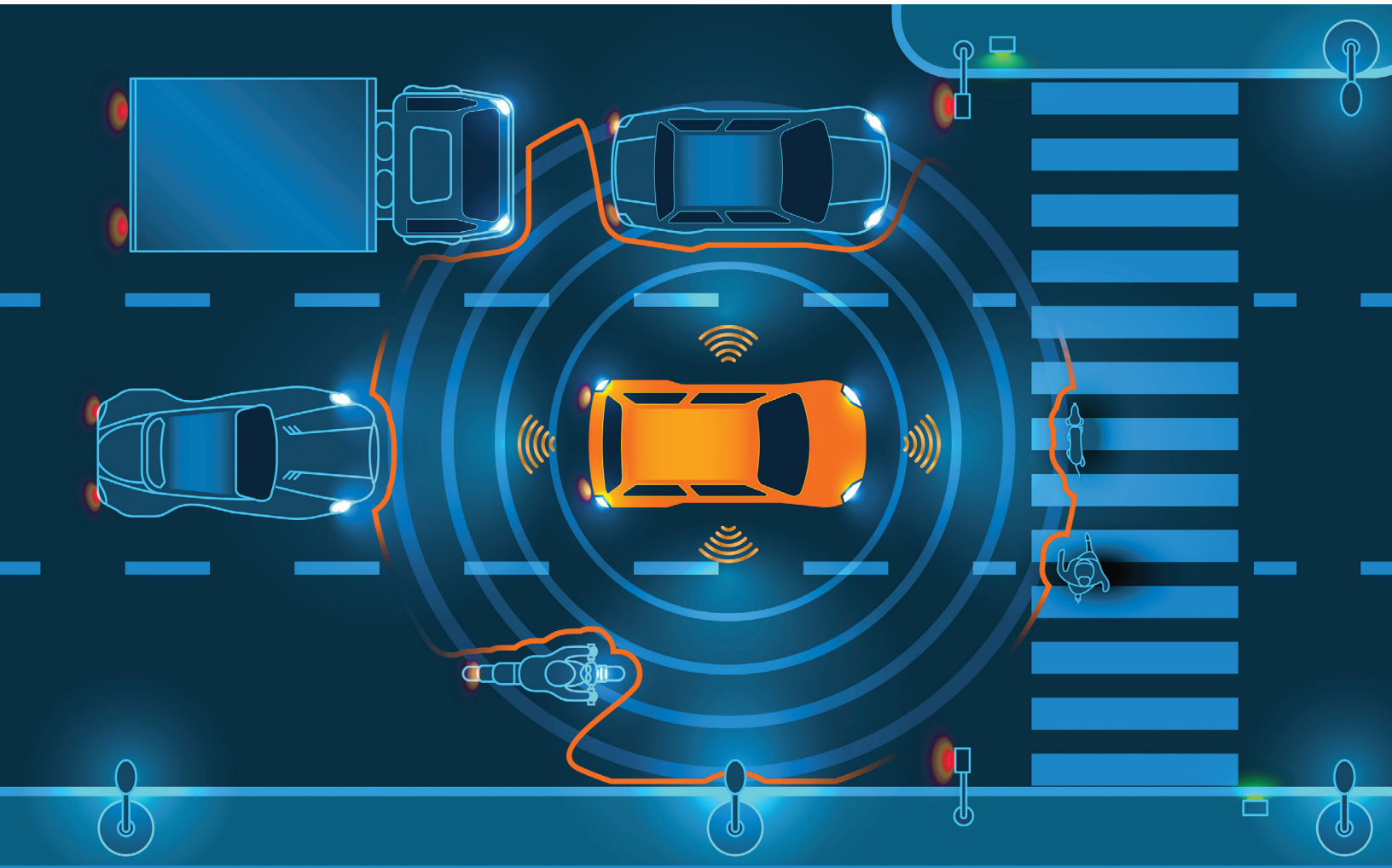

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Abbreviations and Acronyms

AAA	American Automobile Association
ADS	Automated driving system
AI	Artificial intelligence
ATMA	Autonomous truck-mounted attenuator
AV	Automated vehicle *A vehicle that has one or several of a wide range of automated driving features and replaces certain aspects of driver perception and control.*
BDD	Berkeley DeepDrive
CACC	Cooperative Adaptive Cruise Control
CalSTA	California State Transportation Agency
CAT	Cooperative automated transportation
CAV	Connected and automated vehicles
CCTA	Contra Costa Transportation Authority
CHP	California Highway Patrol
CPUC	California Public Utilities Commission
CTP	California Transportation Plan
CV	Connected vehicle *A vehicle enabled for standardized communication between vehicles or with the roadside to support driver assistance applications for the purpose of safety, traffic efficiency, reduced fuel consumption, or reduced emissions.*
C-V2X	Cellular vehicle-to-everything (V2X)
DES	Caltrans Division of Engineering Services
DMV	Department of Motor Vehicles
DOT	Department of transportation
DRISI	Caltrans Division of Research, Innovation and System Information
DSRC	Dedicated short-range communications
FCC	Federal Communications Commission
FHWA	Federal Highway Administration
HAV	Highly automated vehicle, SAE Level 3 and above
GHG	Greenhouse gas
IOO	Infrastructure owner operator
IT	Information Technology
ITS	Intelligent Transportation System
MaaS	Mobility as a service
MMITSS	Multi-Modal Intelligent Traffic Signal System
MoD	Mobility on demand
MPO	Metropolitan planning organization
NPRM	Notice of proposed rulemaking
ODD	Operational design domain
OEM	Original equipment manufacturer
PATH	Partners for Advanced Transportation Technology
PFS	Pooled Fund Study
RPG	Regional Proving Ground, San Diego
SAE	Society of Automotive Engineers
SHOPP	State Highway Operation and Protection Program
STIP	Statewide Transportation Improvement Program
TMC	Traffic management center
USDOT	United States Department of Transportation
VMT	Vehicle miles traveled
V2I	Vehicle-to-infrastructure
V2V	Vehicle-to-vehicle
V2X	Vehicle-to-everything *Includes V2I, V2V, and vehicle communication with other road users, such as motorcyclists, cyclists and pedestrians.*

Executive Summary

This report is the culmination of a year-long effort to develop a connected and automated vehicle (CAV) Strategic Plan for the California Department of Transportation (Caltrans). The purpose of the CAV Strategic Plan project is to define a vision and tactical strategy for Caltrans in preparation for CAV deployment in California and to begin a policy development process to keep California at the forefront of this emerging industry. This plan recommends actions for Caltrans to carry out within the next five years. Caltrans has a strong interest in planning for the fast-moving evolution in CAVs and intends to accelerate its leadership and outreach in this field.

The scope of the Caltrans CAV Strategic Plan is internally focused and limited to Caltrans-led activities. The primary objectives of the project were to:

- Develop a vision and goals for the Caltrans CAV program and a summary of current and planned CAV efforts, both nationally and within California
- Gather input from a broad cross section of Caltrans and its partner agencies through in-person meetings and stakeholder workshops
- Summarize how CAV fits into Caltrans business processes now and in the future
- List the actions that Caltrans should take in the next five years to facilitate successful, ongoing CAV deployment
- Consolidate findings from the above tasks into a Caltrans CAV Strategic Plan report

CAV Basics

CAV technology has the potential to save lives, provide greater mobility for all people, make our roadways more efficient, make California more economically competitive, and make our environment and people healthier. There are many different aspects to CAV technology, and the terminology continues to grow and evolve. It is important to distinguish between connected vehicle (CV) and automated vehicle (AV) technologies and to understand the concept of CAV.

CV technology broadly represents communication between vehicles, infrastructure, and other road users, such as pedestrians and cyclists. The primary purpose of CV technology is to provide real-time data and warnings to allow road users to avoid crashes and increase road safety for all users, but it is not intended to take over driving functions. AV technology provides automated control for various aspects of driving, including steering, acceleration, and braking. The term AV covers a broad range of automated functions, from partial to full automation. The term CAV allows for the beneficial combination of the two technologies to provide a redundant source of data for AVs and to enable cooperation between vehicles, the infrastructure, and other road users.

Currently, CVs and AVs are pursuing parallel technological and policy paths and their relationship is evolving. The major national stakeholders, including the United States Department of Transportation (USDOT) and state transportation agencies, are actively considering the impact of both CVs and AVs and are encouraging a supportive relationship between these technologies. State departments of transportation (DOT) are carrying out pilot CV deployments using roadside communication technology with the understanding that this technology will also support future AV deployments. The goal for most stakeholders is to achieve the potential benefits of widespread CAV deployment, although many technical and institutional hurdles remain.

CAV Goals

The CAV Strategic Plan provides mission and vision statements and a set of goals for CAV that are consistent with Caltrans' priorities and the nearly completed Caltrans Strategic Plan. The CAV goals in this plan target each of these Caltrans goals:

- Safety first
- Cultivate excellence
- Enhance and connect the multimodal transportation network
- Strengthen stewardship and drive efficiency
- Lead climate action
- Advance equity and livability in all communities

California's Progress Toward CAV Deployment

Over the past three decades, Caltrans and California Partners for Advanced Transportation Technology (PATH) have developed a strong partnership, emerging as leaders in research and testing of CAV technology. Caltrans and PATH were both original members of the National Automated Highway System Consortium that conducted the groundbreaking demonstration of automated driving systems on I-15 in San Diego in 1997. California was the first state in the country to embrace work on the vital CV technology of 5.9 gigahertz (GHz) dedicated short-range communications (DSRC) and implement the first public roadside DSRC installation. Furthermore, Caltrans has been an active member of the CV Pooled Fund Study (PFS), a group of over 20 state and local transportation agencies focused on preparing for the deployment of CV infrastructure.

More recently, California became one of the first states to issue regulations governing driverless testing and the public use of AVs on public roads when the California Department of Motor Vehicles (DMV) issued AV regulations in early 2018. At the same time, PATH has been developing and testing Level 1 automated driving systems (ADS) on full-scale vehicles (truck platooning and bus lateral guidance), developing new methods for applying deep learning to driving automation, defining a research roadmap for Caltrans on CAVs, and providing technical support to DMV for the development of their regulations on ADSs. California has at least eight on-road CV testing sites, either developed or under development, and three AV proving grounds where AV manufacturers can test their vehicles safely in a controlled setting.

CAV Stakeholder Input

The Caltrans CAV Strategic Plan project is led by the Caltrans Division of Research, Innovation and System Information (DRISI). The project involved three major stakeholder activities. The first activity was 17 interviews with personnel across Caltrans divisions and districts, as well representatives from the California State Transportation Agency (CalSTA) and California DMV. The second activity was an interactive virtual CAV workshop with 35 participants held on July 24, 2020. The final stakeholder activity, carried out under a separate Caltrans-funded project, was a survey of the AV industry conducted online and through follow-up interviews to gather information on how infrastructure impacts AV performance.

Most of the stakeholders who participated in the interviews and the CAV workshop believe that CAV will have a meaningful impact on Caltrans. While many believe that widespread deployment is still many years out, they believe that Caltrans should prepare now, especially considering that not all outcomes of this change could be beneficial. Almost everyone who was interviewed stated that safety was the number-one goal of Caltrans and that CAV can eventually have a positive impact on safety. Most staff who were interviewed felt it was important that Caltrans be a strong partner to support CAV deployment in California. Many staff suggested the need for additional funding and greater organizational support and coordination with respect to CAV. The general consensus is that new skill sets would be needed within Caltrans to support CAV deployment, including data science, systems engineering, computer science, and other high-tech skills. Finally, while there was no clear consensus on whether Caltrans should lead a statewide CAV consortium, a majority of the respondents believed that Caltrans should focus its leadership on the infrastructure aspects of CAV deployment and that any CAV consortium that is set up in California should be tailored to the state's unique attributes and goals.

CAV Action Plan

The CAV Action Plan is based on the findings from these stakeholder activities. The project team identified 40 possible actions that Caltrans should take to better prepare for future CAV deployments. Many of the actions were suggested directly by interviewees, and some were inferred by the project team. The actions are grouped into six areas:

1. Organizational change and workforce development
2. Planning and programming
3. Pilot deployments and testing
4. Deployment readiness
5. External outreach and partnerships
6. Policy

Each action is rated as either near term (within two years) or medium term (three to five years) and is tentatively assigned to a specific Caltrans division to take the lead on executing that action. In some instances, supporting divisions are identified. Implementation of each action is subject to resource availability.

CAV Action Plan

ID	CAV Action	Phase	Responsible Parties (lead party is in *italics*)
	Organizational Change and Workforce Development		
1.1	Coordinate CAV actions with the Caltrans Innovative Leadership Council	Near term	*DRISI*
1.2	Establish an internal CAV working group	Near term	*DRISI*
1.3	Establish an internal CAV outreach and awareness program	Near term	*DRISI*
1.4	Provide internal CAV training to practitioners	Medium term	*DRISI* and HR
1.5	Build new skill sets within the Caltrans workforce	Medium term	*DRISI* and HR
1.6	Investigate the need for new CAV positions, a new CAV group, or other organizational changes at Caltrans	Medium term	*DRISI* and HR (with approval from Director's Office)
1.7	Increase Caltrans procurement process flexibility	Medium term	*Administration*
	Planning and Programming		
2.1	Develop a CAV Implementation Plan	Near term (underway)	*Traffic Operations*, DRISI, Design, DES, Maintenance, Planning
2.2	Investigate opportunities for additional CAV funding	Near term/ continuous	*DRISI*
2.3	Conduct a risk assessment of alternate CAV rollout scenarios	Near term	*Risk and Strategic Management,* Planning
2.4	Integrate CAV into the Caltrans planning process	Near term (underway)	*Planning*
2.5	Update SHOPP and STIP structure and definitions	Near term	*Programming*
2.6	Develop a plan for upgrading the Caltrans IT and telecommunications network to support CAVs	Near term	*IT*, Traffic Operations, Design
2.7	Devise more-precise factors for CAV to be analyzed in planning models	Medium term	*Planning*
2.8	Update ITS architectures to incorporate CAV	Medium term	*Planning*, Traffic Operations
2.9	Investigate possible changes to roadway design standards resulting from widespread CAV deployment	Medium term	*Design*, DES

CAV Action Plan

ID	CAV Action	Phase	Responsible Parties (lead party is in *italics*)
Pilot Deployments and Testing			
3.1	Expand existing CAV testbeds and add new CAV testbeds	Near term	*DRISI* and Districts
3.2	Publish a complete list of California CAV testbeds and their assets	Near term	*DRISI* and Districts
3.3	Partner with CHP, DMV, and the AV industry to capture additional safety data regarding CAVs	Near term	*Legal*, Safety
3.4	Conduct pilots to study how safely and efficiently CAVs operate in specific operational settings	Medium term	*Traffic Operations*, Districts, DRISI
3.5	Partner with transit agencies on CAV pilots that have a goal of multimodality	Medium term	*Department of Rail and Mass Transportation*, Planning, Districts, DRISI
3.6	Partner with regional and local agencies on CAV pilots that have a goal of increasing walking and biking, reducing VMT, and improving safety for vulnerable road users	Medium term	*Planning*, Districts, DRISI
3.7	Partner with agencies, such as CHP, and other states to support innovation in freight movement, such as truck platooning	Near term (underway)	*DRISI*, Planning, Districts
3.8	Use CAV technology to increase the safety of Caltrans staff near incident scenes and work zones (multiple pilots)	Medium term	*Safety*, Construction, Equipment, Maintenance, Districts, DRISI
Deployment Readiness			
4.1	Investigate need for CAV design standards for California's physical infrastructure and implement as needed	Near term	*Traffic Operations*, Safety, Design, DES
4.2	Investigate the need for CAV design standards for	Near term	*Traffic Operations*, IT
4.3	California's digital infrastructure and implement as needed Install and maintain clear and conspicuous pavement markings and standardized roadway signage	Near term (underway)	*Construction*, Maintenance
4.4	Provide CAV guidance to the districts and local agencies	Medium term	*Traffic Operations*, Maintenance, DRISI, Districts
4.5	As defined in the CAV Implementation Plan, strategically upgrade Caltrans infrastructure to make it CAV-ready	Medium term	*Traffic Operations*, Maintenance, Districts
4.6	Pilot the use of state-owned, CAV-equipped fleet vehicles	Medium term	*Equipment*, Districts
4.7	Build out IT and telecommunications network per IT upgrade plan (from Action 2.6)	Medium term	*IT,* Traffic Operations, Design

CAV Action Plan

ID	CAV Action	Phase	Responsible Parties (lead party is in *italics*)
External Outreach and Partnerships			
5.1	Participate in federal CAV stakeholder efforts	Near term	*DRISI*, Traffic Operations
5.2	Engage with the AV industry to better understand how infrastructure and data from infrastructure impacts CAV operations	Near term (underway)	*DRISI*, Maintenance, Traffic Operations, Design, DES
5.3	Develop a Communications and Outreach Plan	Near term	*DRISI*
5.4	Share CAV information and best practices through partnerships with regional and local transportation agencies, other state agencies, and the private sector	Near term	*DRISI*
5.5	Explore new public-private business models to facilitate CAV deployment	Medium term	*DRISI*, Operations
Policy			
6.1	Work with CalSTA to identify gaps in laws, regulations, policies, and practices related to implementing CAV technologies and infrastructure	Near term	*Traffic Operations*, CalSTA
6.2	Monitor federal CAV policy to support and inform California CAV implementation	Near term	*Traffic Operations*, CalSTA
6.3	Pursue related federal grant opportunities that build on existing CAV efforts	Near term	*DRISI*, Traffic Operations, Districts
6.4	Review and update existing Caltrans policies and procedures to consider CAV	Medium term	*Traffic Operations*, Safety, Maintenance, Design

The CAV Action Plan is a convenient tool for charting a path forward for Caltrans, but the project team recognizes that questions remain regarding how CAV fits within Caltrans. Many fundamental questions arose in our discussions, such as:

- How will CAV contribute to or detract from the Caltrans policy goals, and which additional policies need to be implemented to put the right controls in place?
- To what extent should CAV have a separate identity in the organization, and to what extent should it be widely integrated?
- How would this "identity of CAV" affect planning, budgeting, and funding?
- Is CAV a technology, such as Intelligent Transportation Systems (ITS), or a program, such as Complete Streets?
- Many actions in the plan either involve, or depend on, specific knowledge of CAV deployment and operations. Real planning cannot occur without demonstrable expertise and direct experience with AVs, CVs, and CAVs. How will the needed experience be obtained?
- Should CAV be considered on a localized basis (for example, corridors), regionally, or statewide?
- How does CAV compare with other special programs, such as managed lanes?
- What does a broad range of staff need to know about CAV? What do specialists (such as traffic operations, safety) need to know about CAV?

Not all these questions can be answered today, but the answers will become clearer as the near-term actions of the plan are implemented.

Next Steps

Completing a CAV Strategic Plan is the first major step in the CAV planning process. The Caltrans CAV Strategic Plan provides a framework on which Caltrans can better prepare for CAV deployment and start a policy development process to keep California at the forefront of this emerging industry. The actions recommended in the CAV Action Plan focus on steps that Caltrans should take within the next five years to facilitate successful, ongoing CAV deployment.

The scope of the Caltrans CAV Strategic Plan is internally focused and limited to Caltrans-led activities, but Caltrans needs to coordinate these Caltrans-led activities with broader CAV activities in California to ensure that the CAV activities support state policy goals. Caltrans should work closely with related agencies, such as CalSTA, California DMV, and California Highway Patrol (CHP), on broader CAV planning efforts while continuing to keep its focus on carrying out the CAV actions in this plan. Also, because the stakeholder outreach in this project was limited to Caltrans staff and a few related agencies, it is important for Caltrans to engage with metropolitan planning organizations (MPO) and local transportation agencies as it begins to implement the plan. Many near-term actions in this plan can be initiated in the recently awarded CAV Implementation Plan project (see Action 2.1), which will continue the work started by this planning project. Implementing the actions in this plan requires strong leadership and a concerted effort by Caltrans staff to complete the actions and continuously monitor progress and outcomes during the coming years.

CHAPTER 1

Introduction

Among the many changes that public sector transportation agencies, and notably DOTs, are experiencing, the development of CAVs is potentially transformational. Some observers consider CAVs to be a tipping point in transportation of a magnitude only seen at intervals of many decades. Therefore, CAVs create significant opportunities, challenges, and uncertainties in planning, managing, and operating the transportation infrastructure. Public agencies such as Caltrans are encouraged to undertake steps to enhance their CAV readiness and prepare for its impacts.

Project Background

This report is the culmination of a year-long effort to develop a CAV Strategic Plan for Caltrans. The purpose of the CAV Strategic Plan project is to define a vision and tactical strategy for Caltrans in preparation for CAV deployment in California and to begin a policy development process to keep California at the forefront of this emerging industry. This plan recommends actions for Caltrans to carry out in the next five years. Caltrans has a strong interest in planning for the fast-moving evolution in CAVs and intends to accelerate its leadership and outreach in this field.

The scope of the Caltrans CAV Strategic Plan is internally focused and limited to Caltrans-led activities. The primary objectives of the project are to:

- Develop a vision and goals for the Caltrans CAV program and a summary of current and planned CAV efforts both nationally and in California
- Gather input from a broad cross section of Caltrans and its partner agencies through in-person meetings and stakeholder workshops
- Summarize how CAV fits into Caltrans business processes now and in the future
- List the actions that Caltrans should take in the next five years to facilitate successful, ongoing CAV deployment
- Consolidate findings from the above tasks into a final Caltrans CAV Strategic Plan report

Detailed findings from the above tasks were compiled in a series of technical memorandums, including *State of CAV in California and the United States* and *Summary of Staff Interviews Discussing CAV Impacts on Caltrans*. This final report summarizes the technical memorandums and presents a consolidated *Caltrans CAV Strategic Plan*.

Potential Positive and Negative Impacts of CAVs

The first critical question that must be answered before any state or agency begins developing a CAV strategic plan is why do we care about CAVs? The answer is that CAV technology has the potential to save lives, provide greater

mobility for all people, make our transportation system more efficient, make California more economically competitive, and make our environment and people healthier. At the same time, CAVs could have unintended negative consequences if deployed without proper attention and planning.

Safety—USDOT research has shown that more than 90 percent of traffic-related fatalities are caused by human error.[1] Connectivity and automation have the capacity to mitigate human errors and save lives on a scale well beyond other safety countermeasures. However, while CAVs have great potential to increase safety, drivers could trust too much in early CAV systems before they have been proven to be fully reliable.

Mobility and equity—CAV deployments could reduce transportation barriers by providing more transport choices and allowing people broader access to live, work, and play where they choose. For example, CAVs could provide first- and last-mile solutions that make mass transit more accessible in all communities. One risk is that CAVs might not be widely available in all communities.

Efficiency—CAVs have the potential to reduce traffic congestion and use our transportation infrastructure more efficiently. Research has shown that when fully deployed, CAVs can increase freeway capacity by 92 percent.[2]

Economic competitiveness—CAV technology can provide opportunities to improve and ease the movement of people, goods, and services and create jobs and new public-private partnerships in a growing industry.

Health and environmental impacts—If CAVS are deployed as part of a rideshare business model that encourages less single-occupant driving, they can help create a more sustainable and less carbon-intensive transportation system. On the other hand, if they are not deployed with a ridesharing strategy, CAVs have the potential to increase vehicle miles traveled (VMT), which could increase vehicle emissions and negatively impact our environment.

Basics of CAV Technology

CAV technology includes many different aspects, and the terminology surrounding this technology continues to grow and evolve. It is important to understand the differences between CV and AV technologies and the basic concepts of CAV and cooperative automated transportation (CAT).

CV technology refers to robust, standardized vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and vehicle-to-everything (V2X) communication, broadly representing communication between vehicles, infrastructure, and other road users, such as pedestrians and cyclists. V2V technology is typically applied to in-vehicle safety applications. V2I involves connectivity between vehicles and the infrastructure, and it interfaces with traffic signals, dynamic message signs, and other traffic control devices.

The purpose of CV technology is to provide real-time data to quantify crash risks and deliver warnings to help road users avoid crashes. Although CV technology is not intended to provide automatic intervention, it can provide AV technology with an additional source of information. On-board applications use standardized packets of data (position, speed, and direction) to derive warnings related to specific types of traffic conflicts and resulting

[1] https://www.nhtsa.gov/technology-innovation/automated-vehicles-safety

[2] http://www.virginiadot.org/vtrc/main/online_reports/pdf/21-r1.pdf

crashes. Other applications that are not directly related to safety can use the same data to smooth traffic flow, reduce energy use, and reduce emissions. But regardless of the end purpose, CV technology is intended only to provide warnings to drivers and other road users and does not automatically take corrective action.

In contrast, AV technology provides driving control in relation to steering, acceleration, and braking. The term AV covers a broad range of automated functions, both in terms of the extent to which it replaces functions of the human driver and the intended operating environment. Depending on the intended functionality—from partial to full automation—the AV's ADS includes the elements of sensing, communicating, monitoring, navigating, decision-making, behavior, and driving control required for the AV to progress in traffic. An ADS is designed and evaluated for certain types of operations on public roads and to satisfy safe driving guidelines. An ADS can be designed for one or more operational design domains (ODDs). An ODD can include physical restrictions, such as dedicated lanes and geo-fenced areas and require specific road classifications, traffic conditions, time of day, and weather conditions.

The widely referenced Society of Automotive Engineers (SAE) Standard J3016, *Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles*, identifies six driving automation levels from no automation (Level 0) to full automation all the time (Level 5).[3] See Figure 1 for an explanation of the six levels of automation.

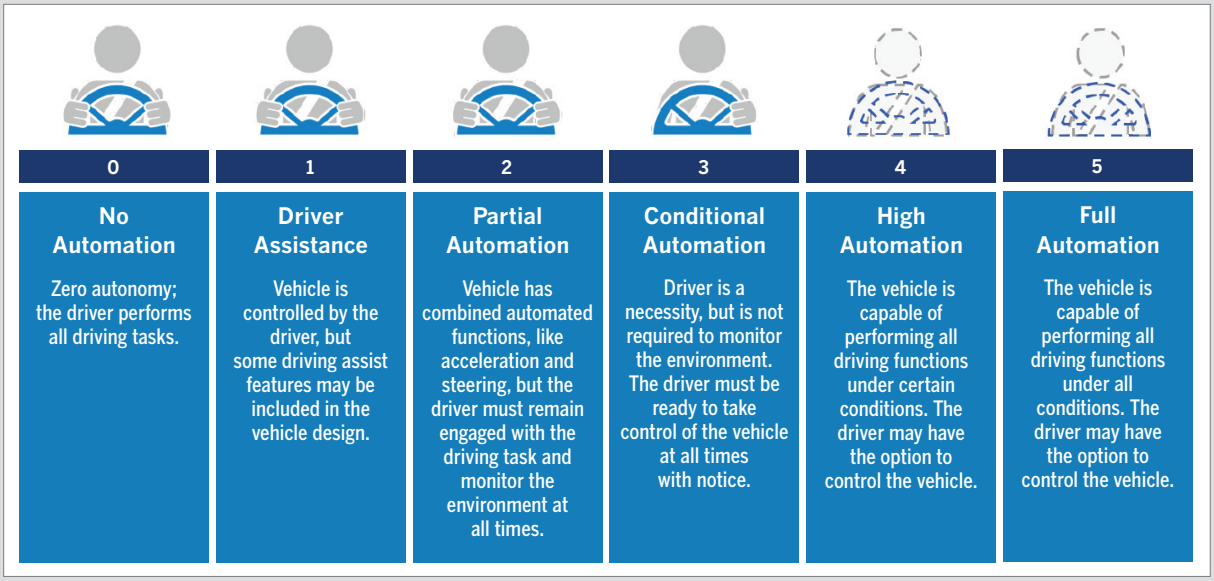


FIGURE 1. SAE Levels of Vehicle Automation (source: SAE)

USDOT has integrated this standard into its guidelines for safe testing and deployment of AVs, thereby aligning and formalizing a commonly used shorthand for quickly and concisely categorizing AV technologies and capabilities. Highly automated vehicles (HAV), those comprising Levels 3, 4, and 5, are often distinguished from the lower levels of automation (Levels 0–2) that we see on the roadway today. The term "autonomous vehicle" is often used to refer to a fully automated Level 5 vehicle.

[3] http://standards.sae.org/j3016_201401

Currently, CVs and AVs are pursuing parallel technological and policy paths and their relationship is evolving. The major national stakeholders, including USDOT and state transportation agencies, are actively considering the impact of both CVs and AVs and are encouraging a supportive relationship between these technologies. DOTs are carrying out CV pilot deployments through the provision of roadside communication technology with the understanding that this technology will also support future AV deployments.

The common use of the term "connected and automated vehicle" allows for the beneficial combination of the two technologies, as shown in Figure 2. In this context, CV can be regarded as an additional data input or "sensor" in the ADS's suite of sensors. Many uses of the term CAV are driven mainly by the AV component. The terms CV and AV are often used separately as well.

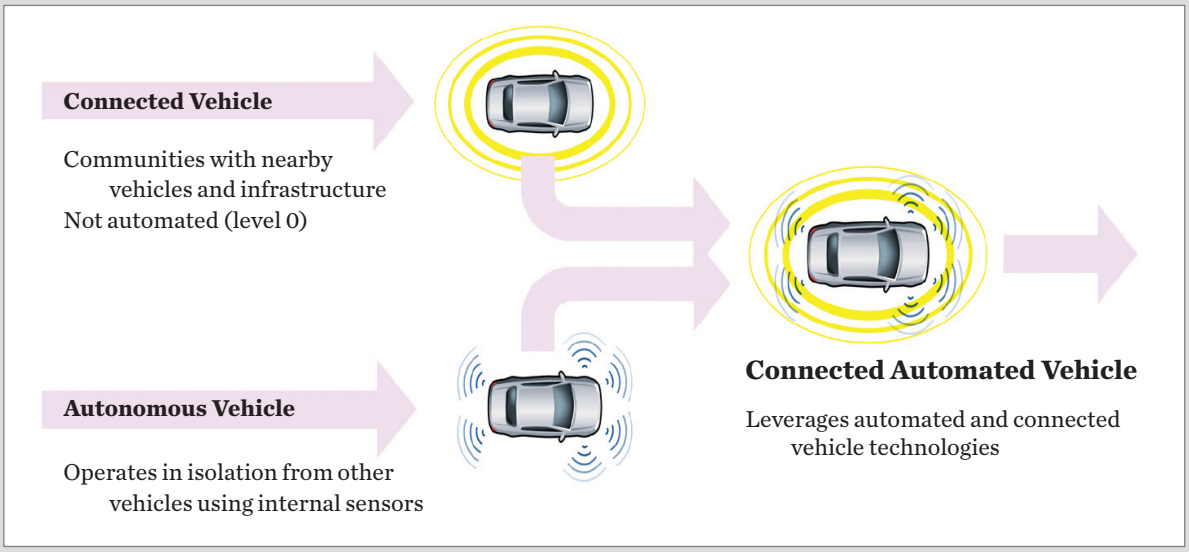


FIGURE 2. CAV Combines CV and AV Technology (source: USDOT)

In the United States and Europe, the term CAT encompasses CAV technologies but also brings elements of usage into the picture, expanding the scope from just vehicles to the possible inclusion of trips, traffic, and transportation systems comprising several modes. Considerable attention is being focused on ride hailing, ridesharing, mobility on demand (MoD), and mobility as a service (MaaS). Other terms with a similar overall meaning are being used overseas, including "connected and automated driving" and "Cooperative Intelligent Transportation Systems." In this report, consider CAT as a broader multimodal mobility concept encompassing MoD. CAT nevertheless relies on CAV as its most central enabler, and we refer to CAV throughout this document.

Readiness of CAV Technology

While the quantity and maturity of CAV technologies and activities continues to grow and evolve, here is the current state of technology readiness for CVs, AVs, and the supporting infrastructure.

CONNECTED VEHICLES

CV technologies include licensed wireless communications systems, such as DSRC, that operate on a dedicated band of radio frequency known as the 5.9 GHz band, as well as the newer cellular technologies, such as cellular V2X (C-V2X) and the forthcoming fifth-generation wireless network, 5G. Collectively, these CV technologies are often referred to as V2X.

CV technology using DSRC is well researched, and robust standards are available. It is ready for production vehicles, as evidenced in announcements by original equipment manufacturers (OEM), such as General Motors (GM) and Toyota. Similarly, considerable research and development effort has been recently devoted to V2I technology and applications using DSRC. Work led by the Federal Highway Administration (FHWA) and the Collision Avoidance Metrics Partnership has developed an increased range of V2I applications. The FHWA has developed standards for the connections between roadside DSRC units and traffic controllers, and controller companies have developed products based on these standards. In addition, many states have deployed CV technology, both DSRC and C-V2X, on key corridors throughout the country in a variety of geographic environments, roadway scenarios, and weather conditions.

In January 2017, the National Highway Traffic Safety Administration (NHTSA) issued a notice of proposed rulemaking (NPRM) for V2V communications that would have required all future vehicles to install DSRC technology. However, this NPRM was never acted upon, and it was left to the OEMs to determine the applicable standards and timing for inclusion of V2V and V2I functionality in new vehicles. Since then, some OEMs, including GM and Toyota, stated a preference to use DSRC, and some, such as Ford, said they preferred the C-V2X methodology. This uncertainty in the marketplace has led to a slower rollout of CV technologies.

A recent action by the Federal Communications Commission (FCC) has created even greater uncertainty. In December 2019, the FCC issued an NPRM that would open a significant portion of the currently reserved 5.9 GHz band for non-licensed users. Under current law, all 75 megahertz (MHz) of the band is reserved for transportation safety uses. The NPRM proposal would keep the upper 30 MHz of the band dedicated to transportation safety purposes while making the lower 45 MHz available for unlicensed operations to support high-speed broadband applications. On November 18, 2020, the FCC adopted a First Report and Order (First R&O), Further Notice of Proposed Rulemaking, and Order of Proposed Modification related to its proposal to reallocate the 5.9 GHz safety spectrum band. As summarized by the Intelligent Transportation Society of America,[4] this First R&O basically follows the original FCC proposal of allowing unlicensed use on the lower 45 MHz and restricting transportation safety uses to the upper 30 MHz. It also requires all CV applications that use the band to transition from DSRC technology to C-V2X technology over a yet to be determined transition period.

This FCC action will clearly have a major impact on the CV industry. It is likely to reduce the number of radio channels available for transportation safety applications and force some OEMs and transportation agencies to shift from DSRC to C-V2X technology. However, nothing yet is set in stone. There will be an extended comment period and many details to work out, so nobody knows how it will turn out. Despite the uncertainty that this action brings, OEMs are still likely to deploy CV technology in some form, and states and local agencies need to plan for it.

[4] https://itsa.org/wp-content/uploads/2020/10/FCC-5.9-GHz-Report-and-Order-Summary-ITS-America.pdf

AUTOMATED VEHICLES

Examples of new AV technologies and vehicle types are vast, and new concept vehicles, prototypes, test vehicles, and early field trial vehicles seem to appear every year at major events, such as the Consumer Electronics Show in Las Vegas and the Los Angeles AutoMobility event. Additionally, there have been several high-profile partnerships and deals between traditional OEMs and AV technology providers in recent years. Some notable examples include the GM acquisition of Cruise, a self-driving car company, in 2016 for over $1 billion and Ford's $1 billion investment in Argo AI, an autonomous driving technology company, in 2017.

From the perspective of the OEM, many of the basic challenges associated with enabling Level 1 and 2 driving have been solved as extensions of driver-assist technologies. In fact, Level 2 vehicles are commercially available and becoming more common. Such vehicles are often privately owned and still under the control of a human driver. In contrast, ADSs capable of driverless operation and intended to underpin a new on-demand mobility system are still in development, including all HAVs intended for fleet operation in defined environments. While there is a growing number of automated test fleet deployments, such ADSs are far from mature or commercially viable, and these technologies are highly competitive and closely guarded.

Current efforts by OEMs and AV manufacturers are oriented around developing artificial intelligence (AI) software for vehicular control. Developers have achieved meaningful advancements in two categories of AI that are best positioned to solve the complex challenges associated with higher levels of automated driving: machine learning and deep learning. It is intended that ADS software will have a "self-learning capability" that recognizes and corrects driver misperceptions and misbehaviors.

There have also been major developments in AV sensor technology. Many view Light Detection and Ranging (LIDAR) technology, which is able to accurately gauge a vehicle's surroundings in many complex situations, as essential to enabling higher levels of automation. Major efforts continue to reduce the size and cost of historically bulky and expensive units. The sensor suites used in AVs are changing rapidly and will continue to do so. They can also require frequent updating and continuous maintenance.

INFRASTRUCTURE

The continued engagement of infrastructure owner operators (IOO) is crucial to preparing roads for CAVs. While HAVs can be tested in off-roadway facilities, all companies engaged in AV development place high value on miles logged on public roadways. Most manufacturers maintain a position of non-reliance on infrastructure assistance, although improved road maintenance in relation to markings, signage, and road surface condition—and their national consistency—is an important factor in the deployment of HAVs. There is an emerging sense that IOOs can apply "no regrets" actions in the infrastructure, such as wider, higher-contrast lane markings, with the understanding that it benefits drivers of both AVs and non-AVs. However, OEMs remain reluctant to provide IOOs with definitive infrastructure guidance for the operation of ADSs. Important infrastructure issues include real-time information regarding work zones and other road conditions, pick-up and drop-off areas (including curb design and access), use of dedicated or managed lanes, and dynamic lane assignment.

FHWA has awarded multiple ADS Demonstration Grants to specific combinations of IOOs, universities, and private companies. These collaborative demonstrations include data architecture development on the part of the IOOs and focus on the safe integration of HAVs in the transportation system. The grants provide a good opportunity for IOOs to engage in CAV development and testing.

Impacts of COVID-19 Pandemic

The novel coronavirus known as COVID-19 will have major impacts on transportation, certainly in the near term and possibly in the long term. How exactly this pandemic will impact CAV deployment is difficult to determine at this time, but its potential impacts need to be considered as Caltrans moves forward with implementing its CAV Strategic Plan. At the time of this writing, COVID-19 impacts are already being felt in dramatic ways, but it remains to be seen if those impacts will last beyond this pandemic as well as how they could potentially affect CAV deployment.

CHAPTER 2

Caltrans CAV Mission, Vision, and Goals

The project team and the Caltrans personnel participating in this study based the mission, vision, and goals for CAV on the current priorities of California's state government and Caltrans as an organization.

California State Priorities

California has long been a leader when it comes to protecting the environment, and the environment has become an even greater priority for the state as evidence of climate change continues to mount. On September 20, 2019, Governor Newsom issued Executive Order N-19-19,[5] which proposes a bold climate agenda directing every agency of state government to redouble their efforts to reduce greenhouse gas (GHG) emissions and mitigate the impacts of climate change. Specifically, CalSTA is directed to:

- Align the state's climate goals with transportation spending where feasible
- Reduce VMT by strategically directing discretionary transportation investment in support of housing production near available jobs and in accordance with the state's smart growth principles
- Reduce congestion through innovative strategies designed to encourage people to shift from cars to other modes of transportation
- Fund transportation options that contribute to the overall health of Californians and reduce GHG emissions, such as transit, walking, and biking
- Mitigate increases in transportation costs for lower-income Californians

On September 23, 2020, Governor Newsom went a step further by issuing Executive Order N-79-20.[6] This order states that by 2035, all new cars and passenger trucks sold in California must be zero-emission vehicles. Because transportation currently accounts for more than 50 percent of California's GHG emissions, this order aggressively moves the state further away from its reliance on climate change–causing fossil fuels while creating jobs and spurring economic growth.

With respect to CAVs, California has adopted similar goals and priorities. The California Multi-agency Workgroup on AVs developed draft public policies for AVs that are primarily related to sustainability and public health. The group comprised staff from several California agencies, including Caltrans, California Environmental Protection Agency, CalSTA, DMV, California Air Resources Board, Department of Public Health, California Energy Commission,

[5] https://www.gov.ca.gov/wp-content/uploads/2019/09/9.20.19-Climate-EO-N-19-19.pdf
[6] https://www.gov.ca.gov/wp-content/uploads/2020/09/9.23.20-EO-N-79-20-Climate.pdf

and Office of Planning and Research. According to the group's principles, which are described in detail on the OPR website,[7] AV deployments shall prioritize:

- Shared use
- Low emissions
- Right-sized
- An efficient multimodal system that:
  Strengthens high-quality transit service rather than duplicating it
  - Replaces low-quality transit service
  - Strengthens active transport
  - Provides efficient freight transport and delivery
- Efficient land use
- Complete and livable streets
- Transportation equity

California's transportation priorities are clearly focused on protecting the environment and ensuring equity for its citizens, and these important state priorities need to be a foundation of the mission, vision, and goals being developed for the Caltrans CAV Program.

Caltrans Priorities

Caltrans' priorities as an organization closely align with the state's priorities of protecting the environment and ensuring transportation equity. These priorities are demonstrated in two major plans: *Caltrans Strategic Plan* and *California Transportation Plan (CTP) 2050*.

CALTRANS STRATEGIC PLAN

Caltrans is currently in the process of developing a new strategic plan, which is expected to be completed in early 2021. The mission, vision, and goals that are in the draft plan have been finalized and closely align with California's transportation priorities of protecting the environment and ensuring equity for its citizens.

The Caltrans mission is to "provide a safe and reliable transportation network that serves all people and respects the environment." Caltrans' vision is "a brighter future for all through a world-class transportation network."

Caltrans has established the following six goals as an organization:

- Safety first
- Cultivate excellence
- Enhance and connect the multimodal transportation network
- Strengthen stewardship and drive efficiency
- Lead climate action
- Advance equity and livability in all communities

[7] https://opr.ca.gov/docs/20181115-California_Automated_Vehicle_Principles_for_Healthy_and_Sustainable_Communities.pdf

CALTRANS TRANSPORTATION PLAN 2050

CTP 2050 is the state's long-range transportation plan that articulates strategic goals, policies, and recommendations to improve multimodal mobility and accessibility while reducing GHG emissions.[8] The purpose of the plan is to present innovative, sustainable, and integrated multimodal mobility solutions, including CAVs, to help guide the planning and implementation of a low-carbon transportation system. The plan, which is expected to be published in early 2021, aims to address many objectives, such as:

- Improving travel times and easing traffic congestion
- Increasing safety and security on bridges, highways, and roads
- Fostering healthy lifestyles through active transportation
- Expanding economic opportunities through the movement of people, freight, services, and information
- Creating a low-carbon transportation system that protects human and environmental health

Caltrans CAV Mission, Vision, and Goals

It is important that the Caltrans CAV mission, vision, and goals support California's transportation priorities and Caltrans' organizational goals, which both emphasize protecting the environment and ensuring transportation equity.

The Caltrans CAV mission is: "Manage the infrastructure necessary for the safe, efficient, and reliable application of CAV technologies on a transportation system that serves all people and protects the environment."

Its vision is: "A safe, efficient, reliable, clean, and equitable transportation system supported by CAV technologies."

These CAV goals align with each of the six Caltrans goals from the recent Caltrans Strategic Plan.

Safety first—Partner with industry and other agencies to deploy CAV in a manner that enhances the safety of the traveling public and the Caltrans workforce.

Cultivate excellence—Leverage Caltrans CAV activities to cultivate excellence in the Caltrans workforce and operations.

Enhance and connect the multimodal transportation network—Utilize CAV technologies to enhance the effectiveness of all transportation modes and reduce VMT.

Strengthen stewardship and drive efficiency—Partner with industry and other agencies to deploy CAV in a manner that maximizes efficient use of the infrastructure and long-term value from public investment.

Lead climate action—Partner with industry and other agencies to deploy CAV and related technologies to reduce GHG emissions and improve resilience of the transportation system to climate change.

Advance equity and livability in all communities—Foster the equitable deployment of CAV technologies to advance accessibility and livability in all communities.

[8] https://dot.ca.gov/programs/transportation-planning/california-transportation-plan-2050

CHAPTER 3

CAV Developments in California

California was an early player in researching and developing CAV technology and has been a leading state in terms of setting regulations for safe operation. It is currently active in testing and deploying CVs and AVs, with some projects being funded or led by public sector agencies, and others by the private sector and industry consortiums. Caltrans, together with other agencies, advocates integrating CAV considerations into all aspects of transportation planning in the state. This CAV Strategic Plan is an important step in creating an environment that supports successful CAV testing and deployment in a manner that also supports state policy goals.

History of CAV Leadership in California

California's entry into the field of automated driving started with the formation of California PATH, a research program founded in 1986 through a collaboration between Caltrans and the University of California, Berkeley that is dedicated to solving transportation problems through advanced ideas and technology. Over the past three decades, Caltrans and PATH have developed a strong partnership, emerging as international leaders in research and testing of CAV technology. Caltrans and PATH were both original members of the National Automated Highway System Consortium that conducted the groundbreaking demonstration of automated driving systems on the I-15 in San Diego in 1997 (see Figure 3).

FIGURE 3. Automated Highway System Demonstration in San Diego in 1997 (source: PATH)

California was the first state in the country to embrace work on the vital CV technology of 5.9 GHz DSRC. Caltrans and the San Francisco Bay Area's Metropolitan Transportation Commission supported demonstrations of the then-new technology at the 2005 ITS World Congress in San Francisco and implemented the first public roadside DSRC installations in the country. Caltrans and PATH currently have 16 signalized intersections equipped with DSRC along a three-mile stretch of El Camino Real in Palo Alto and are in the process of expanding that to an additional 15 intersections, as shown in Figure 4.

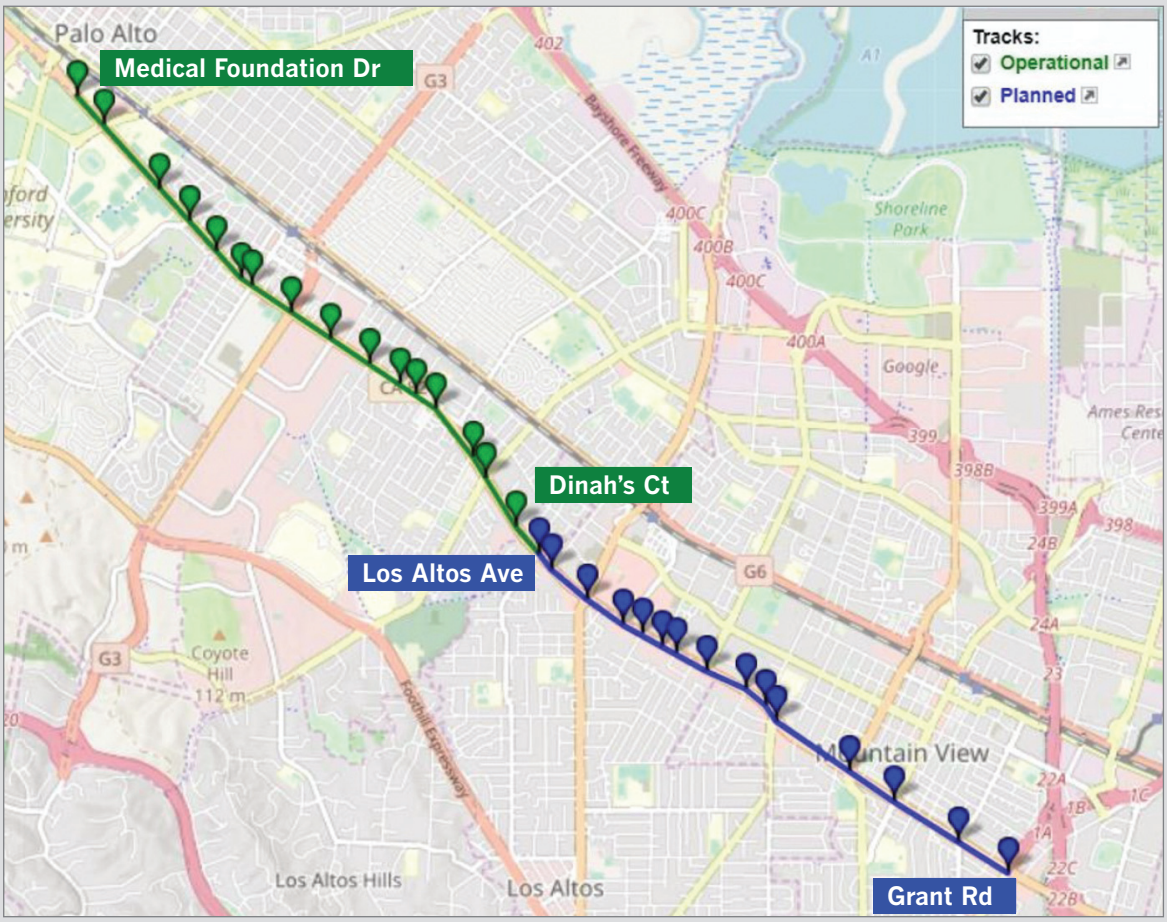


FIGURE 4. California Connected Vehicle Testbed (source: PATH)

Furthermore, Caltrans has been an active member of the CV Pooled Fund Study,[9] a group of over 20 state and local transportation agencies focused on preparing for the deployment of CV infrastructure. The PFS members are in their tenth year of a multiphase program that facilitates field demonstrations, deployment, and evaluation of CV infrastructure and applications at the local level. Caltrans and PATH (in collaboration with the University of Arizona) were involved in one of the more high-profile PFS projects: the development and field testing of a Multi-Modal Intelligent Traffic Signal System (MMITSS), which was successfully demonstrated on California's CV Testbed in 2015. This demonstration is noteworthy because it involved the integration of MMITSS software and

[9] http://www.cts.virginia.edu/cvpfs

DSRC technology into Caltrans' operated traffic signal controllers in a live traffic environment. MMITSS demonstrated the potential to improve traffic operations along the corridor through better signal timing and reduced idling, and also offering safer conditions for pedestrians and cyclists.

More recently, California became one of the first states to issue regulations that govern driverless testing and public use of AVs on public roads when the DMV issued AV regulations in early 2018. At the same time, PATH has been developing and testing Level 1 driving automation systems on full-scale vehicles (truck platooning and bus lateral guidance), developing new methods for applying deep learning to driving automation, defining a research roadmap for Caltrans on CAVs, and providing continued technical support to the California DMV on their regulations for automated driving systems.

Current CV Deployment Activities

Most CV activities in California have been led by the public sector. As described above, Caltrans and PATH have been operating a CV testbed in Palo Alto since 2005. Starting in 2019, Caltrans has been working with PATH to expand the testbed size from its current 16 intersections to 31 intersections between Medical Foundation Drive in Palo Alto and Grant Road in Mountain View (see Figure 4). This expansion is expected to be completed in 2021 and will support future testing of an operational transit signal priority application through a partnership with the Santa Clara Valley Transit Authority, who will operate up to five CV-equipped buses along the corridor.

Other CV applications to be tested include red light violation warning, pedestrian safety, and bicycle detection and priority. It is expected that this CV corridor will serve as a model deployment that can be duplicated on similar corridors in other urban regions of California.

In addition to the CV Testbed in Palo Alto, these seven CV deployment sites have been installed or programmed by state and local transportation agencies:

- City of Anaheim deployment of DSRC at 26 signalized intersections near Disneyland
- Los Angeles County Metropolitan Transportation Authority, Los Angeles County, the City of Carson, and Volvo Group partnership on the Zero Emission Drayage Truck Demonstration Project,[10] a deployment of DSRC at ten intersections and in 20 drayage trucks near the Port of Los Angeles to enable eco-drive for freight applications
- San Diego Port Tenants Association deployment of DSRC and freight signal priority at 12 intersections near the Port of San Diego
- Los Angeles DOT ongoing deployment of DSRC and transit signal priority along 54 signalized intersections near Hollywood Boulevard (supported by a USDOT grant)
- City of Fremont planned deployment of DSRC with bicycle and pedestrian detection at up to 34 intersections on Fremont Boulevard[11]
- Caltrans District 11 planned deployment of DSRC and C-V2X devices on I-15, I-805, and SR-52 and in Caltrans fleet vehicles to enable traveler information and other CV applications
- Caltrans District 12 planned deployment of DSRC and/or C-V2X on freeway infrastructure and in Caltrans fleet vehicles to enable traveler information and other CV applications

[10] https://www.fleetowner.com/running-green/article/21703576/volvo-tests-ecodrive-technology-in-california

[11] https://fremontsmartcorridor.org/wp-content/uploads/2019/12/Fremont_Concept_Report_Nov2019.pdf

All these CV activities are led by the public sector, with the exception of the Caltrans District 11 deployment, which is supported by private sector partner Qualcomm. In addition, Caltrans and PATH have partnered with Prospect Silicon Valley, a nonprofit innovation hub, to attract additional users to the California CV testbed in Palo Alto. Prospect Silicon Valley has hosted several meetings with private sector companies describing and showcasing the features of the CV testbed. Many companies, including Toyota, Ford, and Delphi, have shared that they use the testbed to some degree to test CV applications with their DSRC-equipped test vehicles. These meetings have also led to collaborations with Silicon Valley startups to conduct additional CV research using the CV testbed.

Public Sector–Led AV Testing Activities

California has three major facilities for controlled AV testing. Caltrans is also in the process of piloting an autonomous truck mounted attenuator (ATMA). Other important projects include FHWA-funded truck platooning in an operational setting, the safe integration of ADS on roadways, and field experimenting a traffic operating system that uses CAV technology.

AV PROVING GROUNDS

California has three major AV testing sites that allow for controlled AV testing. GoMentum Station in Concord is one of the largest testing grounds for CAVs in the country. AV testing occurs in a controlled environment on the facility's roadways, and CV testing uses the facility's smart V2I infrastructure, including traffic signals. GoMentum is managed by the American Automobile Association (AAA) of Northern California with support from the Contra Costa Transportation Authority (CCTA). Recent collaborators have included Toyota Research Institute, Honda, Uber, Lyft, and EasyMile.

The San Diego Regional Proving Ground (RPG) AV testing site is managed by Caltrans District 11 in partnership with the San Diego Association of Governments and City of Chula Vista. San Diego RPG facilities include the San Diego freeways and highways, Chula Vista arterials and local streets, and Marine Corps Air Station Miramar. The RPG consortium kicked off in October 2017 with a goal of facilitating testing and validation of CAV technologies while ensuring public safety and security. Key consortium partners include Ford and Qualcomm. Qualcomm recently announced the launch of a C-V2X program at San Diego RPG to demonstrate vehicle safety and traffic efficiency.[12]

A third AV testing site was recently developed in Merced County. Located adjacent to the Silicon Valley on the former Castle Air Force Base, the California AutoTech Testing and Development Center is a purpose-planned 700-acre testing and development environment to support the needs of the rapidly changing automotive industry. The facility has been designed with guidance from the international automotive industry and research institution professionals for use as a state-of-the-art testing and development complex. The site is private and has secure access points. A range of OEMs, technology companies, and startups use it on a scheduled, shared-use basis.

[12] https://www.qualcomm.com/news/releases/2020/07/21/san-diego-regional-proving-ground-joins-efforts-qualcomm-launch-c-v2x

AUTONOMOUS TRUCK-MOUNTED ATTENUATOR PILOT PROJECT

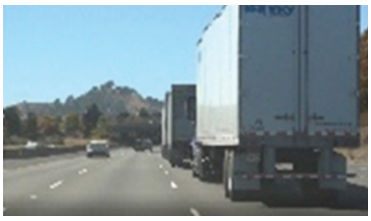
Caltrans is working with the Advanced Highway Maintenance Construction Technology Research Center at the University of California, Davis to test the ability of an ATMA to provide the same protection as a conventional truck-mounted attenuator (TMA). Caltrans highway maintenance activities often require a shadow or trailing truck equipped with a TMA to provide impact protection for workers from errant vehicles. The nature of a shadow truck, or TMA truck, dictates that it will be hit by errant vehicles, so while the TMA truck increases safety for the workers, each collision still compromises the safety and well-being of the shadow truck driver. The purpose of this project is to evaluate the ATMA truck's ability to provide the same protection to Caltrans workers as a standard TMA truck and to study the feasibility of using an ATMA in operations.

In early 2020, an ATMA was acquired from vendor Kratos and demonstrated to Caltrans Division of Equipment. The ATMA was tested again in October 2020 at the San Diego RPG on a closed section of SR-905. The test involved driving the ATMA under an actual highway overcrossing, which is a more challenging test scenario. The test encountered some technical issues related to the ATMA's ability to accurately track the leader vehicle as it traveled under the overcrossing. Caltrans is checking with other states to see if they have encountered similar issues during their ATMA testing and working with the vendor to consider potential technical solutions and next steps in the project.

FIGURE 5. ATMA in Operation (source: AHMCT)

TRUCK PLATOONING

California has always been a leading state in partially automated truck platooning. In 2018, Caltrans, PATH, and Volvo completed an FHWA-funded research project to develop and demonstrate a three-truck platoon using Co-operative Adaptive Cruise Control (CACC) technology. CACC regulates the speed of the truck using V2V communications and other sensors, allowing the trucks to follow at close headways. It has shown the potential to save 5–13 percent on fuel usage at gaps of 0.6–1.8 seconds. The three-truck platoon was demonstrated in multiple locations, as shown in Figure 6.



- 10 miles round trip on I-580
- First Volvo truck platoon demonstration in North America

Jun 2016

- 12 miles round trip on I-110
- First truck platoon demonstration in Southern California

Mar 2017

- 12 miles round trip on I-66
- First truck platoon demonstration in the DC area

Sep 2017

FIGURE 6. California Truck Platooning Project Milestones (source: PATH)

Caltrans, CHP, and the I-10 Corridor Coalition are currently supporting a new FHWA- funded project that aims to deploy and assess truck platooning in an operational setting. Led by PATH, the project partners include Westat, Cambridge Systematics, and Roly's Trucking, with technical support from Volvo. The team recently completed phase 1 of the project, which developed a comprehensive truck platooning deployment plan for an operational test. Phase 2, which was awarded in July 2020, is a one-year field test that integrates truck platooning into the daily operations of a fleet operator (Roly's) along the I-10 corridor between Los Angeles and Fort Worth, Texas.

ADS DEMONSTRATION IN CONTRA COSTA COUNTY

In September 2019, USDOT awarded $60 million to eight projects in seven states to test the safe integration of ADS on the nation's roadways. The intent is to gather significant safety data to inform rulemaking and foster collaboration among state and local governments and private partners. One of the grant recipients is CCTA, which aims to demonstrate and collect data from Level 3 and Level 4 vehicles using shared on-demand, wheelchair accessible ADS-equipped vehicles. CCTA was awarded $7.5 million to conduct three demonstration projects, shown in Figure 7. The CCTA team includes the following partners: AAA of Northern California, AMG Consultants, PATH, Lawrence Berkeley National Laboratory, Amazon Web Services, Verizon, and Intel. The project is expected to begin in early 2021.

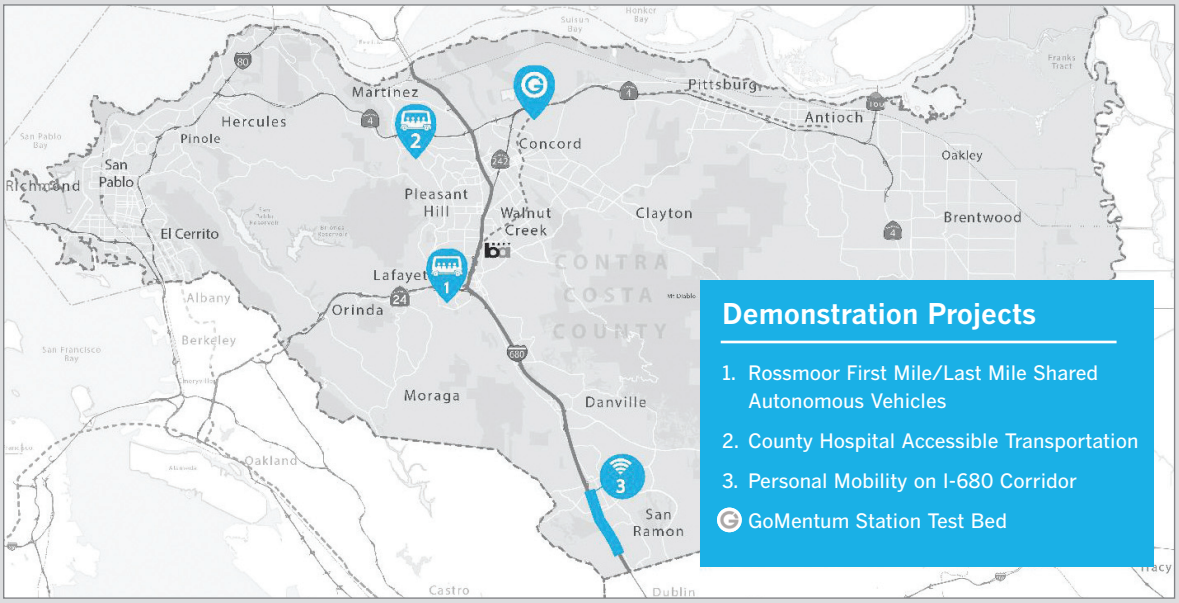


FIGURE 7. CCTA ADS Demonstration Sites (source: CCTA proposal to USDOT)

CACC DEMONSTRATION IN ARCADIA

Since 2017, University of California, Berkeley has been conducting the CAV research project, Traffic Operating System for Smart Cities, funded by the National Science Foundation. Through V2I field experiments, the project aims to develop, simulate, and test a traffic operating system that uses CAV technology to minimize congestion by increasing traffic throughput and enhance safety by reducing driver error through the use of CACC strategies.

These goals are achieved through integration of traffic measurements with the traffic management on vehicle, road link, and network levels, making effective use of a dynamic traffic model and simulation. At the vehicle level, the car speed and headway are automatically adjusted to increase throughput and safety. At the road link level, signal timings are optimized and special lanes reallocated. For example, bus lanes can be opened for all traffic when necessary. At the network level, traffic demand is managed via route advisory, day-to-day intersection timing adjustments, and traffic information dissemination.

The objectives of this project are to:

- Articulate interconnections and dependencies between different data and control levels
- Study the impact of actions at one level on the other level's performance
- Provide methodology of effective control for a given combination of technologies—sensing, actuation, and communication
- Demonstrate that the assumptions and parameters of inter-vehicle communication and dynamics used in the simulation models are reasonable and implementable in the real world

The project was successfully demonstrated in Arcadia on February 28, 2020 through a partnership with Hyundai Motor Group, Sensys Networks, and the City of Arcadia. The demonstration showed that a platoon of three CACC-enabled vehicles could safely travel through eight connected intersections on Live Oak Avenue.

Private Sector–Led AV Testing Activities

California DMV issues permits to AV manufacturers for Level 3 and above testing on California roads with and without a driver in the vehicle. As of October 15, 2020, DMV's website[13] shows 60 companies with active permits for testing with a driver, and five companies with permits for driverless testing. California-based Waymo has the largest number of testing vehicles (see Figure 8) and has completed the most miles of HAV testing in California. GM subsidiary Cruise is a close second to Waymo in terms of test vehicles and miles driven. So far, only five companies have been issued a permit to test HAVs in California without a safety driver: Waymo, Cruise, Zoox, Nuro, and AutoX Technologies. DMV requires AV testing permit holders to report all collisions and system disengagements.

FIGURE 8. Waymo's Highly Automated Vehicle (source: Wired)

In 2016, University of California, Berkeley formed the Berkeley DeepDrive (BDD) industrial consortium, an affiliate program of PATH. BDD's mission is to merge deep learning with automotive perception and bring computer vision technologies to the forefront. The BDD industrial consortium investigates state-of-the-art technologies in computer vision and machine learning for automotive applications. The consortium partners with private industry sponsors and brings in faculty and researchers from multiple departments and centers to develop new and emerging technologies with real-world applications in the automotive industry. Research is proposed by the University of California, Berkeley faculty and approved by a BDD advisory board made up of faculty and sponsor representatives. Currently, BDD has 20 industry sponsors, including major AV industry players, such as Ford, GM, Toyota, Hyundai, Continental, Panasonic, Sony, and Allstate. For a complete list of BDD sponsors and descriptions of its research activities, see the BDD website.[14]

[13] https://www.dmv.ca.gov/portal/vehicle-industry-services/autonomous-vehicles

[14] https://deepdrive.berkeley.edu

Current CAV Policy and Partnering Activities in California

California has been a leading state in setting regulations for the safe operations of AVs. Caltrans has recently adopted new policies for infrastructure maintenance to better support both AVs and non-AVs. The state has organized workshops and working groups to discuss how to prepare for CAV technology.

AV REGULATIONS

California DMV has been the lead agency for setting AV regulations in the state. On September 16, 2014, DMV released the requirements for companies to apply to test HAVs (Levels 3–5) on public roadways with a safety driver in the driver's seat. The second round of regulations took effect on April 2, 2018, which provided the requirements for true driverless testing and deployment. In 2019, Waymo was the first company to receive permission to test on California roadways without a human driver. They were followed in 2020 by AV companies Cruise, Zoox, Nuro, and AutoX Technologies.

On April 12, 2019, California DMV published proposed AV regulations that would provide the requirements for the testing and deployment of autonomous motor trucks (delivery vehicles) weighing less than 10,001 pounds on California's public roads. On December 16, 2019, the Office of Administrative Law approved a revised version of these regulations, allowing these delivery trucks to operate with an approved permit from DMV. DMV has not yet released requirements to test or deploy large trucks or vehicles weighing more than 10,001 pounds.

California DMV requires companies who want to test or operate AVs on public roads to acquire a testing or deployment permit. Testing permit holders must report all collisions and disengagements to DMV each year. All AV testing permit holders and the number of collisions reported are shown on the DMV website.[15] As of October 15, 2020, DMV had reported the following:

- 60 active AV testing permits (requires safety driver)
- 5 active AV testing permits to test without a safety driver
- 272 collisions

CALTRANS INFRASTRUCTURE MAINTENANCE STANDARDS

Caltrans has recently adopted policies for infrastructure maintenance to better support AVs and non-AVs. Caltrans adopted a new standard for pavement striping on all state highways that increases the width to six inches and heightens the contrast to improve visibility. Caltrans has decided to no longer use "Botts' Dots—the raised pavement markers on highways—because they have become too difficult to maintain and are hard to see at night. Caltrans has also adopted a new standard for signage. It is switching to retroreflective signs on all state highways to improve visibility at night. Caltrans has adopted these standards because they believe they will improve safety for both today's human-driven vehicles and the AVs of the future. These new policies for infrastructure maintenance will need to be revisited periodically based on input from the AV industry and other stakeholders. The next opportunity to do this will be during the development of the Caltrans CAV Implementation Plan (see Action 2.1 in Chapter 5).

[15] https://www.dmv.ca.gov/portal/vehicle-industry-services/autonomous-vehicles

2019 CALTRANS CAV PLANNING WORKSHOP AND WHITE PAPER

In 2019, Caltrans completed an internal CAV planning activity that included a CAV Awareness Workshop and a white paper on CAV readiness. The workshop, held on April 18, 2019 at Caltrans Headquarters in Sacramento, was organized by DRISI and facilitated by PATH and its partner CAVita. The event had over 30 attendees, including the Caltrans director and other executive-level representatives from Caltrans headquarters and districts, CalSTA, and California DMV. The outcome of the workshop included several recommendations related to CAV planning. The major recommendations were:

- Integrate CAV considerations into all aspects of transportation planning in the state
- Update California's research strategies to provide an applied research roadmap that compliments and informs the CAV strategic plan
- Establish a CAV advisory body and related CAV working groups for policy, technology, and infrastructure—this must begin with a comprehensive picture of the stakeholder community for CAV in California, both within and external to Caltrans
- Incorporate CAV technology into state fleets
- Identify workforce challenges and needs, and embolden state efforts to recruit and retain the workforce of the future to sustain CAV

The white paper, which was completed by PATH and CAVita in June 2019, focused on developing a framework to plan and prepare for CAV technology. The result of this workshop and white paper was the initialization of the current Caltrans CAV Strategic Planning effort.

AV ADVISORY BODIES AND WORKING GROUPS

Although a formal statewide council or advisory body focused on CAV issues has not yet been established, California does have at least two AV working groups that have met for the past few years. The California State Transportation Agency AV Visioning Group comprises representatives from Caltrans, CalSTA, CHP, California DMV, California Office of Traffic Safety, and other agencies. They meet periodically to discuss how to prepare for AV technology and to share information on each agency's activities related to AVs.

In addition, the California Multi-agency Workgroup on AVs was convened to look at AV policy issues primarily related to sustainability and public health. The group established a list of AV principles for healthy and sustained communities.[16]

California's Place on the Global Stage

The surface transportation field is in a transformational period. The rapid development and application of a range of communication in-vehicle and roadside technologies have both the promise and early signs of success in making our transportation system safer, more efficient, and better able to serve the needs of the traveling public and movement of goods.

[16] http://opr.ca.gov/docs/20181115-California_Automated_Vehicle_Principles_for_Healthy_and_Sustainable_Communities.pdf

A look at what has been happening around the country suggests a common thread when real progress happens. When states and localities pass core AV legislation, embrace CAVs in their mainstream transportation planning processes, and develop CAV planning and program-specific approaches, they are better positioned to respond to, partner with, and where appropriate, lead the stakeholder community in the development of a CAV responsive transportation ecosystem.

By completing this CAV Strategic Plan, Caltrans has taken an important first step to create an environment that supports successful CAV testing and deployment in a manner that also supports state policy goals. This plan is dependent on effective collaboration with public agency partners at all levels and the private sector with assistance from the academic sector—whether it is related to communication, vehicle, or infrastructure solutions.

Broader engagement with the stakeholder community is also essential. Public agencies at all levels and representative groups of affected interests, ranging from the general public and its constituencies, to the business and environmental community, all have an interest in, and are impacted by, how a CAV network will play out. Some states have created advisory bodies where multiple state agencies, public interest groups, industry, and academia come together to consider CAV in a broad context of mobility, the environment, community access, and economic development.

In the eyes of the rest of the United States, and indeed the world, California is seen as a dynamic economy, trendsetter, and conscientious steward of its physical and natural environment. With its fabric of institutional actors and abundant high-tech players, the potential partnerships in California would ensure that the public interest is richly served, tailored to individual needs, and integrated in a way that shows how CAV, deployed in a widespread and comprehensive way, should look in a vibrant, populous, civic-minded setting. Some might see this complicated setting as a barrier. Rather, it is the platform for a modern transportation system, responsive to the call that it can ensure economic prosperity for years to come.

CHAPTER 4

Stakeholder Input

To gather input from stakeholders for the Caltrans CAV Strategic Plan, PATH interviewed Caltrans, CalSTA, and California DMV staff, held an interactive CAV workshop and the AV Industry Survey, and surveyed a broad cross section of the AV industry to collect information on how infrastructure impacts AV performance.

Staff Interviews

The first major stakeholder activity in this project was to conduct face-to-face interviews with members of the Caltrans CAV Strategic Plan project panel (see Appendix A). The project panel provides broad, high-level representation across Caltrans divisions and districts and includes representatives from CalSTA and California DMV.

INTERVIEW METHODOLOGY

The first step in the CAV interview process was to develop a comprehensive questionnaire. To do this, the PATH team reviewed several state CAV strategic plans and the findings from the 2019 Caltrans CAV Planning Workshop and came up with eight major CAV themes that are of the greatest interest to Caltrans. Each theme brings up specific issues and questions raised at the 2019 CAV Workshop.

1. Significance of CAV
2. Broadening the Caltrans CAV knowledge base
3. Current opportunities for direct CAV engagement
4. CAV research strategies and testbed engagement
5. Preparation for AV deployment in California
6. Caltrans active visioning for CAV
7. Broad insertion of CAV into Caltrans' transportation planning processes
8. Caltrans CAV working method

The interview questionnaire (see Appendix B) was sent to each member of the Caltrans project panel at least one week prior to the scheduled interview. The questionnaire included several issues and questions related to each theme. The issues and questions were intended as a starting point for our discussion, so not all questions were asked in each interview. Also, because there were too many questions to cover in a 1–2 hour interview, each interviewee was asked to select which themes were of highest priority from their perspective. We asked that all interviewees cover themes 1 and 8 because those themes were particularly broad. We then requested that each interviewee select their two most important themes among themes 2 through 7.

For most of the themes, the questionnaire used the following format:

> ***x.*** ***Theme* of high overall relevance to Caltrans**
>
> x.y *Issue* of concern to the panel
>
> - First *question* to explore issue with panel member
>   - Second question…….

The PATH team conducted interviews with 17 of the 20 project panel members between February and April 2020. The first eight interviews were face-to-face meetings between the PATH team and project panel members with members of their team. The last nine interviews had to be conducted via web meetings due to COVID-19 travel restrictions. Project panel members were encouraged to invite members from their team to participate in the interview. In total, 54 staff members from Caltrans, CalSTA, and California DMV participated in the 17 interviews. The following summary is a brief synopsis of the findings only from themes 1 and 8. The major findings from themes 2 through 7 are captured in the CAV Action Plan presented in Chapter 5.

SUMMARY OF INTERVIEW FINDINGS

In general, the interviewees felt that CAV will have a meaningful impact on Caltrans in both the near and long term. They recognized that widespread CAV deployment, and the benefits and impacts that come with it, are still many years out but that Caltrans should take actions now to prepare. Almost everyone stated that safety was the number-one goal of Caltrans and that CAV can eventually have a positive impact on safety by reducing crashes. Staff felt that CAV will also have a smaller but potentially significant impact on other Caltrans priorities, including multimodality, efficiencies, partnerships, and innovation.

Respondents felt that CAV, with the right mix of policies in place to guide deployment, has many promising aspects that could help them meet their goals within their areas of responsibility, including:

- Increased safety for the traveling public
- Increased worker safety
- Operational improvements
- More efficient freight movement
- Data for planning and operations
- Potential new options to provide accessibility for the elderly, disabled, and other underserved populations
- Improved transit operations
- Opportunity for innovation

The respondents also noted some aspects of CAV that should be addressed through policy interventions to ensure a successful deployment in California. Concerns that were mentioned included:

- Decreased safety, especially for vulnerable users, and during the transition period
- Cybersecurity
- Data management
- Technological uncertainty
- Equity and access issues
- Increased passenger and freight VMT
- Increased costs for infrastructure maintenance
- Tort liability

Most staff who were interviewed felt it was important that Caltrans be a strong partner to support CAV deployment in California. The key partners that were mentioned mostly included CalSTA, California DMV, CHP, California Public Utilities Commission (CPUC), local agencies, USDOT, and the private sector. The other key roles that Caltrans should lead in CAV deployment include, from most important to least, are integrator, facilitator, researcher, educator, regulator, promoter/advocator, and innovator.

In terms of changes to Caltrans business methods to support CAV, most felt that it would be necessary to form an internal working group to ensure that CAV actions are carried out with no redundancies across Caltrans, although it was suggested that existing working groups be leveraged to the greatest extent possible. Most interviewees believed that additional funding is needed to support CAV deployment but that it would be challenging politically to acquire this funding. Staff felt it would be easier to acquire funding if they first demonstrate the benefits of CAV through successful pilot deployments.

Many suggested the need for greater organizational support and coordination with respect to CAV. This could be achieved through additional CAV positions or perhaps a new CAV group within the existing Caltrans structure. There was general consensus that new skill sets would be needed within Caltrans to support CAV deployment, such as data science, systems engineering, computer science, and other high-tech skills. This could require additional training, recruitment, new job classifications, and changes to position descriptions. There was also a suggestion to update Caltrans' procurement processes to be more flexible and able to keep up with fast-changing technology.

With respect to new CAV initiatives, one that was mentioned by several interviewees was to set up an internal CAV outreach program that focused on internal communication of CAV activities and basic CAV education. Another initiative mentioned was to provide CAV training and assistance to local transportation agencies. There was no clear consensus on whether Caltrans should lead a statewide CAV consortium. Some were cautious and noted that Caltrans already had several competing initiatives underway, such as Complete Streets and Connected Corridors. They suggested building on what has already been done in the state rather than starting a new initiative. Others felt that it was important for Caltrans to be a strong leader in this area and suggested building partnerships with the private sector, MPOs, and local agencies to share in the cost of conducting pilot deployments. Despite the differing opinions on Caltrans leading a CAV consortium, a majority of the respondents believed that Caltrans should focus its leadership on the infrastructure aspects of CAV deployment and that any CAV consortium that is set up in California should be tailored to the state's unique attributes and goals.

Interactive CAV Workshop

The second major stakeholder activity was an interactive virtual CAV workshop held on July 24, 2020 to review the aggregated CAV actions arising from the previous staff interviews.

WORKSHOP METHODOLOGY

Based on the findings from the staff interviews, the project team identified possible actions that Caltrans should take to better prepare for future CAV deployments. These actions formed the basis of a preliminary CAV Action

Plan, similar to the one presented in Chapter 5. Many of the actions were suggested directly by the interviewees, and some were inferred by the project team. The actions were grouped into six areas:

1. Organizational change and workforce development
2. Planning and programming
3. Pilot deployments and testing
4. Deployment readiness
5. External outreach and partnerships
6. Policy

Each action was rated as either near term (within two years) or medium term (three to five years). Also, each action was tentatively assigned to a Caltrans division to take the lead on executing that action. It was generally recognized that each action would need to undergo a more detailed analysis, and its implementation would be subject to resource availability. The preliminary CAV Action Plan was sent to the workshop invitees one week prior to the event.

The July 24, 2020 workshop provided an opportunity for stakeholders, principally Caltrans, DMV, and CalSTA representatives drawn from the project panel, to review the aggregated CAV actions arising from the staff interviews. In total, 35 stakeholders participated in the workshop. The workshop began with a summary of the findings from the interviews, followed by a discussion of the Caltrans CAV vision, mission, and goals, which were refined into the ones presented in Chapter 2.

The final half of the workshop was interactive. The participants were separated into three virtual breakout rooms to concentrate on refining the CAV actions. Each breakout group was assigned two action plan areas to review, as follows:

Group 1
- Organizational Change and Workforce Development
- Planning and Programming

Group 2
- Pilot Deployments and Testing
- Deployments

Group 3
- External Outreach and Partnerships
- Policy

The grouped CAV actions, originating from open-ended, relatively unconstrained discussions, were discussed in detail by each breakout group. Each action was reviewed with an eye on clarity, priority, resource constraints, competing programs, and identifying a champion. These discussions were conducted in three parallel sessions to allow ample time to review the actions. In the end, all the actions were reviewed, and the stakeholder inputs were recorded.

WORKSHOP OUTCOMES

The first outcome of the interactive CAV workshop was a revised set of CAV mission, vision, and goals. After the workshop, they were further refined, eventually resulting in those presented in Chapter 2. The other major outcome was detailed stakeholder feedback on the CAV Action Plan. In general, the stakeholders agreed with the majority of the actions presented at the workshop, but many actions were edited for clarity and accuracy. The stakeholders also updated some priorities and division assignments. The final CAV Action Plan is presented in Chapter 5.

AV Industry Survey

PATH conducted an online survey and follow-up interviews with a broad cross section of the AV industry to gather information on how infrastructure impacts AV performance. This activity was carried out under a separate Caltrans-funded project, but is summarized below because some of the findings are relevant to the CAV Strategic Plan.

AV INDUSTRY SURVEY METHODOLOGY

State and local agencies who own, maintain, and operate transportation infrastructure can benefit from working jointly with the AV industry to provide for safe and efficient operations. A key question being asked by transportation agencies is, "What transportation infrastructure improvements or modifications will facilitate and improve AV performance?" To address this question, the PATH team conducted a questionnaire survey with in-depth interviews.

A total of ten questions were included in the survey, as shown in Appendix C. Many of the questions ask the respondents to identify roadway characteristics, enhancements, or modifications that they believe can help facilitate safe and efficient operation of AVs on California roadways. Roadway characteristics can include physical things, such as lane markings, signage, highway lighting, guardrails, crash barriers, and traffic control devices. They can also include digital features, such as provision of real-time map updates, digital signage, signal phase and timing, incidents, work zone information, roadway closures, and construction zone information. Most of the questions were open-ended.

The PATH research team sent the survey to all the companies who have obtained an AV testing permit from California DMV. The project team also reached out to other stakeholders who are involved in the AV industry, even though they might not hold a DMV testing permit or conduct tests directly. As of this writing, the project team has received 20 survey responses from a mix of traditional car manufacturers, automotive suppliers, startup AV companies focusing on passenger vehicles, startup AV companies focusing on heavy-duty trucks, and startup AV companies focusing on low-speed shuttles. To get a deeper understanding of their feedback, the research team also conducted follow-up interviews with eight of the companies.

AV INDUSTRY SURVEY FINDINGS

The project is ongoing and is expected to be completed in early 2021. Here are the preliminary findings based on the 20 survey responses.

- Most respondents mentioned clear and high-contrast lane markings and rated them as a high-priority roadway characteristic that would benefit AV deployment.
- There seems to be no specifications or standards of roadway characteristics that would support a minimum performance level. The roadway infrastructure that works well for human drivers should work well for automated vehicles. For example, lane markings that are visible to humans will be visible to cameras.
- Well-maintained infrastructure is important to provide consistently high AV performance. Degradation can limit AV capabilities. Poorly maintained roadway surfaces, such as potholes and buckled asphalt, can increase the risk of damaging vehicle sensors and can reduce a vehicle's lifetime durability. It is better to identify areas where the road infrastructure (for example, lane markings) is bad and make them good rather than trying to make already good areas perfect.
- ADSs are trained on available data and recorded observations. Consistency is critical. For instance, if there is a construction zone and temporary signs are needed, what types of signs are used should be consistent.
- Timely, accurate, and secure digital information is useful. Notification of work zone and road closures is very important. A little information for all situations is more important than a lot of information for only a few.
- Both DSRC and C-V2X are potential CV technologies at the moment, and the industry is still trying to figure out the benefits of one technology over the other. When it comes to safety-critical information, it would be good to have CV data (no matter the technology) as an additional source of data to provide redundancy.
- AV technology will continue to progress beyond current levels over time. The estimated timeline for HAV (L3–5) deployment varies among survey respondents from years to decades. Some companies are only focusing on the even numbers (Level 2 and Level 4) of automation.
- AV companies expect the infrastructure to be rolled out in phases with improvements over time, and many technology developers stated they will work with what is currently available. Infrastructure policies are expected to be maintained uniformly across agencies.
- Common venues for interaction between industry and government include the SAE, conferences, and consortiums with government and industry representatives. Continuous conversation and collaboration between transportation agencies and the AV companies will be essential to successful AV deployment.
- A good portion of survey respondents expressed their willingness to share data that might help infrastructure improvement, although they have concerns regarding proprietary information and liability.

CHAPTER 5

CAV Action Plan and Next Steps

The CAV Action Plan is based on input received from the CAV stakeholders that included Caltrans, California DMV, CalSTA, and a targeted group of AV companies.

Recommended CAV Actions

Based on the findings from the Caltrans CAV Strategic Plan interviews, the CAV interactive workshop, and the AV industry survey, the project team identified possible actions that Caltrans should take to better prepare for future CAV deployments. Many of these actions were suggested directly by Caltrans staff, and some were refined by the project panel during the interactive workshop.

The table on the next page lists the preliminary CAV action plan for Caltrans leadership to consider. The actions are grouped into six areas. Each action is described in more detail later in this chapter.

1. Organizational change and workforce development
2. Planning and programming
3. Pilot deployments and testing
4. Deployment readiness
5. External outreach and partnerships
6. Policy

Each action is rated as either near term (within two years) or medium term (three to five years). Each action has been assigned to a Caltrans division tasked with taking the lead on executing that action. Supporting divisions are also listed for some actions. Implementation of each action is subject to resource availability.

CAV Action Plan

ID	CAV Action	Phase	Responsible Parties (lead party is in *italics*)
	Organizational Change and Workforce Development		
1.1	Coordinate CAV actions with the Caltrans Innovative Leadership Council	Near term	*DRISI*
1.2	Establish an internal CAV working group	Near term	*DRISI*
1.3	Establish an internal CAV outreach and awareness program	Near term	*DRISI*
1.4	Provide internal CAV training to practitioners	Medium term	*DRISI* and HR
1.5	Build new skill sets within the Caltrans workforce	Medium term	*DRISI* and HR
1.6	Investigate the need for new CAV positions, a new CAV group, or other organizational changes at Caltrans	Medium term	*DRISI* and HR (with approval from Director's Office)
1.7	Increase Caltrans procurement process flexibility	Medium term	*Administration*
	Planning and Programming		
2.1	Develop a CAV Implementation Plan	Near term (underway)	*Traffic Operations*, DRISI, Design, DES, Maintenance, Planning
2.2	Investigate opportunities for additional CAV funding	Near term/ continuous	*DRISI*
2.3	Conduct a risk assessment of alternate CAV rollout scenarios	Near term	*Risk and Strategic Management,* Planning
2.4	Integrate CAV into the Caltrans planning process	Near term (underway)	*Planning*
2.5	Update SHOPP and STIP structure and definitions	Near term	*Programming*
2.6	Develop a plan for upgrading the Caltrans IT and telecommunications network to support CAVs	Near term	*IT*, Traffic Operations, Design
2.7	Devise more-precise factors for CAV to be analyzed in planning models	Medium term	*Planning*
2.8	Update ITS architectures to incorporate CAV	Medium term	*Planning*, Traffic Operations
2.9	Investigate possible changes to roadway design standards resulting from widespread CAV deployment	Medium term	*Design*, DES

CAV Action Plan

ID	CAV Action	Phase	Responsible Parties (lead party is in *italics*)
Pilot Deployments and Testing			
3.1	Expand existing CAV testbeds and add new CAV testbeds	Near term	*DRISI* and Districts
3.2	Publish a complete list of California CAV testbeds and their assets	Near term	*DRISI* and Districts
3.3	Partner with CHP, DMV, and the AV industry to capture additional safety data regarding CAVs	Near term	*Legal*, Safety
3.4	Conduct pilots to study how safely and efficiently CAVs operate in specific operational settings	Medium term	*Traffic Operations*, Districts, DRISI
3.5	Partner with transit agencies on CAV pilots that have a goal of multimodality	Medium term	*Department of Rail and Mass Transportation*, Planning, Districts, DRISI
3.6	Partner with regional and local agencies on CAV pilots that have a goal of increasing walking and biking, reducing VMT, and improving safety for vulnerable road users	Medium term	*Planning*, Districts, DRISI
3.7	Partner with agencies, such as CHP, and other states to support innovation in freight movement, such as truck platooning	Near term (underway)	*DRISI*, Planning, Districts
3.8	Use CAV technology to increase the safety of Caltrans staff near incident scenes and work zones (multiple pilots)	Medium term	*Safety*, Construction, Equipment, Maintenance, Districts, DRISI
Deployment Readiness			
4.1	Investigate need for CAV design standards for California's physical infrastructure and implement as needed	Near term	*Traffic Operations*, Safety, Design, DES
4.2	Investigate the need for CAV design standards for	Near term	*Traffic Operations*, IT
4.3	California's digital infrastructure and implement as needed Install and maintain clear and conspicuous pavement markings and standardized roadway signage	Near term (underway)	*Construction*, Maintenance
4.4	Provide CAV guidance to the districts and local agencies	Medium term	*Traffic Operations*, Maintenance, DRISI, Districts
4.5	As defined in the CAV Implementation Plan, strategically upgrade Caltrans infrastructure to make it CAV-ready	Medium term	*Traffic Operations*, Maintenance, Districts
4.6	Pilot the use of state-owned, CAV-equipped fleet vehicles	Medium term	*Equipment*, Districts
4.7	Build out IT and telecommunications network per IT upgrade plan (from Action 2.6)	Medium term	*IT,* Traffic Operations, Design

CAV Action Plan

ID	CAV Action	Phase	Responsible Parties (lead party is in *italics*)
External Outreach and Partnerships			
5.1	Participate in federal CAV stakeholder efforts	Near term	*DRISI*, Traffic Operations
5.2	Engage with the AV industry to better understand how infrastructure and data from infrastructure impacts CAV operations	Near term (underway)	*DRISI*, Maintenance, Traffic Operations, Design, DES
5.3	Develop a Communications and Outreach Plan	Near term	*DRISI*
5.4	Share CAV information and best practices through partnerships with regional and local transportation agencies, other state agencies, and the private sector	Near term	*DRISI*
5.5	Explore new public-private business models to facilitate CAV deployment	Medium term	*DRISI*, Operations
Policy			
6.1	Work with CalSTA to identify gaps in laws, regulations, policies, and practices related to implementing CAV technologies and infrastructure	Near term	*Traffic Operations*, CalSTA
6.2	Monitor federal CAV policy to support and inform California CAV implementation	Near term	*Traffic Operations*, CalSTA
6.3	Pursue related federal grant opportunities that build on existing CAV efforts	Near term	*DRISI*, Traffic Operations, Districts
6.4	Review and update existing Caltrans policies and procedures to consider CAV	Medium term	*Traffic Operations*, Safety, Maintenance, Design

The action plan provides a snapshot of 40 activities across six areas of CAV planning, management, and action. The action plan is a convenient tool for charting a path forward for Caltrans, but the project team recognizes that many questions remain with respect to how CAV fits within Caltrans. Many fundamental questions arose during our discussions, such as:

- How will CAV contribute to or detract from the Caltrans policy goals, and which additional policies need to be implemented to put the right controls in place?
- To what extent should CAV have a separate identity in the organization, and to what extent should it be widely integrated?
- How would this "identity of CAV" affect planning, budgeting, and funding?
- Is CAV a technology (such as ITS) or a program (such as Complete Streets)?
- Many actions in the plan either involve, or depend on, specific knowledge of CAV deployment and operations. Real planning cannot occur without demonstrable expertise and direct experience with AVs, CVs, and CAVs. How will the needed experience be obtained?
- Should CAV be considered on a localized basis (for example, corridors), regionally, or statewide?
- How does CAV compare with other special programs, such as managed lanes?
- What does a broad range of staff need to know about CAV? What do specialists (such as traffic operations, safety) need to know about CAV?

Not all these questions can be answered today, but the answers will become clearer as the near-term actions of the plan are implemented. After these fundamental steps are taken, it will logically follow that some of the more-concrete steps to operationalize and sustain CAV can occur. The action plan contains many of these concrete actions in the "Pilot Deployments and Testing" and "Deployment Readiness" areas.

The following sections describe each action in more detail.

Organizational Change and Workforce Development Actions

These actions focus on internal changes that need to take place to extend CAV awareness to the entire agency and prepare for the skills, expertise, and processes necessary for success.

1.1 **Coordinate CAV actions with the Caltrans Innovative Leadership Council.** This action involves introducing CAV as a key topic for discussion in the Innovative Leadership Council, an existing executive-level group that meets regularly to discuss ways to advance Caltrans' culture of innovation. The group would provide strategic direction and oversight to the CAV working group described in Action 1.2. This action should be internally managed and executed and will not require additional funding.

1.2 **Establish an internal CAV working group.** It is generally recognized that a CAV working group is needed at Caltrans to help guide CAV actions, but this group would not be responsible for carrying out the actions. The new internal working group would coordinate and monitor CAV actions, such as those in the CAV Action Plan. It might make sense to leverage existing groups to complete the actions. Action 1.2 should be coordinated with the Caltrans Strategic Plan described in Chapter 2. This action should be internally managed and executed and will not require additional funding.

1.3 **Establish an internal CAV outreach and awareness program.** This action's goal is to regularly communicate with the Caltrans workforce on CAV activities, developments, and policies occurring within Caltrans and provide staff with general CAV awareness. This action should be internally managed and executed and will not require additional funding.

1.4 **Provide internal CAV training to practitioners.** A major effort is needed to provide different levels of CAV training to Caltrans staff. The training should be integrated with existing division- and district-level training based on gaps to be identified by the divisions and districts. This action is different than the general CAV awareness mentioned in Action 1.3. This would be more detailed information for CAV practitioners, and the format should include a mix of classroom and hands-on training. Successful completion of the training courses should result in certification. This action should be internally managed, but execution might require contracting for external expertise. Utilize the existing training budget to the extent possible, but some additional funding might be needed.

1.5 **Build new skill sets within the Caltrans workforce.** Caltrans has traditionally focused on designing, building, and maintaining California's large freeway network. Lately, a stronger focus is being placed on real-time transportation network operations through new technologies, such as CAV. This action is a major workforce development undertaking to bring in new knowledge, skills, and abilities in growing areas, such as network and systems engineering, cybersecurity, and data science. It might require creating appropriate job classifications, position descriptions, hiring guidelines, and competitive salary ranges. Another consideration is to establish a pool of highly specialized workers (for example, data scientists and network engineers) who can be housed in a particular functional unit and sent to other functional units or districts to share their technical expertise. This action should be internally managed and executed and might require additional funding.

1.6 **Investigate the need for new CAV positions, a new CAV group, or other organizational changes at Caltrans.** This action involves investigating potential changes to the Caltrans organizational structure, such as creating a CAV group at Caltrans or adding positions entirely focused on CAV-related work. This activity must be coordinated with the Caltrans Strategic Plan because organizational changes require approval of the Director's Office. This action should be internally managed and executed and might require additional funding if positions are added.

1.7 **Increase Caltrans procurement process flexibility.** Caltrans' procurement process was designed to suit 20th-century roadway construction, not today's fast-changing CAV industry. This action focuses on working with state agencies, such as the Department of General Services, to make the Caltrans procurement process more flexible to better match today's environment. For example, with ongoing CAV projects, staff have identified the need for a quicker turnaround when ordering specialized equipment or parts to reduce delays and save money. This action should be internally managed and executed and will not require additional funding.

Planning and Programming Actions

These actions address the planning efforts involved in implementing a rollout strategy, including funding considerations, risk assessment, and infrastructural upgrades and changes, starting with the creation of an Implementation Plan.

2.1 **Develop a CAV Implementation Plan.** This is a major planning effort to identify a rollout strategy for CAV infrastructure from pilot to deployment. It builds on the Caltrans CAV research roadmap and includes lifecycle funding needs of CAV deployment, including design, construction, operations, and maintenance. It needs to be developed as a phased plan, starting with basic upgrades, then pilots, and finally building up to eventual widespread deployment. This plan should emphasize how to leverage existing Caltrans resources (such as the fiber optic communications backbone) to the greatest extent possible. This activity requires consultation across the organization. This action has already been funded, and a contractor has been acquired to develop the plan. The Division of Traffic Operations is leading the effort.

2.2 **Investigate opportunities for additional CAV funding.** This action recognizes the need and the challenge associated with obtaining additional funding for CAV projects. Opportunities to leverage existing state funding toward CAV efforts might be available from programs such as the State Highway Operation and Protection Program (SHOPP) and Statewide Transportation Improvement Program (STIP). Alternatively, CAV funding could be available from external sources, such as the federal government and the private sector through new partnerships. This action should be internally managed and executed and might require additional funding.

2.3 **Conduct a risk assessment of alternate CAV rollout scenarios.** Given the uncertainty and constantly changing landscape in the CAV industry today, it would be prudent for Caltrans to conduct a comprehensive risk assessment to account for various rollout scenarios and how they might impact Caltrans. For example, if the federal government allows unrestricted use of the 5.9 GHz spectrum, how does that impact CV technology and the CV market? The risk assessment should also consider legal issues, such as how Caltrans might address potential liability and intellectual property rights. This action should be completed in close coordination with CalSTA and other state agencies. This action should be internally managed, but execution might require contracting for external expertise. Some additional funding might be needed.

2.4 **Integrate CAV into the Caltrans planning process.** This action involves making appropriate adjustments to the Caltrans planning documents to accommodate CAV impacts. This activity is already occurring on some level as CAV is being included in some long-term planning documents. It is also necessary to consider how to best incorporate CAV in other planning documents, including recently completed plans. Substantial progress with this action would benefit from direct experience with CAV pilot deployments (see the actions in the Pilot Deployments and Testing section). This action should be internally managed and executed and will not require additional funding.

2.5 **Update the SHOPP and STIP structure and definitions.** This action involves making changes to the definitions in certain funding programs to better facilitate funding of CAV projects. Many existing programs, such as SHOPP and STIP, are eligible to be used for spending on CAV projects; however, their

current structure makes this difficult. This applies to new purchases and maintenance of CAV equipment. CAV expenses need to have specific reporting codes for tracking, which could be used to project future maintenance costs. This is an important near-term activity. This action should be internally managed and executed and will not require additional funding.

2.6 **Develop a plan for upgrading the Caltrans IT and telecommunications network to support CAVs.** This action is a major effort to develop a plan for upgrading the Caltrans Information Technology (IT) and telecommunications network to be able to support a full CAV build-out. A key focus of this plan should be how to best leverage existing Caltrans resources, such as its fiber optic network, to support future CAV deployments. This action will be managed by Caltrans IT with support from the Division of Traffic | Operations. It is linked to Action 2.1. This action will require external assistance and additional funding.

2.7 **Devise more-precise factors for CAV to be analyzed in planning models.** Current planning models account for CAVs in their estimates of future travel demand and behavior with a high degree of uncertainty. This action involves updating the planning models used by Caltrans to better account for CAVs. Because this is also a problem encountered by other states, there might be opportunities to leverage federal research or best practices in other states. This action should be internally managed and executed and will not require additional funding.

2.8 **Update regional ITS architectures to incorporate CAV.** Currently, the regional ITS architectures in California are not considered to be adequate to fully support the deployment of CAV. This action would build on work being done at the federal level to update regional ITS architectures so that they include CAV elements and related standards. This action needs to be done in close coordination with the MPOs, who usually take the lead on developing regional ITS architectures. This action might require external assistance and additional funding.

2.9 **Investigate possible changes to roadway design standards resulting from widespread CAV deployment.** As CAV deployment becomes more widespread in the future, changes to current roadway design standards might need to be made. For example, it might make sense to have narrower lanes, pavement structures resistant to more lateral concentration of wheel paths, and more dedicated lanes. These new standards should be based on real-world experience with model deployments and testbeds because they will have long-term ramifications. This action should be internally managed but might require external assistance and additional funding.

Pilot Deployments and Testing Actions

Piloting CAVs in a variety of environments and conditions to test their safety and operation requires expanding the number of testbeds. Action items include testing interaction with active modes of transportation and work zones, transit uses cases, and truck platooning.

3.1 **Expand existing CAV testbeds and add new CAV testbeds.** This action involves expanding the existing CAV testbeds in California, both off-roadway and on-roadway, so that they can support broader CAV testing. A key piece of this testbed expansion is to engage with the AV industry to encourage more testing on these facilities. There might also be opportunities to establish new CAV testbeds in different geographic

areas (for example, rural or mountainous areas) to broaden the types of testing environments. This action requires close coordination with the districts that host the testbeds. It should be internally managed by DRISI but will likely require external assistance and additional funding.

3.2 **Publish a complete list of California CAV testbeds and their assets.** This action is to create a detailed inventory of the existing California CAV testbeds and their assets and publish it on the Caltrans website. The list should be publicized to CAV stakeholders throughout the state to attract additional users and partnerships. It should be internally managed by DRISI, but will likely require assistance from the districts. No additional funding should be needed.

3.3 **Partner with CHP, DMV and the AV industry to capture additional safety data regarding CAVs.** The amount of AV data being collected by DMV is currently limited to basic crash reports and disengagement reports that are submitted by AV permit holders. This action works to better understand the principles of AV safety investigation and to explore opportunities to capture additional data regarding AVs involved in collisions. Such data could be pertinent to pre-crash and post-crash vehicle dynamics, the level and state of AV systems at the time of the crash, and infrastructure factors that are more relevant to automated driving systems than human drivers. These more data-centric changes to crash investigations are needed to better inform factors contributing to crashes, infrastructure improvements, and CAV safety policy. This task should also investigate ways to gather more information from CVs, such as how many are on the road and how many AVs are also CAVs (connected). This action requires close coordination with DMV and CHP and awareness of AV safety research efforts by other states and federal agencies. It should be internally managed and executed and will not require external assistance or additional funding.

3.4 **Conduct pilots to study how safely and efficiently CAVs operate in specific operational settings.** This action is a large undertaking that involves planning and executing CAV pilots that focus on specific operational settings or ODDs. For example, a pilot could be conducted on a managed or dedicated lane facility in California to see how that type of environment impacts the safety and efficiency of CAV operations. Other potential ODDs to test include low-speed urban environments, rural mountain areas, and inclement weather conditions. This action requires partnering with districts, local agencies, and private sector AV providers and seeking grant opportunities to conduct the pilots. It should be internally managed but will require external assistance and additional funding.

3.5 **Partner with transit agencies on CAV pilots that have a goal of multimodality.** This action is a large undertaking that involves planning and executing CAV pilots that focus on transit use cases. It requires partnering with districts, local transit agencies, MPOs, and private sector AV providers (with a transit focus) to conduct the pilots. Because of the COVID disruption and its disproportionate impact on transit ridership, this is a medium-term action. It should be internally managed but will require external assistance and additional funding.

3.6 **Partner with regional and local agencies on CAV pilots that have a goal of increasing walking and biking, reducing VMT, and improving safety for vulnerable road users.** This action is a large undertaking that involves planning and executing CAV pilots that focus on active transportation. For example, a pilot could be conducted in a dense area that has issues with pedestrian and bicycle safety and CAV could help. This action requires partnering with districts, local agencies, MPOs, and private sector AV providers (with a focus on cyclists or pedestrians) to conduct the pilots. It should be internally managed but will require external assistance and additional funding.

3.7 **Partner with agencies, such as CHP, and other states to support innovation in freight movements, such as truck platooning.** This action is a large undertaking that involves planning and executing a CAV pilot that focuses on freight movements. One pilot currently being funded by FHWA is set to operate from 2020–2022 along the I-10 corridor from Los Angeles to Fort Worth, Texas. This action requires partnering with USDOT, CHP, other states, districts, and private sector fleet operators to conduct the pilots. It should be internally managed but will require external assistance and additional funding.

3.8 **Use CAV technology to increase the safety of Caltrans staff working near incident scenes and work zones.** This is a large undertaking that involves several types of pilots in or around work zones and incident scenes. On the CV side, CV technology could be used to improve safety by warning drivers and workers of potential dangers at both fixed and moving work zones. On the AV side, Caltrans could field-test automated fleet vehicles, such as the ATMA described in Chapter 3 to use in dangerous maintenance activities. Another potential activity is to partner with an AV company to test a work zone information exchange between Caltrans and CAVs.

Deployment Readiness Actions

These actions involve investigating whether new physical and digital design standards are needed, and if so, tested and planned for.

4.1 **Investigate the need for CAV design standards for California's physical infrastructure and implement as needed.** This action involves greater leveraging of federal standards and guidelines to investigate if statewide standards are needed for physical infrastructure to support CAVs, including striping, signage, traffic control devices, and roadside communications devices. As standards are identified, they should be tested and then implemented. One example is the recent 6-inch stripe standard for all state highways. This action could eventually link to Action 2.9. It should be internally managed but might require external assistance and additional funding.

4.2 **Investigate the need for CAV design standards for California's digital infrastructure and implement as needed.** This action involves greater leveraging of federal standards and guidelines to investigate if statewide standards are needed for digital CAV infrastructure, including digital mapping, data message sets, traffic management center (TMC) software, and cybersecurity. As standards are identified, they should be tested and then implemented. This action should be internally managed but might require external assistance and additional funding.

4.3 **Install and maintain clear and conspicuous pavement markings and standardized roadway signage.** This policy has already been adopted by Caltrans because it improves safety for both CAVs and non-CAVs. This action builds on standards established in Action 4.1, such as the 6-inch stripe on all state highways. It is listed as a near-term action, but it is also an ongoing maintenance activity for the medium term. This action should be internally managed and executed and will not require external assistance or additional funding.

4.4 **Provide CAV guidance to the districts and local agencies.** This action involves the Division of Traffic Operations and the districts working with the MPOs to provide local agencies the latest CAV guidance regarding CAV infrastructure. This action could be linked to Action 4.1 and Action 4.2 if relevant CAV design

standards have been established. This action should be internally managed and executed and will not require external assistance or additional funding.

4.5 **As defined in the CAV Implementation Plan, strategically upgrade Caltrans infrastructure to make it CAV-ready.** This action is guided by the CAV Implementation Plan described in Action 2.1 and the standards identified in Action 4.1 and Action 4.2. It involves preparing for future CAV deployments by opportunistically upgrading infrastructure so that it is suitable for future CAVs. For example, when a traffic signal needs to be replaced, it is replaced with a modern controller and provided with high-speed, secure backhaul communications to the TMC. This action might include some pilot deployment of CV equipment at key locations, including traffic signals, ramp meters, and dynamic message signs. This action requires coordination between the Division of Traffic Operations, Maintenance, and the districts. This action should be internally managed but might require external assistance and additional funding, particularly for maintenance.

4.6 **Pilot the use of state-owned, CAV-equipped fleet vehicles.** This action leverages findings from the pilots described in Action 3.8 to expand the testing of CAV-equipped state fleet vehicles. It could involve upgrading existing vehicles or purchasing new ones. It is possible that light fleet vehicles could be deployed sooner than heavier state vehicles in the medium term. This action should be internally managed but might require external assistance and additional funding, particularly for new fleet vehicles.

4.7 **Build out IT and telecommunications network per IT Upgrade Plan.** This action is a major effort that builds on the findings from the IT Upgrade Plan identified in Action 2.6. It involves building out the IT and telecommunications network identified in the plan. It might make sense to split this action into two actions—one for the IT network and one for the telecommunications network—since those efforts involve different actors. This action is dependent on the success of previous related actions, as well as the significant backlog of IT needs and budget constraints. This action should be internally managed but will likely require external assistance and additional funding.

External Outreach and Partnership Actions

Participating in federal CAV efforts, engaging with the AV industry, and sharing information and best practices with other agencies and the private sector are beneficial in terms of funding and staying in the forefront of CAV technology.

5.1 **Participate in federal CAV stakeholder efforts.** This action involves keeping an inventory of the various CAV stakeholder efforts and participating in those that provide the greatest benefit to Caltrans and the state. Examples of relevant federal stakeholder groups include the Cooperative Automated Transportation Coalition, ITS America's V2I Deployment Coalition, the CAV Pooled Fund Study, American Association of State Highway and Transportation Officials Subcommittee on CV/AV, and several CAV research programs within the National Cooperative Highway Research Program. Participation in such groups should be coordinated with CalSTA and the Governor's Office. This action should be internally managed and executed and should not require additional funding.

5.2 **Engage with the AV industry to better understand how infrastructure and data from infrastructure impacts CAV operations.** This action has already begun with the AV Industry survey conducted by PATH, as described in Chapter 4. Follow-on engagement to better understand the AV industry's challenges will be needed. This action should be managed by DRISI with support from the Division of Traffic Operations, Maintenance, Design, the Division of Engineering Services (DES), and other Caltrans divisions. Future efforts might require additional funding.

5.3 **Develop a CAV Communications and Outreach Plan.** While it is not the responsibility of Caltrans to inspire consumer confidence in CAV technology, a proactive approach to communicating CAV efforts through websites, factsheets, or other material would pave the way for eliminating confusion and improve the standing of Caltrans as a leader in emerging transportation technology. This plan should prepare Caltrans to respond to requests for information and questions from media, the public, and legal entities. This action should be internally managed and executed and might require additional funding.

5.4 **Share CAV information and best practices through partnerships with regional and local transportation agencies, other state agencies and the private sector.** This action focuses on leveraging existing partnerships with MPOs, local agencies, other state agencies, including CalSTA, DMV, CHP, California Air Resources Board, CPUC, and the Department of Finance, and potentially adding new private sector partners, such as OEMs and AV technology companies. The goal is to share information related to CAV activities and policies and to explore opportunities for partnerships and joint projects. This action should be internally managed and executed and should not require additional funding.

5.5 **Explore new public-private business models to facilitate CAV deployment.** This action involves working with the private sector to find new ways to fund CAV infrastructure deployments. This action should be internally managed and executed and should not require additional funding.

Policy Actions

These actions focus on monitoring federal CAV policies and reviewing and updating Caltrans policies.

6.1 **Work with CalSTA to identify gaps in laws, regulations, policies, and practices related to implementing CAV technologies and infrastructure.** This action inventories existing laws, regulations, policies, and practices related to the implementation of CAV technology and infrastructure and makes recommendations for how to expand, modify, or improve them. A priority will be given to policies that encourage shared use, ridesharing, and low-emission vehicles, safety, especially for vulnerable road users, efficient land use, complete and livable streets, transportation equity, and a multimodal system. This action should be internally managed and executed and should not require additional funding.

6.2 **Monitor federal CAV policy to support and inform California CAV implementation.** This action involves keeping track of new and modified federal CAV policies and guidelines as it relates to CAV deployment. Additions or changes to policies will be shared with Caltrans and related agencies. The Division of Traffic Operations and CalSTA will lead this action and it should not require additional funding.

6.3 **Pursue related federal grant opportunities that build on existing CAV efforts.** This action monitors federal grant opportunities and pursues them when appropriate. Pursuing grant opportunities that leverage existing Caltrans CAV efforts and meet Caltrans CAV goals is a priority. This action should be internally managed and executed and should not require additional funding, with the exception of possible match requirements.

6.4 **Review and update existing Caltrans policies and procedures to consider CAV.** This action reviews existing Caltrans policies and procedures, such as incident management, safety procedures, and data collection, to consider how CAV might impact them. The policies and procedures will be updated as needed. This action should be internally managed and executed and should not require additional funding.

Next Steps

Completing a CAV Strategic Plan is the first major step in the CAV Planning process. The Caltrans CAV Strategic Plan provides a framework on which Caltrans can better prepare for CAV deployment in California and start a policy development process to keep California at the forefront of this emerging industry. The actions recommended in the CAV Action Plan focus on steps that Caltrans should take within the next five years to facilitate successful, ongoing CAV deployment. This plan should better prepare Caltrans for the fast-moving evolution in the CAV industry and help the agency accelerate its leadership and outreach in this field.

The scope of the Caltrans CAV Strategic Plan is internally focused and limited to Caltrans-led activities, but Caltrans will need to coordinate these Caltrans-led activities with broader CAV activities in California to ensure that they support state policy goals. Caltrans should work closely with related agencies, such as CalSTA, California DMV, and CHP, on broader CAV planning efforts while continuing to keep its focus on carrying out the CAV actions in this plan. Because the stakeholder outreach in this project was limited to Caltrans staff and a few related agencies, it is important for Caltrans to engage with MPOs and local transportation agencies as they begin to implement the plan. Many of the near-term actions can be initiated in the recently awarded CAV Implementation Plan project (Action 2.1), which will continue the work started by this planning project. Implementing the actions in this plan requires strong leadership and a concerted effort by Caltrans staff to complete the actions and continuously monitor progress and outcomes during the coming years.

Caltrans CAV Strategic Plan Project Panel

Caltrans Project Manager	Pete Hansra, Caltrans DRISI

Panel Members

Name	Division or District
Jeanie Ward-Waller	Planning and Modal Programs
Ellen Greenberg	Sustainability
Dara Wheeler	DRISI
Brian Simi	DRISI
Jesse Bhullar	Traffic Operations
Blair Thompson	Risk and Strategic Management
Dennis Agar	Maintenance
Lisa Kunzman	Equipment
Sean Nozzari	District 4
Rafael Molina	District 7
Sam Amen	District 11
Alan Steinberg	Legal
Celso Izquiredo	Construction
Scott Sauer	Planning
Karl Kopper	IT
Robert Effinger	Design
Ted Evans	Administration/HR
Susan Hida	DES
Chad Baker	Geospatial Data Officer
Lori Pepper	CalSTA
Stephanie Dougherty	CalSTA
Bernard Soriano	California DMV

Caltrans CAV Strategic Plan Interview Questionnaire

1. Significance of CAV

- Did you have a chance to review the State of CAV Report? Do you have any major comments or reactions? (specific comments are welcome in writing)
- How critical is CAV to Caltrans' future?
  - Short term (one to five years)?
  - Long term? (over five years)
- Of Caltrans' high-level priorities – *safety, multimodality, efficiencies, partnerships, and innovation* – which are most impacted by CAV solutions? Which are least?
- What is the most promising aspect of CAV in terms of helping your area of responsibility?
- What is the most concerning or problematic aspect of CAV?
- What role(s) should Caltrans play with CAV?
  - Innovator, promoter, educator, partner, regulator, researcher, integrator? Other?

2. Broadening the Caltrans knowledge base

- Internal transfer and application of Caltrans' CAV experience
  - How should Caltrans build on its recent CAV experience (with pilots and testbeds) to better inform the broader Caltrans workforce? Workshops? Regular seminars? Demos?
- Expectations/capabilities/needs of the AV industry – direct industry engagement
  - How should Caltrans engage directly with AV manufacturers, and what should be achieved by such engagement?
- Defining Caltrans' stakeholder community
  - What private, public, academic and other sectors should be included?
  - What activities/issues should stakeholders be involved in?
- Current and future needs for Caltrans workforce – the challenge of workforce development is currently underestimated
  - What range of CAV skills are needed within Caltrans? Under what timeframes?
  - How can quality candidates be attracted and retained?

3. Current opportunities for direct CAV engagement

- Ensuring that CAV activities fully consider vulnerable road users (VRUs), environmental benefits, and effective land use
  - What opportunities does an agency like Caltrans have to apply CAV to VRUs, environmental needs, and land use?

- Involvement in CAV industry pilots and rollouts, and ensuring that multimodality is a key goal of CAV-enabled mobility systems
  - How can Caltrans shape early CAV deployments to ensure that they address multimodality?
- Trucking industry use of platooning and AV technology
  - Should Caltrans play a more proactive role in facilitating and expanding truck platooning and/or higher levels of AV technology? How?
- Use of CAV in Caltrans fleet and operations
  - How can CAV improve safety for Caltrans staff engaged in all areas of Caltrans operations, including construction, traffic operations, condition monitoring, and maintenance?
- Any other opportunities for direct CAV engagement?

4. CAV research strategies and testbed engagement

- Learnings from existing CAV testbeds in California and elsewhere
  - Do existing CA testbeds adequately cover the interests of Caltrans or should they be updated and/or expanded? How?
  - Is there a need for a "manual" or "standard" to document design standards and data structures for CAV?
- Access to CAV data
  - What forms of data would Caltrans wish to access from AV manufacturers and others?
  - What new resources may be needed for the integration of CAV data within your current data architecture?
- Access to federal (and other) sources of research funding
  - How could Caltrans and partners be better positioned for federal research awards and other funding opportunities?
- Caltrans role in new deployments of CAV-enabled, multimodal mobility services
  - What is Caltrans' role for deployment of CAV-enabled multimodal mobility services?
  - How could Caltrans become a national leader in such deployments?

5. Preparation for AV deployment in California

- Safety risks of early-stage AVs operating in mixed traffic
  - What forms of safety assessment should be applied to AVs?
  - What should be the role of Caltrans in measuring or monitoring AV safety?
- Role of physical infrastructure design and maintenance
  - How can Caltrans better understand the capability of current AVs to comprehend the physical aspects of roadways?
  - What should Caltrans do now to better prepare for future changes to infrastructure design and maintenance needs resulting from CAV?
- Expanded role for ITS
  - In what ways may current ITS programs need to be expanded/modified to accommodate ADSs?
  - How will the state manage CAV uniformity or interoperability across cities, districts, and state lines?
- Workforce development and training
  - How can candidates with CAV skills be best recruited into Caltrans?

- What forms of training may be needed for existing staff?

- Cybersecurity
  - What are the main security vulnerabilities for Caltrans?
  - What aspects of CAV are of greatest concern as additional threats to network security?

6. Caltrans active visioning for CAV

- Role of Caltrans (and CAV) in future mobility
  - Should Caltrans (or California) seek a distinctive national leadership position in CAV? (e.g., akin to CA's stance on vehicle emissions)
- Caltrans effort to map out alternative CAV-related futures
  - What might an alternative future(s) look like in terms of mobility, depending on how – and how quickly – CAV is deployed in California
  - What criteria/methods should be used to consider such scenarios from a Caltrans perspective?
- Input on the draft CAV Program Mission, Vision and Goals in tech memo #1
  - Comments on the strawman mission, vision and goals?

7. Integration of CAV into Caltrans' transportation planning processes

- Impact of CAV on all aspects of transportation planning
  - Is there sufficient consideration of innovation, such as CAV and MaaS in Caltrans' current planning process?
  - Is CAV of sufficient importance to require significant changes in medium-term and long-term planning by Caltrans?
  - What new planning tools and approaches may be needed to integrate CAV into all aspects of Caltrans planning?
- Development of specific CAV plans (e.g. CAV safety plan)
  - Should Caltrans consider the development of specific CAV plans addressing the major priorities of the organization or integrate CAV into existing plans and processes?

8. Caltrans CAV working method

- Activities of advisory panel and working groups
  - What new internal bodies may be needed to implement the CAV Strategic Plan?
  - What partnership arrangements may be needed to connect Caltrans' CAV efforts with other bodies – public, private, etc.?
- Resources for CAV within the Caltrans financial model and operating budget
  - Is there a need for specific CAV funding?
  - Is there a need for new positions or units within Caltrans to support CAV?
- Potential initiatives to accelerate Caltrans' CAV expertise and leadership
  - What new CAV initiatives could be established?
  - How can Caltrans support local agencies with CAV deployment?
  - Should Caltrans take the lead with establishing and funding a CAV consortium with public and private sector partners focused on Caltrans goals (akin to Mcity in Michigan)?

AV Industry Survey Questionnaire

(1) What roadway characteristics or features do you believe will benefit your ADS systems? You can choose to prioritize them into high, medium, and low factors. Examples of roadway features include lane markings, signage, lighting, traffic signals, digital maps and signage, work zone and incident information, V2X data, etc.

(2) Are there any specifications or standards associated with the roadway characteristics that you believe would support a minimum performance level? If possible, please provide quantifiable specifications or use specific terms. Some exemplar types of specifications include level of contrast for lane markings, lighting, visibility, markings for barriers, etc.

(3) Deterioration is common in infrastructure, and maintenance is performed periodically. Do you see the need for different infrastructure maintenance requirements when considering the use of ADS rather than human-driven vehicles? How might the degradation of roadway features affect your system?

(4) What particular issues (if any) exist for ADS to interpret certain physical infrastructure elements, such as lane marking, traffic signals, High Occupancy Vehicle lanes, bike lanes, and signs? Please give specific examples if applicable.

(5) What types of digital features of infrastructure and transportation operations, if available, do you believe would help accelerate safe and efficient deployment of the ADS? Types of information include traffic signal phase and timing, work zone or road closures, incidents, traffic congestion, etc.

(6) How would you anticipate receiving such information? For example, through cellular connection onboard or dedicated communication units, such as DSRC[17] or dual cellular units (as proposed in cellular V2X[18] concepts)?

(7) How do you envision AV deployment in three, five, and ten years?

- At what levels of automation, per SAE L1–L5?
- What do you believe will be the likely operational modes or targeted applications of higher levels of automation?

(8) What types of infrastructure policies do you believe state and local agencies should consider related to the deployment cases identified in the previous question?

- Do you see evolving changes in the needs of infrastructure support as deployment progresses? If so, in what ways?

[17] Dedicated Short-Range Communication, https://www.its.dot.gov/communications/media/1probe.htm

[18] C-V2X, https://www.qualcomm.com/invention/5g/cellular-v2x

(9) What are the venues or mechanisms for governmental agencies to interact with the industry? Are there commonly accepted industrial standards and/or best practice guidelines related to infrastructure that you might recommend?

(10) What data might your company be willing to share that would be beneficial for public agencies? Have any open data sets been developed by the AV industry that would be similarly beneficial? For example, data regarding vehicle operating conditions (speed, route traveled, occupancy, etc.), operating environment (traffic conditions, congestion, incidents, etc.), or observed infrastructure damage (downed signs, potholes, malfunctioning signals, etc.).