Connected and Automated Vehicle Policy Development for California

A Research Report from the University of California Institute of Transportation Studies

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August 2017

PROJECT ID: ####### | DOI: #######

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ACKNOWLEDGEMENTS

Add acknowledgements here. Will need to confer with Maddie about official language.

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EXECUTIVE SUMMARY

Connected Vehicles (CV), Automated Vehicles (AV) and their combination as Connected Automated Vehicles (CAVs) have been among the most important developments in surface transportation within the past few years. California has been a national leader in the development of these technologies and their predecessors for several decades, but that leadership position is in jeopardy. Although much of the national private industry effort on developing CAV systems is currently happening in Silicon Valley, this has been proceeding despite the absence of a strong commitment to support CAV development and deployment on the public sector side.

While California's public sector has been relatively inactive on CAV, other states have become very pro-active, with commitments from their Governors and state DOTs to invest heavily to attract the CAV industry to their states. They are actively courting the companies that are currently working in California to move their development and testing work to the other states, and are offering to smooth the path to deployment through investments in cooperative infrastructure on their road networks and incentives for companies to relocate their research, development and industrial production activities. Those states have seen the potential for simultaneously creating new high-technology industry jobs and improving the performance of their transportation systems through encouragement of CAV systems. This is an area in which California needs to become more pro-active to retain and enhance its leadership position.

Several areas are suggested for active engagement in CAV implementation by the California public sector:

- Encouraging and supporting the development of state-of-the-art testing facilities where the latest CAV systems can be tested safely and efficiently under realistic conditions, in both closed sites and on public roads;
- Permitting testing of a wider range of vehicle types under a wider range of conditions on public roads in California (including heavy vehicles and human subjects testing by naïve drivers);
- Outreach to regional and local government agencies to help them understand the realistic prospects for CAV availability and to educate them about how best to prepare themselves for the deployment of these systems;
- Exploration of new public-private business models to facilitate deployment of vehicle-infrastructure cooperative systems;
- Supporting careful and comprehensive assessments of the transportation system impacts of various CAV systems so that state and local decision makers can make well-informed decisions about investments in support of deployments;

- Developing authoritative assessments of the importance of connectivity and cooperative infrastructure to the effectiveness of CAV systems, so that public agencies can understand how their investments in cooperative infrastructure are likely to affect transportation system performance;
- Assessing the broader societal impacts of CAV technology and producing credible estimates of the timing for implementation of each level of CAV capability;
- Investing in the deployment and operation of cooperative infrastructure for CAV systems, especially the DSRC communication infrastructure that is an important enabler of many of the CAV safety and mobility applications;
- Building on the existing work of the DMV to develop an appropriate regulatory framework that balances protection of public safety with encouragement of new technological innovations;
- Convening open public discussions of the safety of CAV systems to facilitate answering the vital societal question, "how safe is safe enough"?

We are at a critical time in the development of our transportation system, when the application of information technology has the potential to make significant contributions to its safety, efficiency and productivity. However, these improvements will not simply happen by themselves. Public sector engagement and action are needed in order for California to be able to capitalize on this opportunity. This is also an unusual opportunity in terms of the state's high-tech economy, with a strong synergy between actions that can simultaneously help solve our transportation problems and contribute to the health of our information technology industry.

1. Introduction

Connected and Automated Vehicles (CAVs) have been receiving increased attention in the media, by the general public, and among elected officials. It is important to recognize that there are some differences between connected vehicles (CV), automated vehicles (AV) and their combination as connected automated vehicles (CAV). These are likely to have different implications for the transportation system and they will develop along different time lines. Each of these concepts itself incorporates a wide range of applications, which will be implemented as distinct products and services.

CV technology enables vehicles to communicate with each other (V2V) and/or with the roadway infrastructure (V2I or I2V) wirelessly. This exchange of information enables the vehicles and infrastructure to function as a well-integrated system. A variety of wireless technologies can be used to implement CV functions, with different technologies having differing abilities to support various transportation applications. The CV technology with the strongest affinity for AV technologies is 5.9 GHz DSRC, which is a WiFi variant that has been designed to support time-critical and safety-critical communications with fast-moving vehicles. AV systems incorporate an even broader collection of technologies to take over varying degrees of responsibility for the dynamic driving task from human drivers. These range from driver assistance systems that automate only one driving function such as adaptive cruise control for vehicle following (at SAE Level 1) to fully automated systems that may eventually drive under the full range of conditions in which humans are capable of driving (SAE Level 5).

Until now, CAV developments have been proceeding largely in the private sector, with a relatively low level of public sector engagement. However, in order for California to gain real benefits from these technologies its public agencies need to become more actively engaged than they have been until now. The state, regional and local agencies need to give careful consideration to a wide range of policy questions surrounding the implementation of CVs, AVs and CAVs. Conscious decisions need to be made about how actively to invest resources and political capital in encouraging the deployment of these systems in California and in the encouragement of private industry work on research, development and implementation of these systems in California, where they have the potential to generate significant high-technology employment. California cannot sit by passively and expect the transportation and economic development benefits of CAV technology to occur by themselves, but it needs to be proactive in order to reap these benefits.

The potential applications of CV technologies include:

- Enhanced data collection about real-time traffic conditions to enable transportation management and emergency response providers to respond more quickly, intelligently and safely to traffic problems
- More accurate travel condition data available to travelers so that they can make better choices about when to travel and which routes to follow to minimize time wasted in congestion
- Enhanced information about parking availability so that people can avoid wasting time searching for parking spaces
- Enhanced ability to assign priority at signalized intersections among emergency, transit and goods movement vehicles relative to other traffic, based on locally defined needs
- More responsive pedestrian traffic control, so that pedestrians can cross traffic streams safely with a minimum of disruption to vehicle traffic
- Cooperative collision warnings to alert drivers and vulnerable road users to potential hazards.

The potential applications of AV technologies include:

- Active collision avoidance systems that can assist drivers to enhance traffic safety
- Control assistance systems that can relieve driver stress and enhance traveling comfort and convenience
- Low-speed driverless shuttle vehicles that can provide economically viable first mile-last mile connectivity to transit stations and short-range circulation services within activity centers
- Automatic steering of transit buses so that they can operate safely and smoothly in narrow transit-ways and can precision dock at stations, providing a rail-like quality of service at lower cost and obviating the need to deploy ramps for wheelchair access
- Automation of highway driving to enable drivers to make productive or entertaining use of their traveling time rather than having to concentrate on tedious driving tasks
- Automatic parking of vehicles to relieve drivers of parking tasks and enable vehicles to be parked at higher density in locations where space is expensive
- Automation of taxi services to reduce operating costs.

The more significant potential benefits of AV technologies can be gained when they are combined with CV technologies to produce CAVs:

- Cooperative adaptive cruise control systems that can smooth out traffic flow and increase highway capacity, while improving driving comfort and convenience and reducing emissions and energy use.
- Cooperative truck platooning systems that can significantly increase the fuel efficiency of heavy trucks, while also smoothing out traffic flow, improving driving comfort and convenience, reducing emissions and enhancing safety

- More advanced cooperative truck platooning systems that can enable truck drivers to function as logistics managers while traveling, enhancing the job status and satisfaction associated with truck driving
- Highly-automated cars that can enable their drivers to work, entertain themselves, or even sleep on long, boring highway trips
- Automation of shared vehicle fleets, enabling vehicles to be automatically repositioned for use by the next customer.

California was the first state in the country to embrace work on the vital CV technology of 5.9 GHz DSRC. Caltrans and MTC 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 in the Bay Area. We currently have 11 signalized intersections equipped along El Camino Real in Palo Alto and are in the process of expanding that to 17.

Since that time, more extensive DSRC installations have been implemented in other parts of the country, based on combinations of federal and state funding. These include:

- The Southeast Michigan DSRC testbed, encompassing 50 DSRC sites on freeways and major arterials between Detroit and Ann Arbor
- The Safety Pilot Model Deployment in Ann Arbor, which included 27 DSRC sites and about 2800 test vehicles for a major experiment, and is now serving as the foundation for more extensive implementations (San Diego was the unsuccessful finalist in the competition for the federal funding for this project)
- Virginia DOT has developed an extensive testbed site in the northern Virginia suburbs of Washington DC, with 45 DSRC sites on major freeways (I-66 and the Capitol Beltway) and urban arterials.
- The Connected Vehicle Pilot deployments that the U.S. DOT has funded at $45 million, involving implementations in New York City, Tampa, FL and Wyoming. The New York CV pilot deployment will include 350 roadside units and 8000 equipped vehicles, primarily taxis, city buses and municipal fleet vehicles.

The U.S. DOT Smart City Challenge was won by Columbus, Ohio, which is receiving $60 M to implement a large collection of CAV technologies and is benefiting from extensive publicity as well. San Francisco was one of the finalists in that competition, and then received a “consolation prize” project funded at $11 M from the U.S. DOT’s Advanced Transportation and Congestion Management Technologies Deployment (ATCMTD) program, while Los Angeles received two other projects funded at $3 M each from that program.

Although California is considered the national center for private sector development of AV technologies, the state government has been a passive participant in this field in recent years while other states have been very proactive in trying to attract the industry and federal funding to their locations (Michigan, Texas, Florida, Virginia being the most vocal proponents).

California should seriously invest in ensuring that related industries remains centered here, as well as for reaping the benefits of technological deployment. The level of investment of resources and prestige that the other states have devoted to this subject must not be under-estimated, because at this stage California is widely perceived to be the "sleeping giant" that is being caught unawares by its less well-positioned counterparts.

Major international automotive manufacturers, first-tier suppliers and more general information technology companies have focused much of their research and development activity on road vehicle automation in California because of the highly-skilled workforce and the entire technology innovation ecosystem of Silicon Valley. However, this does not guarantee that the later stages of product development and production, with their even larger economic impacts, will also be located here. The state needs to be looking ahead to ensure that it maintains a central role for the longer term in this dramatically growing industry sector.

Michigan:

As the long-term home of the automotive industry, and one that suffered particularly severely in the Great Recession of 2007-8, Michigan zealously protects its automotive industry interests. The state has set up a permissive approach to regulating the testing and implementation of driving automation systems, but more importantly it has invested significant public resources to promote the advancement of its research universities and test facilities related to connected and automated vehicles:

The Safety Pilot Model Deployment project in Ann Arbor was funded at $30 M, producing the highest profile test of connected vehicle technology and a foundation for continuing projects on connected automation, based on the "Ann Arbor Connected Vehicle Test Environment" that was created as the successor to the Safety Pilot.

- Michigan DOT has invested substantially in other connected vehicle test sites on public roads, drawing additional federal funds and substantial automotive industry participation.
- The University of Michigan established the $10 M M-City test site for vehicle automation systems on 32 acres of university land, with direct investments of University funds as well as funds from Michigan DOT and the Michigan Economic Development Corporation. This led to the creation of the Mobility Transformation Center, with industry commitments of $20 M for research on vehicle automation over its first three years
- Michigan established the American Center for Mobility at the former Willow Run aircraft and automotive plant, with seed funding of $50 M from the state aimed at attracting matching funds of an additional $30 M to build a large-scale test facility on 335 acres where it will be possible to test driving automation systems up to full highway speeds.

- The Michigan State Legislature, through the PA332 legislation, created the Michigan Council on Future Mobility to advise the Governor in matters of CAV technology. It is tasked to make annual recommendations on policy changes. Its members are specified to include a variety of representatives of the executive and legislative branches of state government plus eleven appointees from local government and the private sector.

Florida:

Florida DOT has established the Florida Automated Vehicles Program, intended to attract vehicle industry activities to the state. It has sponsored a variety of automation research projects at Florida universities and organizes an annual "summit" meeting to attract national and international participants as well as in-state participants, and to raise the state's profile in this domain. It has also initiated a pilot project to assess drivers' use of 50 vehicles using a commercially available collision warning system and is developing a freight signal priority project in the vicinity of the Miami International Airport.

Texas:

Texas DOT (TxDOT) has been sponsoring substantial research initiatives on road vehicle automation technology and policy at the two state university systems, the University of Texas at Austin and the Texas A&M System (including the Texas A&M Transportation Institute).

Virginia:

VDOT has been working closely with their University Transportation Centers on developing testing environments and sponsoring research in support of AV development in Virginia. VDOT funded the development of the 2.2 mile "Smart Road" private test site at VTTI, where a variety of driving conditions can be simulated, including artificial adverse weather. They have also developed the Virginia Automated Corridors in response to a strategic direction from their Governor, defining a public road test environment in northern Virginia, where automation systems can be tested under the supervision of VTTI. VTTI claims a combined $110 M infrastructure investment in their test facilities. In May 2017 the Virginia Governor announced the creation of an "Autonomous Systems Center of Excellence" as a state government clearinghouse for facilitating automation industry activities in Virginia.

2. Investments in enabling development and deployment of CAV systems in California

The large majority of the investments in developing the CAV technologies will be made by private companies that are planning to sell products and/or services based on these technologies. Additional investments in some of the underlying scientific advances that will be needed to make the enabling technologies feasible are likely to be funded by traditional federal government support for fundamental scientific research. These do not represent the totality of the investments that will be needed to advance CAV systems into widespread public use. Other investments will be needed at the state and local levels for a couple of different reasons: (1) to ensure California's competitiveness with other states and countries in attracting industry activities developing the technologies here; (2) to prepare specific locations in California for implementation of the CAV technologies, especially for the higher levels of automation, since it is highly unlikely that these implementations will be feasible based only on the actions of private sector actors.

2.1 Enhancing California's Competitiveness as a CAV Development Center

Although many private companies and public research institutes are doing research and development work on CAV technologies in California, they are operating at a disadvantage compared to their counterparts in several other parts of the country. California is not well supplied with publicly accessible test facilities that can be used for testing CAV systems off public roads. Closed-course testing is a vital activity in the earlier stages of developing such new systems for several major reasons:

- Developers need to able to test their newest and most innovative capabilities out of public view, where their competitors cannot observe what they are doing.
- The newest and most advanced functions need to go through extensive testing to refine their capabilities before they are safe enough to share the public roadway network with other road users. This has to be done on closed courses where failures of the technology will not endanger anybody.
- Some functions need to be tested under carefully controlled and repeatable conditions before they can be tried under less predictable conditions such as public roads (where access by others and the behaviors of other road users cannot be constrained).
- Some test conditions require modifications to the roadway infrastructure, which cannot be done safely on public roads, where these could create hazards for the normal road users.

Although a few vehicle manufacturers have their own private proving grounds in California, these are not normally open to other companies (and especially not to their competitors).

Organizations that lack their own proving grounds have very few options available to them in California and because of the long distances involved, they do not even have good access to publicly available proving grounds in other states. California has two of the ten nationally recognized test sites for automated vehicles (GoMentum Station in Concord and the I-15 Express Lanes in San Diego) plus one unofficial test site (at Castle Air Force Base near Merced) and the Caltrans-supported connected vehicle testbed along El Camino Real in Palo Alto. Google (Waymo) has a closed, private section of the Castle Air Force Base site of about 100 acres set up for their closed-course vehicle testing, while the GoMentum Station site is being used on a continuing basis by Honda and has been used intermittently by several other companies (Peloton Technology, EasyMile and Uber Advanced Technology Group) for testing their automated vehicles on its unimproved local roads. However, these sites are not nearly as well developed nor do they yet have as wide a range of the needed road conditions as the competing test sites in Michigan, Ohio and Virginia.

The state needs to seriously explore what it can do to facilitate the development of the large-scale vehicle test facilities needed by local CAV system developers. This could include financial support to enhance the capabilities of the existing sites or developing a new site or sites with better capabilities. Either of these approaches is likely to require a substantial investment of state resources and creative ways of sharing financial and operational responsibilities with other partners (local governments and private industry).

The state also needs to consider how it can improve the conditions for system developers who want to do later-stage testing on California public roads by modifying the existing DMV testing regulations to permit:

- Testing of automation technology on heavy-duty vehicles (over 10,000 pounds)
- Human-factors experiments in which naïve test subjects can drive highly automated vehicles (under the supervision of safety drivers) so that driver interactions with these systems can be better understood.

Several of the state's major cities have recently announced their intention to host testing of automated vehicle systems on their public roads. San Jose and San Francisco have released public requests for information to encourage AV system developers to proposed tests of their systems on the streets of these cities and Los Angeles has announced their desire to host AV tests as well. None of these cities has indicated an interest or ability to provide financial resources to enhance their infrastructure to support such testing, however, which appears to leave the financial burden entirely on the industry participants.

2.2 Helping California Regions and Localities Determine How Best to Capitalize on CAV Technologies

Most public agencies in California have very limited, if any, familiarity with CAV technologies. Even some of those that think they have such familiarity are likely to base their decisions on the very misleading information that is available to the general public on the internet and through the general-interest media, which does not provide a solid basis for decision making. These decisions are likely to be unwise and potentially wasteful, given the large discrepancies between the reality of the current state of the art and the general perceptions conveyed through the media. This topic is a source of great concern to the experts who are developing systems within the industry, who even have difficulty communicating the reality of the remaining technical challenges to senior corporate management.

Outreach is needed to the regional and local government agency staffs and their elected officials to better inform them about the current reality of driving automation technology so that they can make their plans based on realistic estimates of what automation capabilities are likely to become available for public use at what times in the future.

Some of the earliest implementation opportunities for driving automation technology are likely to be in the domain of public passenger transportation and freight movement, yet these receive significantly less attention in the media and by the general public than the more exotic highly automated taxi and passenger car concepts. Both the transit and freight applications are likely to need encouragement by public agency actions in providing the needed cooperative infrastructure, such as dedicated busways, lanes reserved for automated shuttles to provide first and last mile access to mass transit stations, rights of way in pedestrian zones and dedicated truck lanes, as well as infrastructure to vehicle (I2V) communication hot spots at key locations. Site-specific case studies of these types of applications are needed to provide realistic estimates of costs and benefits and implications for the transportation system as a whole. Example designs should be developed for the physical (civil) infrastructure elements that will be needed for the transit and truck-specific lanes so that the costs of implementing these elements can be better understood by potential local agency deployers.

2.3 Development of new public-private business models to facilitate CAV deployment

Throughout most of our history, the roadway infrastructure has been the responsibility of the public sector while the vehicles have been developed, owned and operated by private sector entities. That model has worked effectively while the interactions between the vehicles and the infrastructure have been limited. However, with the advent of CAV technology the roadway infrastructure and the vehicles are likely to be much more closely coupled with each other as a well-integrated transportation system, more like the railways and airways. In this kind of environment, system-level optimization requires trade-offs between the functions performed by the infrastructure and the vehicles. Multiple approaches are possible, and it is not obvious *a priori* what division of functions is best in terms of overall economic efficiency, safety, and transportation system performance. When the responsibilities for investment in vehicle and infrastructure elements are divided between different actors, nobody is in charge of the system as a whole and nobody can do the optimization. The respective self-interest of the separate public and private sector actors works against convergence on the best societal solution, because each is trying to optimize their own position rather than optimizing the system as a whole.

This vehicle-infrastructure cooperation aspect of CAV systems should motivate thinking about new opportunities to bring the vehicle and infrastructure elements together within a common institutional framework. For example, consider a public-private partnership that would be responsible for development and operation of both vehicles and their supporting roadway infrastructure in specific corridors – this could start in the context of public passenger transportation or goods movement, where there are already railroad-based analogies. Another possibility would be for the vehicle developers who want to implement CAV systems on their vehicles to finance the installation of cooperative infrastructure elements along the roadside to enable their vehicle systems to be less costly to implement and to perform better.

2.4 Careful and comprehensive estimation of CAV benefits and costs

There are no comprehensive and authoritative evaluations of the costs and benefits of CV or AV systems. The media is full of stories that exaggerate the benefits and minimize the costs because that is what they think the industry and the public want to see. However, serious evaluations are complicated and challenging because of the large uncertainties on both the supply and demand sides, which leave both cost and benefit estimates subject to large margins of error. Planners and policy makers need authoritative information so that they can make well-informed decisions on behalf of the public and can invest their public resources prudently.

This is an area in which there should be a strong public interest in funding substantial research that can identify the interactions of all the elements that affect costs and benefits for all the relevant stakeholders and develop the assessment framework to produce sensible predictions. It will also be useful to support a variety of case study examples across California, to show what the benefits and costs are likely to be in diverse California settings – large, medium and small urban areas, rural and intercity travel, and for movement of both people and goods. With a moderate number of case study examples in hand, decision makers in other locations with similar attributes should be able to get a first-order sense of what the implications of CAV systems are likely to be in their locations.

2.5 Assessments of importance of connectivity and cooperative infrastructure to generate societal benefits from automation

Divergent opinions have been expressed about the value of adding connectivity to road vehicle automation systems and about modifying the roadway infrastructure to make it "friendlier" for automation systems. This is more than an academic concern, because it has implications for potential public investments to provide I2V/V2I connectivity and other infrastructure modifications in support of AV operations and for planning estimates of the impacts that future AV deployments are likely to have on the major transportation system measures of effectiveness (safety, efficiency, emissions, travel times, congestion, etc.). Significant differences in the impacts of AV systems with and without connectivity or infrastructure changes could also be the basis for policy decisions to actively encourage the incorporation of connectivity in AVs and to invest in supportive or actively cooperative infrastructure.

Because recent research has shown the potential for large differences between automation with and without connectivity and with or without infrastructure modifications in the future (when large numbers of AVs are in regular use), California should initiate a substantial research effort to estimate the differences in each of the important transportation system measures of effectiveness between highly automated vehicles with and without connectivity and with and without supportive infrastructure. This is likely to require full-scale experiments on test vehicles and transportation system modeling and simulation studies to extrapolate the test results to predict the effects when large numbers of either type of vehicles (with and without connectivity and cooperative infrastructure) have been deployed in California.

2.6 Assessment of broader societal implications of CAVs

There has been much speculation about the potential for highly automated vehicles to stimulate broad societal changes, and a significant fraction of the population (and of elected officials and industry decision makers) has become convinced that dramatic changes are right around the corner based on widespread AV deployment. Serious analysis of these potential changes is needed to help guide policy decisions that will be confronting public sector decision makers in the near future. They will be asked by various stakeholder constituencies to adopt policies to actively encourage or discourage use of different types of CAV services. Predictions of the effects of those policies are likely to diverge widely depending on which stakeholder group has commissioned the study.

California needs unbiased and authoritative studies that can estimate the longer-term impacts that CAVs are likely to have on the state in a variety of ways. Given the large uncertainties about the state of the technology, its rate of advancement, the likely rate of market adoption, and the ways in which the public will choose to use the technology, independent analyses that explicitly recognize these uncertainties and approach the problem parametrically, through sensitivity studies, will be needed to guide California decision makers. A recent national study of energy impacts of CAV systems for DOE estimated that the impacts could range from a saving of 90% of current transportation energy usage to an increase of 200% in current transportation energy usage. Such a wide range of outcomes indicates that the uncertainties are so large as to preclude meaningful quantitative analysis, or the studies were based on too extreme a range of assumptions. More focused studies, specific to California scenarios, and with a more realistic and narrower range of assumptions, are needed. These studies should be based on carefully considered assumptions about:

- The years when specific CAV applications will be introduced into public use
- The rate of growth in use of each CAV application in subsequent years based on user needs and desires and the costs of using each application, with and without connectivity
- The amount of roadway infrastructure that has been modified to facilitate automated operations (such as better markings and signage or segregated lanes)
- The technical performance of each CAV application, with and without connectivity, with and without other cooperative infrastructure
- The safety level that each CAV application will be able to achieve, with and without connectivity and with and without cooperative infrastructure.

Given that these are all still highly uncertain factors, sensitivity studies will be needed on each of them, providing a reasonable range of assumed values as inputs.

These sensitivity studies need to consider a broad range of impacts that the CAV deployments could have on the transportation system and on society more broadly, including consideration of:

- Traffic flow speeds and volumes at various strategic locations in the California transportation system
- Changes in energy consumption and emissions associated with transportation
- Changes in the costs of traffic crashes (especially in
- Changes in travelers' personal trip-making decisions based on use of CAV systems
- Changes in traffic fatalities, injuries and the overall costs of traffic crashes

- Changes in land use over the longer term
- Changes in employment in the transportation sector and related affected industries
- Changes in patterns of goods movement around California (OD pairs, routes and modes)
- Net contributions to the California state economy
- Changes in mobility for the transportation disadvantaged.

3. Preparing California's Infrastructure to Support CAV Deployment

Based on the findings from the cooperative infrastructure assessment recommended in Section 2.5, California should be prepared to invest some of its infrastructure construction and maintenance resources and adjust its policies to facilitate the effective deployment of CAV systems. There could be significant differences in the capabilities of the CAV-equipped vehicles and in the timing of their availability for public use based on the availability of suitable infrastructure support. This infrastructure support could be manifested in a variety of ways:

- Installation and maintenance of clear and conspicuous pavement markings
- Installation and maintenance of clear, conspicuous and standardized roadway signage
- Augmenting signage and pavement markings with devices that can be interrogated by passing vehicles (such as RFID tags or passive magnetic markers)
- Installation and operation of DSRC communication systems at key roadside locations such as signalized intersections and ramp meters
- Providing incentives and even financial support to encourage regional, county and local agencies to do more widespread deployment of DSRC communication infrastructure so that California is more CV-ready in general
- Facilitating high precision digital mapping of the state's roadway infrastructure
- Providing a comprehensive real-time database about work zone operations and emergency response actions that may impede travel at specific roadway locations
- Providing physical separations between CAV and conventional vehicles in locations where this could improve traffic flow (managed lanes for CAVs, or dedicated lanes for use by transit vehicles or heavy trucks)
- Providing infrastructure-based sensing to identify hazardous conditions that can be communicated to CAVs (approaching traffic at blind intersections, presence of animals or pedestrians or bicyclists that can't be seen by vehicle sensors, obstacles on the road, low pavement friction, etc.)
- Providing smart parking facilities that can facilitate use of automated valet parking systems by vehicles
- Supporting reconfiguration of urban or suburban streets to provide some separation between conventional vehicle traffic, low-speed automated vehicles, and bicyclists and pedestrians to improve safety for all of them.

If California ignores these infrastructure support opportunities while other jurisdictions become more proactive about implementing them, the availability of CAV system services and benefits could be delayed for Californians compared to the citizens of the other jurisdictions.

3.1 Establishing an appropriate regulatory framework for safe and economically viable deployment of CAV systems

California has already established a national leadership position in development of the regulatory framework for deployment of highly automated vehicle (HAV) systems, through the work of the DMV. This is a challenging topic because of the delicate balance that needs to be struck between protecting public safety and encouraging technological innovation. Although HAV systems have the potential to improve transportation safety in the long run, the earliest prototype and production systems may not necessarily be as safe as they should be, and actually have the potential to reduce public safety. The regulatory approach needs to recognize both the upside and downside potentials to find the right balance. If the regulations are too strict they could deter HAV developers from doing their work and introducing their products in California. On the other hand, if the regulations are too lenient they could lead to immature systems injuring or killing people on the road, and could set back progress if this leads to a public backlash against the automation technology.

Society has not yet grappled with the question about how safe an automated system needs to be in order to be considered acceptable. It seems clear that it needs to be at least as safe as an average driver, but some people have suggested that it needs to be significantly safer (by factors or 2 or 10 or 100, depending on the source), without regard for the increasingly hard technological challenges that would have to be conquered to reach those higher safety goals. The state needs to be proactively engaged in an open discussion among Californians regarding the trade-offs between earlier adoption of systems with less stringent safety requirements versus a longer wait and higher costs for the availability of systems that will be able to meet more stringent safety requirements.

After some level of agreement has been reached regarding the acceptable level of safety that should be required of new HAV systems, it is also necessary to consider what processes to use to determine that any specific system is able to achieve that target safety level. This is a serious challenge that is beyond the current state of the art, but it needs concentrated attention by top-level experts in order to determine how safe any specific system really is. There is a related challenge in determining the best institutional framework for certifying that safety – should this be done by the developer of the system, by a government agency, or by independent thirdparty organizations, and how should that be financed? Serious trade-offs are involved in considering the advantages and disadvantages of these alternative approaches, and those need to be weighed carefully.

Existing motor vehicle codes contain many elements that explicitly or implicitly assume that a human driver is making all the decisions involved in driving a motor vehicle. These assumptions no longer hold for HAVs, so the codes will need to be reviewed carefully to determine how to manage the potential conflicts in assumptions when computer software is making some or all of the driving decisions. Significant changes are likely to be necessary in the language of the motor vehicle codes.

Motor vehicle insurance regulations are similarly based on the assumption of human driver decision making and responsibility for vehicle actions. These will also need to be reconsidered carefully to ensure that they can be modernized to account for software decision making in HAVs. The insurance industry faces large challenges in assessing the safety of HAVs so that they can determine pricing for insurance on HAVs, and the state insurance regulations are likely to need significant modifications to facilitate sensible insurance pricing that realistically reflects the risks of HAVs and provides consumers with appropriate incentives to adopt the CAV technologies that can be demonstrated to improve safety.

4. In Conclusion

At this point, California is still recognized as one of the leaders in CV and AV technology in the U.S., however most of this recognition is based on past glories rather than on recent accomplishments. Most of the major advances on the public sector side in CV and AV systems in the U.S. have been occurring in other states, even while industry continues to be very active in California. However, this cannot be maintained indefinitely, and California needs to adopt a more pro-active approach at the state level to maintain and even advance its standing on the national scene. This includes investing resources on improving its transportation and research infrastructure and adopting regulatory policies that will encourage safe but rapid deployment of the CAV technologies to help address the state's transportation needs. This should have the added benefit of enhancing the industrial economy of the state, enhancing employment prospects in this dynamic new sector of the information economy.