

# **A Roadmap for Connected Vehicle Deployment in California (Draft)**

Benjamin McKeever, P.E.

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The following roadmap has been developed for Caltrans to help guide the actions needed to ensure a successful rollout of connected vehicle (CV) technology and applications throughout the state of California. The roadmap presents eight different research and deployment tracks with associated activities or milestones to be achieved across a 20-year time horizon. Some of the activities are to be led by Caltrans and others are led by other entities such as the federal government or auto manufacturers. For the Caltrans-led research and deployment tracks, the roadmap identifies a number of projects that should be initiated in the coming year to help jumpstart the CV deployment process in California. Additional projects will be added to the roadmap in the future.

## ***Background***

A connected vehicle (CV), broadly speaking, is one that is equipped with a wireless local area network that enables the vehicle to communicate with other vehicles and the transportation infrastructure. The widespread deployment of CV technology and applications is expected to result in many safety, mobility and environmental benefits. For instance, according to the estimates by the United States Department of Transportation (USDOT), connected vehicles can potentially eliminate about 80 percent of vehicular crashes. In addition, CV technologies can enhance transportation system performance through the provision of real-time traffic, transit, and parking data, and reduce travel-related environmental impacts.

Since 2002, USDOT has been working with automotive manufacturers to develop vehicle-to-vehicle (V2V) crash avoidance systems that use very high-speed wireless communications and vehicle-positioning technology. Over time, USDOT and their automotive partners expanded their research activities to include vehicle-to-infrastructure (V2I) and non-safety applications, as well as additional stakeholders such as roadway owner-operators and equipment manufacturers. This USDOT-sponsored initiative is now referred to as the Connected Vehicle Program.

At the time of the CV Program's onset, the Federal Communications Commission (FCC) allocated 75 Megahertz of spectrum in the 5.9 GHz frequency range for the primary purpose of improving transportation safety. In addition to safety of life and public safety applications, the FCC also allowed private and non-safety applications to make use of the spectrum on a lower-priority basis. This spectrum and the technology that uses it has come to be known as dedicated short-range communications (DSRC). USDOT's CV Program was initially built around the use of DSRC for transportation safety, but in more recent years, a greater focus has been placed on

utilizing all forms of wireless communications including cellular, Wi-Fi and others to support safety, mobility and the environmental applications.

In 2014, USDOT's National Highway Traffic Safety Administration (NHTSA) issued an Advanced Notice of Proposed Rulemaking (ANPRM) that started a process for making DSRC-based V2V communications technology required in all new light vehicles. In the following year, NHTSA continued to push forward with a V2V Rulemaking process issuing a V2V Readiness Report and accelerating DSRC interference testing to ensure that V2V devices will not be impacted by other devices operating on the same or neighboring frequencies as DSRC. Most recently, in December of 2016, NHTSA issued a Notice of Proposed Rulemaking (NPRM) that would mandate V2V communications on all new light vehicles and require V2V devices to follow standardized messaging developed with industry<sup>1</sup>.

In a similar manner, the Federal Highway Administration (FHWA) has been working to prepare infrastructure owner-operators for CV deployment. In 2015, FHWA awarded over \$40 million to three CV Pilot Deployment sites in Wyoming, New York City and Tampa Bay, Florida to deploy CV technology and applications with a particular focus on V2I communications. FHWA is also leading efforts to develop a reference implementation architecture and standards for V2I deployments, as well as guidance and tools for states and local agencies to follow. FHWA's V2I Deployment Guidance is expected to be released in 2017.

### ***CV Activities in California***

While CV testing and pilot deployments have moved forward at the federal level, California has also been engaging in CV research and testing. California's involvement in CV research and testing dates back to 2005, when they established the nation's first ever state-funded CV testbed on State Route 82 (El Camino Real) in Palo Alto. In addition, Caltrans has been an active member of the CV Pooled Fund Study<sup>2</sup> (PFS), a group of 14 state and local transportation agencies focused on preparing for the deployment of connected vehicle infrastructure. The PFS members are in their sixth year of a multi-phase program that facilitates field demonstration, deployment and evaluation of connected vehicle infrastructure and applications at the local level. One of the more high-profile PFS projects, the development and field testing of Multi-Modal Intelligent Traffic Signal Systems (MMITSS), was successfully demonstrated on California's CV Testbed last year. This demonstration is noteworthy since it involved the integration of MMITSS software and DSRC communications into Caltrans operated traffic signal controllers in a live traffic environment.

Despite these advances, CV technology is still primarily considered to be in the research phase in California, with CV deployment not yet being treated as a near-term priority. This is demonstrated by the fact that nearly all of Caltrans' CV activity and resources are contained within the Division of Research, Innovation and System Information (DRISI), rather than being spread throughout the organization. CV technology offers Caltrans a great opportunity to better achieve its mission to *provide a safe, sustainable, integrated and efficient transportation*

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<sup>1</sup> <https://www.nhtsa.gov/press-releases/us-dot-advances-deployment-connected-vehicle-technology-prevent-hundreds-thousands>

<sup>2</sup> <http://www.cts.virginia.edu/cvpfs/>

*system to enhance California's economy and livability.* However, in order for states like California to be in a position to successfully leverage the full potential of CV technology in the future, they need to begin planning and budgeting for CV deployment now.

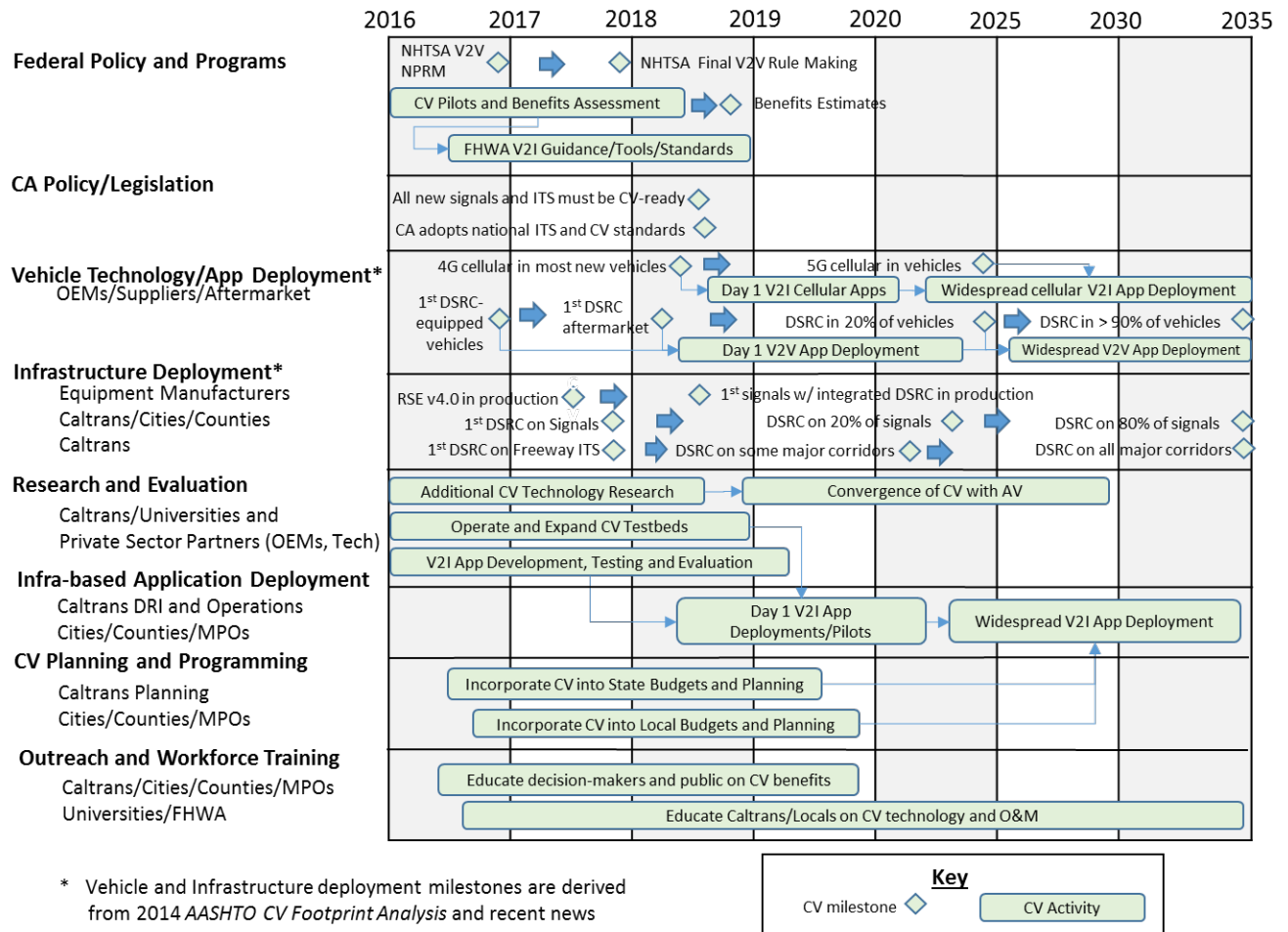
### ***California CV Deployment Roadmap***

With NHTSA's proposed V2V rulemaking and recent announcements by automobile manufacturers of their intent to invest in CV technology, it is apparent that connected vehicles will become a reality in the near future. For California not to be left behind, agencies need to take a series of steps in terms of policy, planning, programming and priority setting that will enable a transportation infrastructure that is advanced enough to support and leverage connected vehicles. The resulting connected transportation system has the potential to transform transportation safety and mobility in ways never before imagined. The roadmap described in this document is intended to be a guide for how California can get from its current environment of limited CV prototype deployment to one that supports a fully built-out connected transportation system.

Figure 1 shows a roadmap for how CV deployment could evolve in California. The roadmap presents eight different deployment tracks, and each track shows a number of different activities or milestones to be achieved across a 20-year time horizon. Some of the activities and/or milestones lead into other activities and/or milestones. The eight CV deployment tracks are as follows:

1. Federal Policy and Programs
2. California Policy/Legislation
3. Vehicle Technology and Application Deployment – led by the vehicle OEMs
4. Infrastructure Deployment – led by infrastructure owner-operators and equipment manufacturers
5. Research and Evaluation – led by Caltrans DRISI, Universities and Private Sector partners
6. Infrastructure-based Application Deployment - led by infrastructure owner-operators and application developers working in partnership with OEMs
7. CV Planning and Programming - led by infrastructure owner-operators and MPOs
8. Outreach and Workforce training - led by infrastructure owner-operators, MPOs and Universities

**Figure 1 – California Connected Vehicle Deployment Roadmap**



These deployment tracks and their associated activities and milestones are explained in greater detail in below.

**Track 1: Federal Policy and Programs**

As explained in the background section, there are a number of CV initiatives being led by USDOT. One of the major drivers of the CV program is NHTSA’s commitment to make V2V communications standard in all new light vehicles, as indicated by their recent NPRM announcement. NHTSA has also announced their intention to issue similar rulemaking for commercial vehicles shortly after the light vehicle announcement, perhaps in 2017. According to NHTSA, the whole process from publication of the NPRM to Final Rule usually takes about a year, resulting in a Federal Motor Vehicle Safety Standard (FMVSS), which in this case would require all vehicle manufacturers to install DSRC devices into new vehicles starting in about

2020.<sup>3</sup> NHTSA usually adopts a three-year phase in period for new rules, which means half of all new vehicles would require V2V technology in 2021, 75% in 2022 and 100% in 2023.

On the infrastructure side, FHWA is utilizing the CV Pilots Program to help jump-start deployment of V2I technology and applications. They plan to use these pilots to help gather examples of real world V2I benefits and also to help owner-operators gain more hands-on experience with V2I deployment. The pilots program will result in a more realistic estimate of CV benefits and also trigger updates to the V2I guidance and standards based on real world experience. Initial V2I Deployment Guidance was formally issued in January 2017 but it was pulled back after a few weeks to allow time for more internal review. Updates to the V2I Guidance are expected in the near future.

### Track 2: California Policy/Legislation

At the state level, there are some policy initiatives that California could undertake to help accelerate the deployment of CV infrastructure. First, in order to increase the penetration of DSRC and CV capability at intersections and on the major corridors, California could pass legislation that requires all new or upgraded traffic signals and ITS stations to be “CV-ready”. This is a policy that is being considered by FHWA (perhaps tying it to the usage of Federal Aid) and it could also be adopted at the state level. According to the FHWA’s *Draft 2015 V2I Deployment Guidance*<sup>4</sup>, “CV-ready” simply means that new or upgraded installations must meet a set of requirements (e.g. sufficient processing capability, reserved cabinet space, secure backhaul communications, digital mapping, FCC license if using DSRC, etc.) that makes a future transition to a CV environment as seamless as possible. The California legislation should be modeled after the most recent FHWA guidance for V2I installations and it should be implemented as soon as feasible, perhaps in 2018.

Second, California could make it a policy or legal requirement for all traffic signal controllers and ITS devices in California to conform to both current national ITS standards and future CV standards. This would be a major shift from current state policy, which requires the state to use the AB3418 protocol rather than the National Transportation Communications for ITS Protocol (NTCIP) in its traffic signals. Requiring all traffic signals to conform to NTCIP would align state policy better with other states and be a major step towards achieving national interoperability. This action would also result in lower CV deployment costs, since California would be part of the national market for the products and services needed to implement ITS infrastructure rather than being a separate market. Many of the CV standards are still evolving at the federal level; nevertheless, this policy action should occur as soon as possible to position California to be ready for the widespread adoption of CV standards. It is reasonable to assume this could occur in 2018.

### Track 3: Vehicle Technology and Applications Deployment

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<sup>3</sup> <http://www.forbes.com/sites/samabuelsamid/2016/12/13/nhtsa-finally-issues-draft-v2v-communications-rule-could-be-mandatory-from-2021/#3d9ee5b96f23>

<sup>4</sup> [http://www.its.dot.gov/meetings/pdf/V2I\\_DeploymentGuidanceDraftv9.pdf](http://www.its.dot.gov/meetings/pdf/V2I_DeploymentGuidanceDraftv9.pdf)

Deployment of CV technology and applications in vehicles is largely controlled by the vehicle original equipment manufacturers (OEMs) and their adoption of these technologies will largely be impacted by NHTSA. As an example, NHTSA's recent V2V activity and NPRM have already had an impact on the rate of DSRC adoption by OEMs. GM has announced plans to include V2V communications (DSRC-based) in its Cadillac CTS sedans in model year 2017 and other OEMs have also shown signs of accelerating their investments in V2V technology. Assuming the Final V2V Rulemaking occurs in 2017, it is likely that some number of new vehicles would be required to have V2V capability as early as market year 2020, with all new vehicles requiring V2V by 2023.

Another major driver of the DSRC market penetration rate will be the availability of aftermarket DSRC devices for existing vehicles. Assuming NHTSA does proceed with its Final V2V Rulemaking in 2017 and momentum continues, aftermarket DSRC devices could become available as early as 2018. There is also a strong likelihood that the Rulemaking would result in dealer-installed retrofits of V2V technology. Given the expected timeline of NHTSA's anticipated Rulemaking, it is reasonable to expect 20% of light vehicles to be equipped with V2V communications by 2025 and over 90% equipped by 2035. This latter estimate is consistent with the *AASHTO Connected Vehicle Field Infrastructure Footprint Analysis*.<sup>5</sup>

It is important to note that the deployment of CV technology and applications in vehicles is not limited to DSRC-based deployments. As described in the background section, there are many V2I applications that can use other forms of wireless communications and thus be deployed sooner. As an example, some OEMs such as Audi are already providing services that advise drivers of signal phase and timing data from traffic signals using in-vehicle cellular communications<sup>6</sup>. Other OEMs such as Ford are already starting to make embedded 4G cellular communications standard in some models,<sup>7</sup> and given current industry trends, it is reasonable to expect 4G cellular communications to be embedded in most new vehicles by 2018. Beyond 4G cellular, some industry analysts are predicting that 5G cellular communications – which may offer up to 100 times current mobile data speeds - will become commonplace in vehicles by 2025, and this technology may even have the potential to support low latency V2V safety applications and automated vehicles.<sup>8</sup> While the business models and technologies for in-vehicle cellular services are still evolving, it is still reasonable to expect widespread deployment of cellular V2I applications as early as 2018 and continuing through the 2020s.

#### Track 4: Infrastructure Deployment

In their *AASHTO Connected Vehicle Field Infrastructure Footprint Analysis*, state DOTs set the following goals to be achieved by 2040:

- Up to 80 percent (250,000) of traffic signal locations will be CV-enabled.
- Up to 25,000 other roadside locations will be CV-enabled.

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<sup>5</sup> <http://stsmo.transportation.org/Documents/Exec%20Summary%20Final.pdf>

<sup>6</sup> <http://www.autoblog.com/2014/01/09/audi-traffic-light-assist-ces-2014/>

<sup>7</sup> <http://www.extremetech.com/extreme/218127-ford-caves-offers-onstar-like-embedded-cellular-sync-connect-in-2017-escape>

<sup>8</sup> <https://www.abiresearch.com/press/5g-be-unifying-connectivity-technology-future-cars/>

- Accurate, real-time, localized traveler information will be available on 90 percent or more of roadways.
- Next-generation, multimodal, information-driven, active traffic management (ATM) will be deployed system-wide.

In order to meet these goals, AASHTO set out to start initial deployment of CV infrastructure by 2018. In fact, this near-term goal is likely to be met, considering the ongoing CV Pilots in Wyoming, New York City and Tampa Bay. Other states and local jurisdictions are also considering their own CV deployments as indicated by the ongoing work of the CV PFS<sup>9</sup> and the V2I Deployment Coalition<sup>10</sup>. One of the V2I Deployment Coalition working groups has even considered setting a nationwide goal of at least 20 DSRC-equipped intersections in every state by 2020. This goal has become known as the “SPaT Challenge”.

While the states are gearing up for more widespread CV infrastructure deployment, the equipment manufacturers are working to have quality products available to meet this growing demand. Several providers of DSRC roadside units (RSU) are working with FHWA to have the next version of RSUs (version 4.0) ready in time for deployment at the CV Pilot sites in 2017. Also, traditional traffic signal vendors such as Econolite have been making advances towards integrating DSRC communications and related Signal Phase and Timing (SPaT) standards into future traffic signal controllers<sup>11</sup>. It is possible that by 2018, some advanced traffic controllers may have DSRC and SPaT capability already built into them.

The deployment of CV infrastructure in California will need to be led by Caltrans with local agencies following suit. In order to stay true to AASHTO’s commitment, Caltrans should strive to have an initial wave of CV installations at traffic signals and select freeway locations by 2018. With the help of the state policy and legislation steps described in Track 2, California should aim to have at least 20% of its traffic signal controllers and some major freeway corridors covered with DSRC by 2023. This penetration rate is based on the assumption that traffic signal controllers have a typical life-cycle of about 20 years, and about 4-5% of controllers need to be upgraded or replaced every year. In the long term, California should aim to have up to 80% of its controllers and all major corridors connected by 2035. These infrastructure assumptions and deployment goals are consistent and in line with the *AASHTO Connected Vehicle Field Infrastructure Footprint Analysis*.

In terms of funding for CV infrastructure deployment, California agencies will need to begin programming CV deployments into their statewide and regional spending plans as soon as possible (see Track 7). From the *AASHTO Footprint Analysis*, the cost of a typical retrofitted V2I installation can range from \$17K to \$50K depending on the need for backhaul or signal controller upgrades. However, these costs are reduced significantly when V2I is built into signal replacement projects that are already planned. FHWA has stated in their *V2I Deployment Guidance* that CV costs are eligible for federal aid in the same manner as other ITS projects, so California agencies may want to treat CV as next-generation ITS deployments. California should

<sup>9</sup> <http://www.cts.virginia.edu/cvpfs/>

<sup>10</sup> <http://www.transportationops.org/V2I/V2I-overview>

<sup>11</sup> <http://econolite.com/files/9714/2445/7009/Econolite-Innovation-2015.pdf>

also continue to explore opportunities for federal CV deployment grants, as described in the Track 1 activities.

#### Track 5: Research and Evaluation

As described above, California has been involved in CV research activities since 2005. While some CV technology and applications have been developed and tested at various locations throughout the nation, there is still a good deal of research and evaluation that is needed to inform CV deployment in the state. In particular, we have to be able to produce solid evidence of the benefits and costs of each CV application under diverse conditions so that there is a rational basis for supporting the deployment decisions. Not all the CV applications will turn out to be cost effective in all locations. Also, there is additional fundamental research that is needed, such as evaluating the effectiveness of DSRC versus other forms of wireless communications and how different wireless technologies can complement one another for certain applications.

Caltrans DRISI and its University partners in California need to continue to lead in this area. They should also look for opportunities to bring in industry partners to participate in research activities, such as developing and testing new CV applications on the California CV Test Bed in Palo Alto. Caltrans will need to ensure that their test bed is reliable and conforms to all of the latest CV standards to attract industry partners.

Initially, Caltrans DRISI will have a large role in leading application development and testing and evaluation of effectiveness until the applications become more mainstream in the state. DRISI will need to work closely with other Caltrans units, like Traffic Operations, to make sure these applications are tested safely and in a manner that is not disruptive. It is expected that CV research and evaluation activities will continue for several years and gradually lead into early deployments or pilots of CV applications as the most promising applications are discovered. Also, it is expected that CV technology and automated vehicle (AV) technology will converge at some point in the future, so it is recommended that there be a research track in this area as well.

#### Track 6: Infrastructure-based Application Deployment

CV applications include a mixture of vehicle-based applications (including both V2V and V2I) and infrastructure-based applications (V2I only). As described in the Vehicle Deployment track, all of the vehicle-based application deployment will be the responsibility of the vehicle OEMs and their suppliers. These applications include safety, mobility and environmental applications (both V2V and V2I) that utilize on-board equipment to provide a direct interface to the driver or the vehicle control systems from inside the vehicle.

Infrastructure-based applications are V2I applications that exchange data between infrastructure and connected vehicles and rely on processors that run either on the roadside (e.g. local MMITSS, SPaT broadcasts, MAP broadcasts, etc.) or in a traffic management center (centralized MMITSS, Queue Warning, Speed Harmonization, etc.). The deployment of these types of applications will largely be the responsibility of the road owner-operators such as Caltrans and the local agencies. These agencies, in turn, will rely on the companies that develop infrastructure-based applications or provide application services.



As explained in Track 5, Caltrans DRISI will have a large role in leading application development, testing and evaluation for the next several years. DRISI will need to work closely with other Caltrans units, like Traffic Operations, as these applications move to early pilot deployments. Ultimately, when CV deployments become more widespread, CV technology and applications will need to be an integrated part of Caltrans standard business practice.

Local transportation agencies and MPOs in California will look to Caltrans for leadership and assistance in CV deployment. Some of the early CV application testing could be done in partnership with the local agencies and MPOs and academia to help build consensus for statewide CV deployment.

#### Track 7: CV Planning and Programming

Caltrans Division of Transportation Planning and the State's 18 Metropolitan Planning Organizations (MPOs) will be responsible for ensuring that connected vehicles are integrated into both the statewide and regional planning processes. They will also need to ensure that CV deployment projects are programmed into the statewide and regional transportation spending plans. Since CV technology is relatively new to most state planners, these activities should start as soon as possible and will likely take several years to accomplish. One of the first steps will involve leveraging FHWA resources and products to begin training Caltrans and MPO planners how to incorporate CV into their planning activities. It will also be important to leverage the results of federal and state research and evaluation activities from Tracks 1 and 5, respectively to ensure that planners have the tools necessary to make sound investment decisions.

#### Track 8: Outreach and Workforce Training

The final track in the California CV Deployment Roadmap is outreach and workforce training. These activities will need to begin almost immediately and will likely coincide with the CV Planning and Programming activities. Caltrans and local agencies should target key decision-makers in the state to make them aware of the importance and value of investing in CV deployment. One way to do this is by showcasing and demonstrating how CV deployments can have a positive impact on the transportation system, perhaps leveraging the existing California CV Testbed for demonstrations. California will also need to educate its transportation workforce (both existing and future) on how CV will play a critical role in our future transportation system. FHWA and the state's universities will be important partners in the area of workforce training.

### ***CV Deployment Roadmap - Initial Projects and Activities***

The following section defines several near-term projects and activities that should be considered by Caltrans in order to support the CV Deployment Roadmap described above. Several of the CV Deployment Roadmap Tracks described above are largely outside of Caltrans' control, but they are listed to show how CV Deployment will come together both at the state and federal level. For example, Track 1 is led by USDOT and Track 3 is led by the vehicle OEMs. Since these tracks are largely outside of Caltrans control, no specific projects have been recommended in these areas. However, there are still some actions that Caltrans can take

under each of these tracks to support California's CV Deployment. These actions are described below. For tracks where Caltrans has more direct influence (i.e. Tracks 4-8), several specific near-term projects are recommended.

### Track 1: Federal Policy and Programs

Federal CV policies and programs are being led by USDOT. For example, NHTSA is the lead agency responsible for the ongoing V2V Rulemaking, and FHWA is the lead agency responsible for funding CV pilots and CV standards activities. While Caltrans cannot directly influence the USDOT's CV policy and programs, it has some ability to influence policy, since it represents large, influential state and one of the leading states in terms of willingness to invest in early CV deployments. Caltrans should continue to participate in the CV Pooled Fund Study and related national CV activities, such as the AASHTO Subcommittee of Transportation System Management and Operations CAV Working Group and the V2I Deployment Coalition. These activities give California a seat at the table when national CV policy is being discussed, as well as an opportunity to share and hear from other leading states on lessons learned from CV deployments. Finally, Caltrans should continue to pursue opportunities to leverage federal funding for CV deployments. There may be future phases of the CV Pilots Program or similar federal funding opportunities, such as the Advanced Transportation and Congestion Management Technologies Deployment (ATCMTD) program in the coming years.

### Track 2: California Policy/Legislation

The California CV Deployment Roadmap identifies two potential policy or legislation milestones, but it is likely that there are other policy or legislative actions that could help enable CV deployment in the state. California should begin the process of setting the strategic direction for CV-related policy decisions that need to be made in future years. For starters, it should identify an appropriate forum for convening key CV stakeholders within the state to try to build consensus on their approach. Stakeholders should include representatives from the CV industry, state, regional and local transportation agencies, as well as representatives from non-transportation agencies such as the Air Resources Board (ARB) and the Clean Energy Commission (CEC).

One possible approach would be to build off of ITS California, which is an established group already familiar with CV. The newly formed stakeholder group could be used to identify strategic investments that the state should make in areas such as research and development, policy and infrastructure enhancements. The group could also define any state policy changes or legislation needed to overcome impediments to CV deployment or to compensate for market deficiencies. Ultimately, the group would look to identify ways that California can take a national lead in definition of policies and regulations that accelerate CV deployment that other states could follow.

### Track 3: Vehicle Deployment

The deployment of CV technology in vehicles is the responsibility of vehicle OEMs and their suppliers. There may also be an important role for the aftermarket suppliers if there is a strong

enough demand for CV technology in existing vehicles. The rate of CV adoption in vehicles will have an impact on California's transportation system. In general, the sooner CV becomes integrated into the vehicle fleet, the sooner Caltrans can leverage the CV-enabled data and communications links to improve safety and mobility on their roadways.

Caltrans cannot influence the rate of CV adoption in vehicles to a great extent, but there are some activities that it can do that might help. For instance, it should continue to be a champion for early CV deployments and show their leadership in this area by expanding and promoting their CV testbeds. Further, Caltrans could pursue opportunities to partner with vehicle OEMs or other private sector companies in large-scale CV pilots in California. This will indicate to the vehicle OEMs and other CV technology providers that California is committed to investing in CV infrastructure and help demonstrate the potential benefits of Day 1 CV applications.

#### Track 4: Infrastructure Deployment

##### *Near-term Projects:*

**Project 4-1:** Establish an initial wave of CV installations at 20 signalized intersections on a California corridor by 2018. The CV infrastructure should be compliant with federal standards (including security), connected to the traffic signal controllers, and set to broadcast SPaT and MAP messages.

**Project 4-2:** Establish an initial deployment of CV installations at select freeway locations (e.g. ramp meters) on a California corridor by 2020. The CV infrastructure should be compliant with federal standards (including security) and connected to a freeway ITS station.

#### Track 5: Research and Evaluation

##### *Ongoing Projects:*

**Project 5-1: Technical Support for CV Pilot Deployment.** Sponsor: Caltrans. This project includes enhancement and testing of transit signal priority and eco-approach and departure applications at the CV Testbed.

**Project 5-2: California CV Testbed Maintenance.** Sponsor: Caltrans. This project includes ongoing maintenance of the CV Testbed and some technical enhancements such as development of a remote monitoring tool and establishing a data connection with the national CV data warehouse.

**Project 5-3: Multi-Modal Intelligent Traffic Signal System.** Sponsor: FHWA and CV Pooled Fund Study. This project is developing and testing an enhanced traffic signal system that uses CV technology and data to improve all modes of travel (buses, commercial trucks, emergency vehicles, and pedestrians).

##### *Near-term Projects:*

**Project 5-4:** Conduct a study of the benefits and costs of connected AVs, with a range of applications and California-specific environments, with and without infrastructure cooperation.

**Project 5-5:** Conduct a study of the potential benefits of deploying CV applications that use California state maintenance fleet as early adopters. Study should consider pilots of these applications.

**Project 5-6:** Conduct technical and policy studies on cybersecurity and privacy challenges and potential solutions for connected vehicle systems (and connected AVs).

**Project 5-7:** Analyze technical requirements for communications to support CVs (and connected AVs), including coverage, capacity, reliability.

**Project 5-8:** Assess the ability of new and emerging communications technologies (e.g. 5G) to meet technical requirements for CVs (and connected AVs).

**Project 5-9:** Assess what it takes to operate and maintain complicated CV infrastructure and the likely impact on transportation agencies.

#### Track 6: Infrastructure-based Application Deployment

TBD (unlikely to begin before 2018, after application testing and evaluation)

#### Track 7: CV Planning and Programming

##### *Near-term Projects:*

**Project 7-1:** Develop a CV primer for state and regional planners to educate them about the benefits of CVs and how to incorporate CV into their planning activities.

**Project 7-2:** Conduct an assessment of current state and regional transportation modeling and planning tools to determine how well they account for CVs.

**Project 7-3:** Develop predictions of CV market penetration growth over time in California under multiple deployment scenarios to provide inputs for planning studies.

#### Track 8: Outreach and Workforce Training

##### *Near-term Projects:*

**Project 8-1:** Develop brochures and marketing materials describing CV and its benefits to educate decision-makers and increase awareness to the public. Leverage existing outreach material from FHWA and AASHTO.

**Project 8-2:** Develop a CV Training course for state and local traffic engineers and maintenance personnel to educate them on CV technology and related O&M needs. Partner with FHWA and state Universities to develop course curriculum and conduct statewide training.