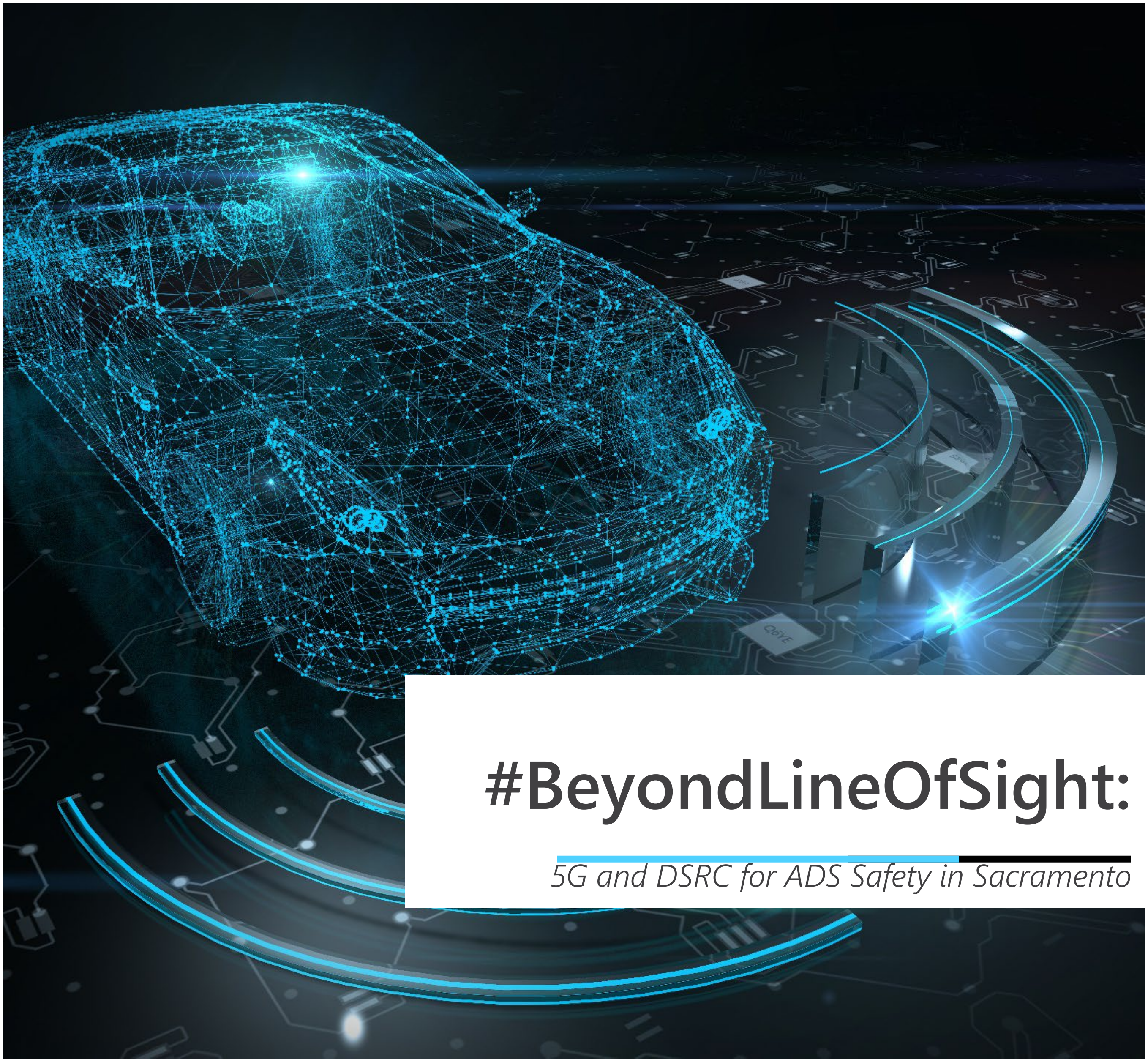
City of
SACRAMENTO



#BeyondLineOfSight:

5G and DSRC for ADS Safety in Sacramento

2019 Automated Driving System Demonstration Grant

Part 1 – Project Narrative and Technical Approach

City of SACRAMENTO
Department of Public Works

US Department of Transportation
Office of the Secretary
Automated Driving System Demonstration Grants
1200 New Jersey Ave, SE
Washington, DC 20590

March 21, 2019

Secretary Chao:

Thank you for the opportunity to be considered for an Automated Driving System Demonstration Grant.

There is no simple way to ensure the safety of automated driving systems, but Sacramento offers the best of proven public-private capacity to conduct cutting edge research and testing of autonomous and connected vehicle communication technologies in a diverse real-world setting.

Sacramento's proposed demonstration project will leverage the City's existing 5G network and Smart City infrastructure to test ADS applications at varying speeds across roadway environments and different wireless communications protocols. The proposed demonstration will contribute to the USDOT's efforts to harmonize connected vehicle technologies and standards.

I am confident that your office will recognize the benefit that Sacramento will bring as a participant in this demonstration program and I look forward to the announcement of the grant recipients.

Please don't hesitate to contact Fedolia "Sparky" Harris in our department at (916) 808-2996 or at fharris@cityofsacramento.org if you have any questions regarding this application.

Best Regards,

Hector Barron
Director, Department of Public Works
City of Sacramento

Department of Public Works
Office of the Director
916-808-7100
915 I Street, Room 2000
Sacramento, CA 95814

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Summary Table

Project Name/Title	#BeyondLineOfSight: 5G and DSRC for ADS Safety in Sacramento
Prime Applicant's Legal Name and Address	City of Sacramento Sacramento City Hall 915 I Street Sacramento, CA 95814
Point of Contact (Name/Title, Email, Phone Number)	Fedolia "Sparky" Harris FHarris@cityofsacramento.org (916) 808-2996
Proposed Location (States and Municipalities)	City of Sacramento, California
Proposed Technologies (briefly list)	5G, DSRC,
Proposed Duration (period of performance)	2020 - 2023
Federal Funding Amount Requested	$8,749,143
Non-Federal Cost Share Amount Proposed, if applicable	NA
Total Project Cost (Federal Share + Non-Federal Cost Share, if applicable)	$8,749,143

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Executive Summary

Vision

Sacramento's Automated Driving System (ADS) project will demonstrate how ADS-equipped vehicles perform across a range of connectivity scenarios, Connected Vehicle (CV) applications, and real-world driving scenarios, providing valuable insight into the capabilities of V2I applications to improve the performance of ADS beyond what on-board sensors can provide.

Goals and Objectives

The proposed project will accomplish four key goals:

Goal 1: Develop a cloud-based, secure and open data management platform and data aggregator framework for ADS and Connected Vehicle (CV) data collection, storage, analysis, and public dissemination.

Objectives

a. Develop a data management plan that identifies data collection methods, types, and storage, and defines the process for accessing and sharing data.
b. Test cybersecurity protocols.

Goal 2: Properly equip proposed test routes with software and hardware that will accommodate ADS and CV operation; Conduct connected ADS tests to collect real time, high resolution safety performance data.

Objectives

a. Identify designated ADS test routes.
b. Develop Highly Autonomous Driving maps (HAD) for use in ADS navigation and data collection.
c. Install 5G mmWave network nodes and Dedicated Short Range Communication infrastructure along ADS test routes and establish communication with ADS.

d. Establish Advanced Traffic Controller communication with ADS.

e. Install vulnerable road user detection systems at intersections and establish communication with ADS.

Goal 3: Conduct ADS tests across a range of connectivity scenarios, evaluate performance, identify points of failure.

Objectives

a. Quantify safety performance of the ADS using onboard systems, 5G, and DSRC.

b. Identify fail points by speed, where onboard, DSRC and 5G are no longer reliable for collision avoidance.

Goal 4: Share data and findings with stakeholders in an open, safe and transparent way, catalyze interest in continued testing beyond the scope of the USDOT grant.

Objectives

a. Conduct in-person meetings with key stakeholders and the public to share the demonstration status and findings.

b. Provide online communications about the demonstration.

c. Conduct a knowledge transfer campaign to communicate findings to key decision makers, industry leaders, and national and international experts.

Unique Value of Sacramento Proposal

We recognize that the USDOT has already invested in research and development of DSRC-based evaluations of ADS applications. Sacramento was one of the first agencies in California to enter into a license agreement with wireless carriers to bring 5G connectivity to the region and this project is thus uniquely positioned to perform real-world tests of ADS across a wide range of connectivity scenarios. The proposed demonstration will examine ADS safety through a range of experiments and will test and compare the capacity of 5G and DSRC communication technologies to augment ADS performance beyond what on-board systems can provide. Findings will likely be an important input into federal and state AV/CV legislation.

The City of Sacramento is additionally unique in that it has already made significant investments in Smart City roadway infrastructure, and intends to bring those investments to bear on this project. These include:

- Over 500 signalized intersections connected over a robust network of over 160 miles of fiber optic cable, connected to an Advanced Traffic Management System (ATMS).
- A Traffic Operations Center (TOC), located in City Hall, where all traffic data is collected, secured and managed within two data centers.
- Closed-circuit television (CCTV) cameras for traffic monitoring at over 100 locations, whose footage streams to the Traffic Operations Center.
- A dedicated team of traffic engineering, operations and maintenance staff eager to engage in deployment of this project.
- An open data portal, where the City already shares traffic counts, collision records, and API access to data.

To this existing smart infrastructure the City will add 5G short cell wireless nodes, DSRC infrastructure and bilateral pedestrian detection systems (discussed further in our Technical Approach below).

Team Members

The project team draws on existing and ongoing collaboration among public, private, and academic partners invested in researching and testing ADS technologies in the Sacramento region.

City of Sacramento

The City of Sacramento will lead the project. Sacramento is continually enhancing its existing infrastructure and systems to evolve Sacramento into a truly Smart City. The City is a regional leader in the development and deployment of advanced technologies that enhance mobility, improve safety, and reduce traffic congestion for residents, commuters, and tourists alike. The City has invested significant effort in the development of smart city technologies, deploying

California's first 5G network to power vehicle-to-vehicle, vehicle-to-infrastructure, and vehicle-to-pedestrian communications.

ATOS Lab

The Autonomous Transportation Open Standards (ATOS) Lab is a public-private consortium of government agencies and connected and autonomous vehicle technology companies working in partnership to co-develop interoperable protocols and standards. Building on momentum in the Sacramento region, Congresswoman Doris Matsui, State Senator Richard Pan, Mayor Darrell Steinberg, and Sacramento Kings Chairman Vivek Ranadivé came together to co-create ATOS Labs in order to establish a beachhead for innovation and technology to flourish in the Sacramento region.

California State University, Sacramento (CSUS)

Faculty and researchers in the College of Engineering and Computer Science at Sacramento State bring to the project their collective expertise in transportation engineering, intelligent transportation systems, wireless communications (5G), inter-vehicle communication, cybersecurity, and big data analytics. In addition to past work with the City of Sacramento, Sacramento State brings the experience of its own campus autonomous shuttle demonstration, known as "Olli."

CSUS will be responsible for much of the software development and data reporting for the project.

UC Davis Institute of Transportation Studies

The Institute of Transportation Studies at UC Davis (ITS-Davis) is the leading university center in the world on sustainable transportation. The Institute partners with government, industry, and non-governmental organizations to inform policy making and business decisions, and advance public discourse on key transportation, energy, and environmental issues. Guidance and participation from ITS-Davis will allow for the efficient development and dissemination of best practices as a trusted source for cutting-edge research. Most recently, UCD was selected by the USDOT to lead the National Center for Sustainable Transportation in collaboration with CSU Long

Beach, Georgia Tech, UC Riverside, the University of Southern California, and the University of Vermont to advance the state-of-the-art in transportation research and technology, and develop the next generation of transportation professionals.

ITS Davis will support the data management, software development and data evaluation efforts of the project.

Valley Vision

Valley Vision will support the project's outreach and collaboration activities. Valley Vision is a civic leadership organization that unites the Sacramento region in order to solve complex and pressing problems in the six-county Sacramento region and beyond. Founded 25 years ago, Valley Vision focuses on triple bottom line issues such as economic prosperity, social equity, and environmental sustainability. Valley Vision's core strengths include:

- Inclusive community engagement, including facilitating focus groups, conducting interviews, using participatory action research, and other methods to gain community input and elevate community views to inform decision-making;
- Data-driven problem-solving, including research, evaluation, and public opinion polling;
- Elevating regional issues, relying on communications and storytelling, and media relations; and
- Network development, management, and coalition building via stakeholder engagement, process design and meeting facilitation.

In addition to specializing in community outreach and stakeholder engagement, Valley Vision benefits from subject matter expertise in the area of autonomous vehicle technology and policy. Further, Valley Vision serves as fiscal agent for the Autonomous Transportation Open Standards (ATOS) Lab in the Sacramento region.

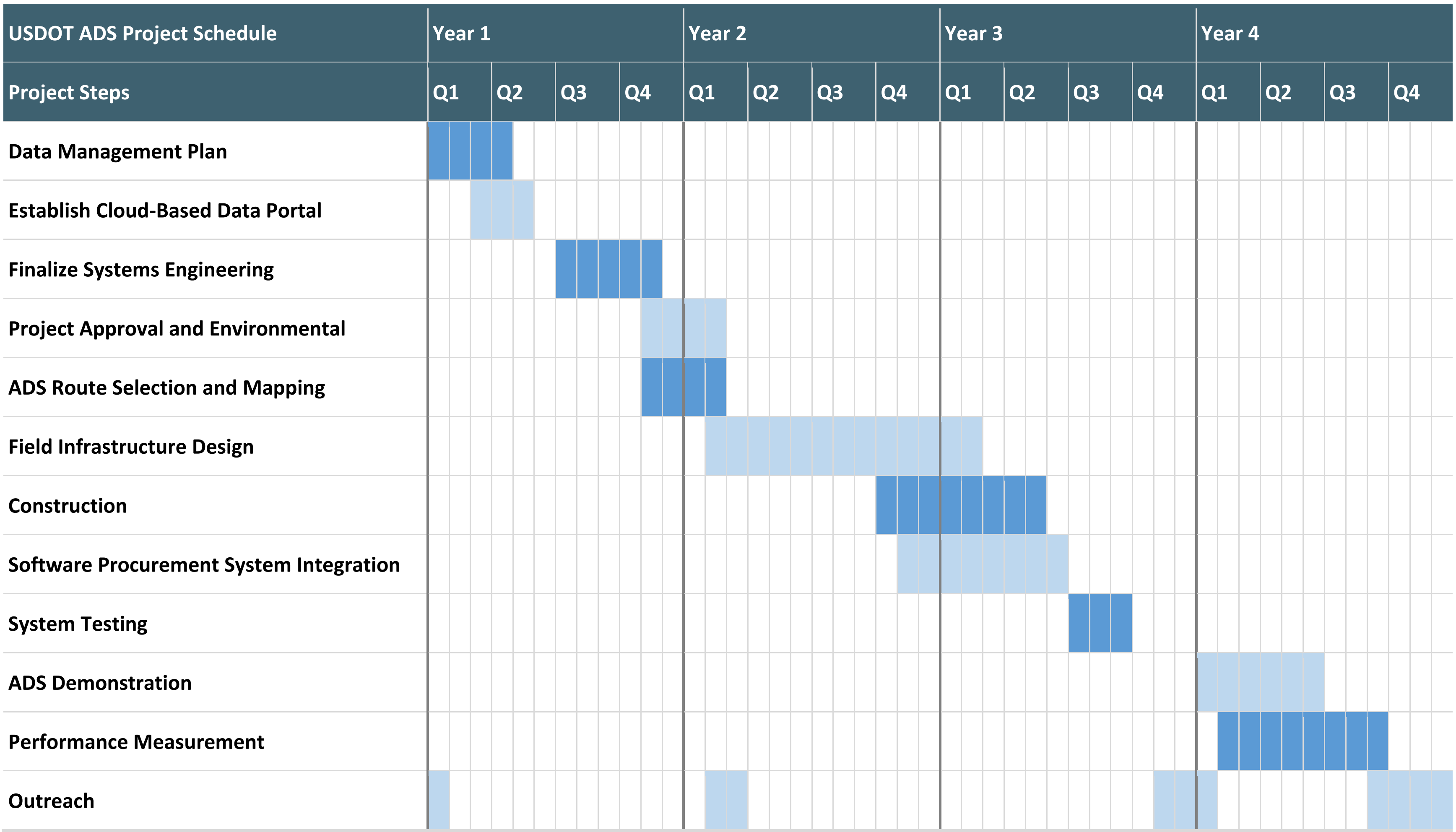
Jurisdiction

The proposed demonstration will be conducted in the City of Sacramento, where three potential demonstration test routes provide a variety of real-world settings and speed limits ranging from less than 10 mph to 45 mph and above.

Demonstration Schedule

Table 1 illustrates the demonstration project's proposed schedule.

Table 1. Proposed Project Schedule



Goals

Test ADS Safety in a Connected Environment

The proposed demonstration will test collision avoidance capabilities of ADS, and test the capacity of CV applications using 5G and DSRC communication technologies to expand ADS capabilities beyond on-board systems. Wireless communications via 5G and DSRC present different and complimentary opportunities to supplement onboard sensors and improve the collision avoidance performance of ADS. This demonstration will produce data and analysis of ADS performance under different conditions and at varying speeds to identify the failure points of 5G, DSRC, and onboard technologies. It will therefore contribute to rulemaking efforts of various federal and state organizations.

The proposed demonstration will also test how the presence of pedestrians in crosswalks is communicated across a variety of technologies (standard active detection at traffic signals using push buttons, connected pedestrians via mobile app, passive detection of pedestrians using sensors). The proposed demonstration will in this way illustrate the benefits and limitations of sensors, and how sensor redundancy can benefit safety of ADS.

Collision avoidance requires round-trip latencies below 50ms. The proposed demonstration will perform the following tests:

- 5G node b and base station handovers (node to vehicle)
- 5G spectrum V2N testing and Uu interface testing.
- 5G/DSRC harmonious coexistence in the same channel/band, MAC, and PHY layers
- C-P2X for vulnerable road users
- Can begin to develop V2X isolation from non-safety domain and evaluate cyber security risks

Where necessary along the selected demonstration test routes, the project will upgrade traffic signals to advanced traffic controller technology and install bilateral pedestrian detection systems, which are enhanced by communicating with infrastructure such as traffic controllers. Such connected infrastructure can provide collision alerts to both drivers and pedestrians in parallel. Such connected pedestrian devices that communicate with various infrastructure components have the potential to more accurately interpret and predict pedestrian movement than pedestrian devices that only communicate with vehicles within a short range.

While traditional vehicles, cyclists, and pedestrians will also benefit from this connected infrastructure, autonomous vehicle operation has been shown to improve significantly with such connectivity. The proposed demonstration will illustrate the benefits and limits of sensory and data redundancy for collision avoidance.

Create a Best-in-Class ADS and CV Data Management Platform

The project will produce several types of data including wireless sensed data, computer software, experimental measures, publications, curriculum materials, and project assessment data. Project data will include software code for computer simulation, numerical analysis, and testbed experiments. For example, 5G and DSRC algorithms code, sensor fusion code, secure communication protocol code, real-time data communication and analysis code.

The proposed demonstration will produce and share data from the ADS' onboard LiDAR, radar data, video and photo data, network test data, and software data. Onboard vehicle sensor related data retrieval will be performed by the OEM auto manufacturer event data recorders and shared with the TOC and USDOT networks. ADS Demonstration vehicles will be outfitted with data modems communicating with TOC servers to transmit infrastructure to vehicle data as necessary.

The project will develop and deploy a vast array of cloud-based data generated by vehicles, applications and infrastructure, in addition to written project deliverables and outreach materials. We will develop a data management platform and data aggregator framework for ADS data collection, storage, analysis, and public dissemination. Project stakeholders and USDOT will have access to raw data; public domain open access data will be scrubbed of all CBI and PPI identifiers before being made available to the public, which will have access for at least five years following completion of the proposed demonstration.

We will examine similar data platforms, including that offered by the California Connected Vehicle Corridor managed by Caltrans and UC Berkeley PATH. Our goal will be to improve upon the data management platforms offered by this and other ADS and CV pilots across the country. Of course, that software can benefit USDOT on further pilots.

Catalyze Regional Collaboration

The proposed demonstration brings together the City of Sacramento and ATOS Lab with faculty from both the College of Engineering and Computer Science at California State University, Sacramento and the University of California, Davis Institute of Transportation Studies, as well as Valley Vision, which specializes in inclusive community engagement. This collaboration builds on existing and ongoing partnerships between the City of Sacramento and several private and public sector players, including:

1. Mobile communications companies currently deploying 5G mobile technology in the California capital,
2. Original equipment manufacturers of ADS including Local Motors “Olli” and others,
3. Dynamic mapping and artificial intelligence firms, and
4. Public entities, such as the Sacramento Area Council of Governments (SACOG) who hosts a regional ITS partnership, with whom Sacramento and their partners are active participants. Also, Sacramento frequently coordinates with the California Department of Transportation (Caltrans) – Sacramento is Caltrans’ Headquarters, as well as the center of their District 3.

This project team combines the best of public sector innovation and service delivery in partnership with new technology startups, academic research and testing, and community engagement. The project team will work closely with local law enforcement to conduct the proposed demonstration and will leverage earned media coverage, online communications, and outreach to engage a broad public, including key stakeholders and other jurisdictions, in the objectives, findings, and dissemination of learning from this project.

Focus Areas

Significant Public Benefits

Expanding ADS collision avoidance beyond what on-board systems provide will have particular benefits for vulnerable road users, including pedestrians, bicyclists, and the visually impaired. Our hope is that in time, these technologies will help every agency advance towards their safety and "Vision Zero" goals. Additionally, the pedestrian applications mentioned here have applicability to the visually impaired population, expanding the pool of vulnerable users that may benefit.

Addressing Market Failure and Other Compelling Public Needs

We recognize that DSRC is an established, tested standard with little organic demand, and 5G is relatively new, untested, but has significant organic demand. To be clear, the City's goal with this project is not to "settle" arguments between those that find themselves camped in either the 5G or DSRC camps. We do recognize however that many of the expected benefits of 5G are hypothetical; this project's goal is to provide equal environments in which to test both technologies and expose shortcomings to help guide future research and legislation.

Economic Vitality

The proposed demonstration project will support the US industrial base through Buy American requirements in accordance with Executive Order 13788. To the extent possible, the proposed demonstration will source material and software from American providers.

Complexity of Technology

The proposed demonstration can accommodate an array of L3, L4, and/or L5 ADS to test the capacity for 5G and DSRC communication technologies to expand ADS connectivity beyond the line of sight. It will also demonstrate applicability of applications and technology over an array of land uses, roadway cross-sections, speeds and modes.

Diversity of Projects

The proposed demonstration will test connected vehicle technologies with the potential to be deployed and scaled across various rural, suburban, and urban networks, with important insights for connected freight, personal mobility, and mass transit implementations.

Transportation-Challenged Populations

The proposed demonstration project will test connected vehicle technologies and identify fail points by speed, where onboard, DSRC and 5G are no longer reliable for collision avoidance. Particular benefits to vulnerable road users, including pedestrians and bicyclists. 5G C-P2X connectivity has the potential to alert the visually impaired to the presence of autonomous vehicle and other connected users, while 5G C-V2X has the potential to alert ADS of vulnerable users.

Prototypes

The City of Sacramento is currently negotiating test arrangements with a variety of ADS OEMs. Outcomes of this project will help us, and countless other agencies, determine policies and guidelines that should be considered for inclusion in AV/CV testing agreements. The choice of test vehicle(s) for the proposed demonstration project will ultimately be determined by its compatibility with both 5G and DSRC technologies. At a minimum, the test vehicle(s) will be in limited prototype state suitable to support safe demonstrations on city streets.

The project will also test and produce collision warning and avoidance algorithms based on collected test data, and simulations will identify optimal vehicular millimeter wave (mmWave) antenna configurations for testing in the live demonstrations.

Requirements

The proposed demonstration will test L3, L4, and/or L5 ADS in a physical demonstration on live city streets and high-speed test track in Sacramento, in addition to simulations for testing project algorithms.

The project's Data Management Plan includes data sharing with the USDOT in real- or near real-time, while the City's existing open data portal may serve as a platform for also sharing project demonstration data to the public.

The ADS will include an input/output user interface. Within the analytics pipeline, the project will build interactive visualizations to complement algorithmic processing of collected test data. Such visualization will include understandable and accessible on-board displays of ADS sensor data.

Outreach will include earned media through the project team's high-profile collaboration, online communications, and in-person engagement with key stakeholders and the public throughout the course of the four-year project schedule.

As a demonstration of sensory redundancy using 5G and DSRC, in addition to onboard LiDAR, the proposed project will provide an example for the safe integration of smart city infrastructure and ADS technologies across the nation. In particular, the project will identify and troubleshoot 5G antenna configurations for establishing communication and facilitating reliable hand-offs with ADS technology.

Approach

Technical Approach

The proposed demonstration includes 9 tasks:

1. **Finalize Data Management Plan**

   For the project's first deliverable, the project team will finalize a Data Management Plan (DMP). The project will develop and deploy a cloud-based data management platform and data aggregator framework for autonomous vehicle data collection, storage, analysis, and public dissemination. The City's Traffic Operations Center and the USDOT will have access to the cloud-based storage, which may utilize the City's existing open data portal. Data will be maintained in customized formats and managed in two forms: raw data restricted access and public domain open access (scrubbed of all CBI and PPI identifiers). The DMP will also detail a procedure for tagging demonstration data and creating metadata for future analysis. Finally, the DMP will include cybersecurity tests and provisions for sharing, storing, and preserving data produced by the demonstration project.

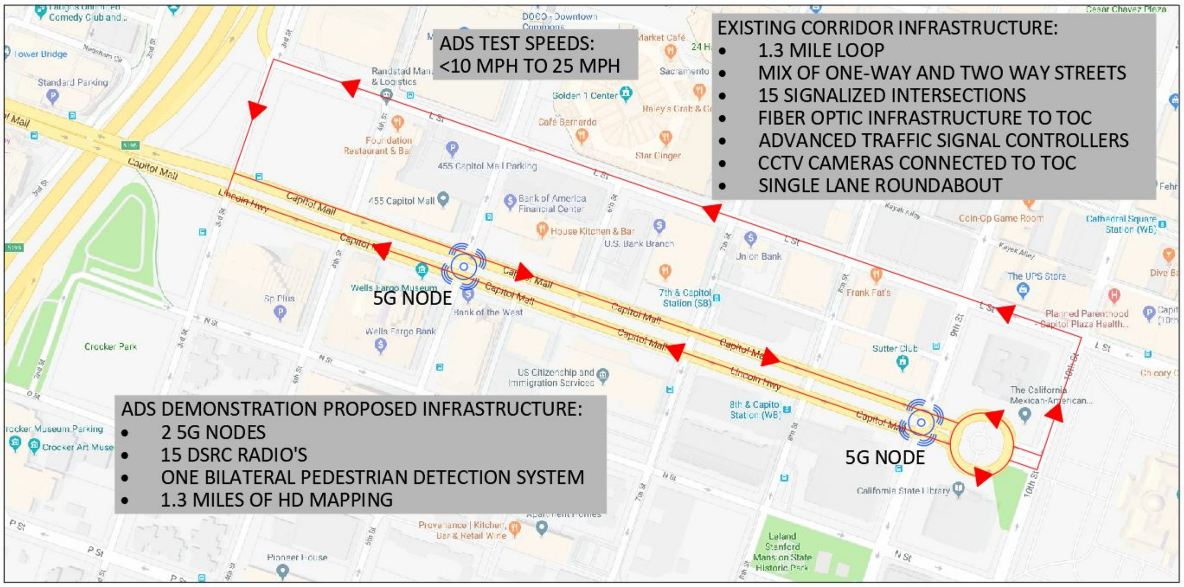
2. **Select Demonstration Test Routes**

   Success of the proposed demonstration relies heavily on the test environment. The attributes that will define the operational design domain (ODD) where the ADS will perform Dynamic Driving Tasks (DDT) include:

   - Physical Infrastructure
   - Operational Constraints
   - Objects
   - Connectivity
   - Environmental Conditions

The three potential demonstration routes identified below represent both open-road testing and closed-track testing to maximize opportunities for object and event detection and response (OEDR) data collection and to allow for testing at speeds of less than 10 mph to 45 mph and above.

Figure 1. Downtown Capitol Mall Loop: a 1.3-mile loop using L Street, Capitol Mall, 3rd Street, and 10th Street



DOWNTOWN CAPITOL MALL LOOP

The Downtown Capitol Mall Loop is 1.3 miles long with a mix of one-way and two-way streets that will provide a real-world environment to test ADS at speeds from less than 10 mph to 25 mph.

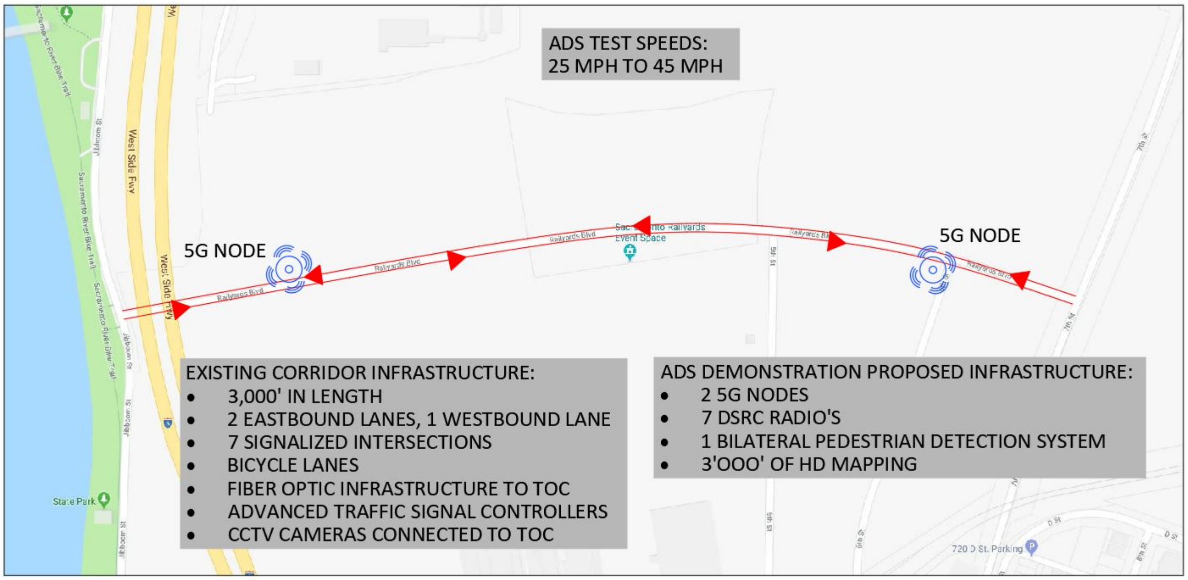
L Street is a three-lane one-way street that runs adjacent to the Golden 1 Center indoor arena. L Street between 5th Street and 9th Street is part of a complex traffic management plan implemented by the City of Sacramento Police Department during arena events. The traffic management plan will provide opportunities for the proposed demonstration to test ADS in navigating large event-related lane closures, road closures, and heavy pedestrian activity.

Capitol Mall is a two-way roadway with a landscaped median, green painted bicycle facilities, and a single lane roundabout. Bicycle facilities along Capitol Mall will provide the proposed demonstration with opportunities to collect ADS sensor data related to bicyclists and bicycle facilities.

Sacramento Regional Transportation Light Rail crosses the Downtown Capitol Mall Loop in two locations. The light rail system operates on priority preemption at two traffic signals along the loop. Light rail preemption will provide an opportunity to test the broadcasting of preemption signal phase and timing messages over DSRC and 5G.

The Downtown Loop features state of the art traffic signal equipment with advanced traffic signal controllers connected to the city's network via fiber optic infrastructure. Traffic signal data, CCTV data, and other infrastructure data is available to the City's Traffic Operations Center.

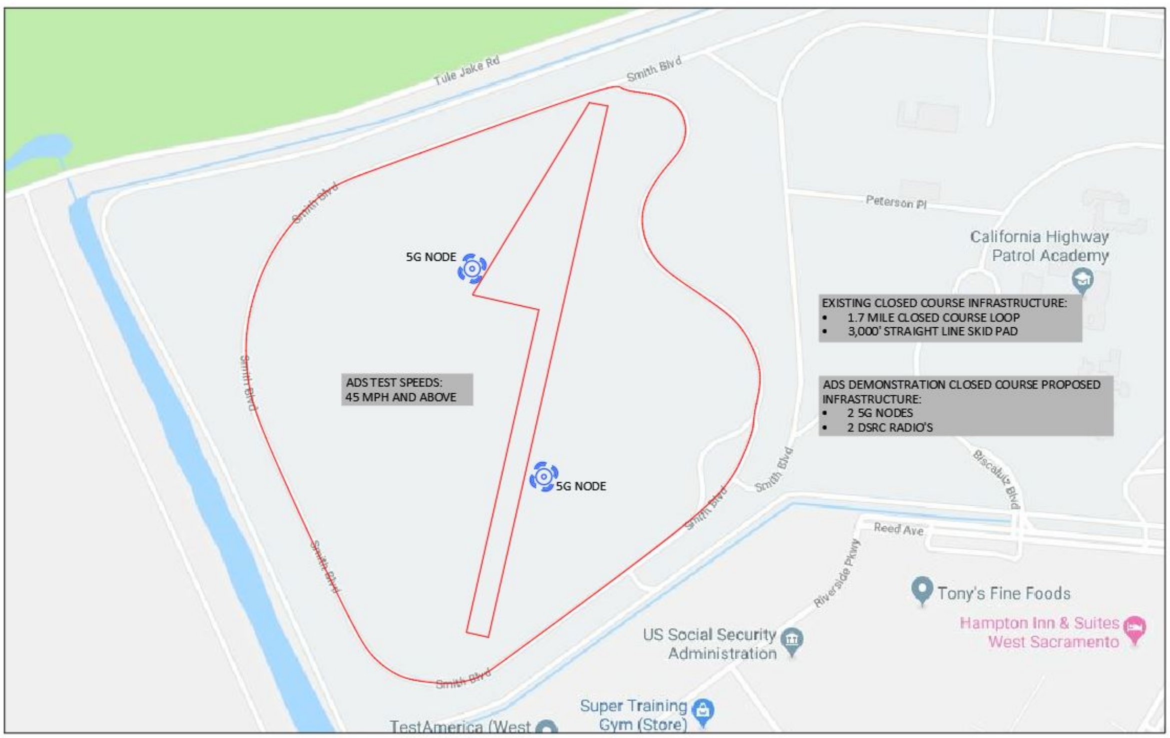
Figure 2. Railyards Boulevard Corridor: a 0.6-mile corridor along Railyards Boulevard from Jiboom Street to 7th Street



RAILYARDS CORRIDOR

Railyards Boulevard is a 0.6-mile corridor with two westbound lanes, a single eastbound lane, and bicycle facilities in both directions. Railyards Boulevard is unique in the City for its recent construction in an undeveloped area, featuring state-of-the-art traffic signal equipment, fiber optic infrastructure connected to the City's Traffic Operations Center, multiple CCTV cameras, and 360-degree vehicle detection cameras. Infrastructure improvements were constructed in anticipation of future development of the Railyards area. Today the Railyards corridor is largely unused and provides a safe environment for the testing of autonomous vehicles. City of Sacramento will coordinate with local police department staff to ensure a low-risk environment for the proposed demonstration at speeds between 25 mph and 45 mph.

Figure 3. California Highway Patrol Test Track: a 1.7-mile loop closed course test track (Smith Blvd)



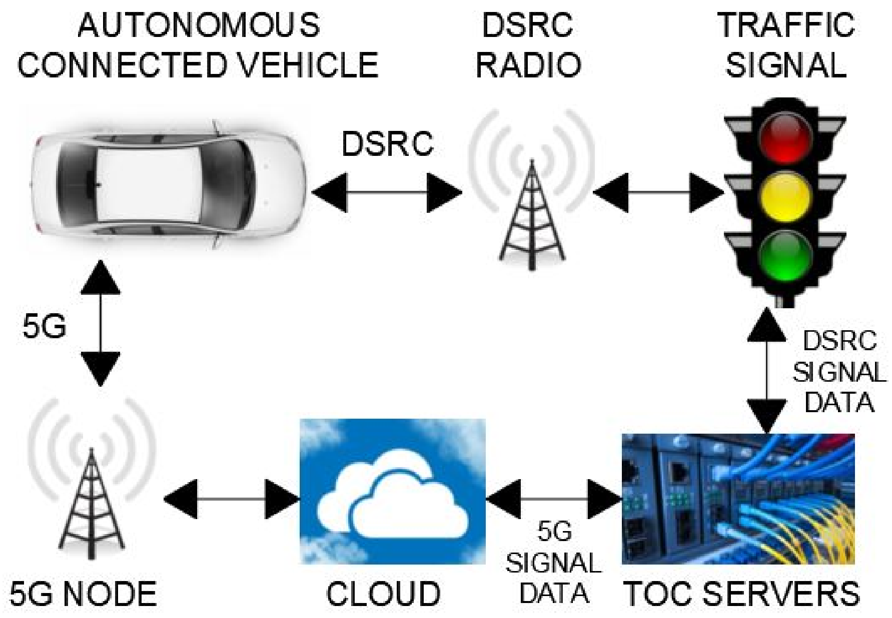
CALIFORNIA HIGHWAY PATROL
ACADEMY CLOSED COURSE

The California Highway Patrol Academy Test Track and skid pad is a closed course environment with restricted public access. The facility features a 1.7-mile loop and a 3,000-foot straight line skid pad. In cooperation with the California Highway Patrol, this facility provides a low-risk environment to perform the proposed ADS demonstration at speeds of 45 mph and above.

3. **Deploy Communication Technologies and Test Equipment**

As part of this project the City plans to deploy 5G and DSRC communications at signalized intersections allowing for infrastructure-to-infrastructure and vehicle-to-infrastructure data exchange. Where necessary, the project will supplement the City's current 5G deployment with additional base stations and add advanced traffic signal controls and bilateral detection systems to ensure coverage of the selected demonstration test routes. Bilateral pedestrian detection systems provide collision alerts to both drivers and pedestrians in parallel through connection with traffic signal infrastructure. This system is enhanced by communicating with infrastructure. That is, a pedestrian device that communicates with various infrastructure components has the potential to more accurately interpret and predict pedestrian movement than a pedestrian device that only communicates with vehicles within a short range. The project will also deploy DSRC roadside units along the test routes and establish communication with the city's smart controllers at signalized intersections. **Figure 4** illustrates the project's proposed communications infrastructure.

Figure 4. Proposed Communications Infrastructure



4. Produce Highly Autonomous Driving Maps of Demonstration Test Routes

Recognizing that fusing 2D, 3D, and HD data together into detailed and accurately annotated maps is a critical step to enabling safe and reliable autonomous vehicle systems, the City of Sacramento is already partnering with mapping companies to create seed maps that may be leveraged as part of the proposed ADS demonstration project.

Technology Company Phantom Auto began building high-definition, 3D maps for autonomous vehicle demonstration routes within the City in February 2019 and will spend the next six months mapping and testing the City's wireless coverage and capacity. The proposed demonstration project will supplement existing Highly Autonomous Driving (HAD) maps where needed along test routes, such as the California Highway Patrol Test Track loop.

5. Finalize Demonstration Test Parameters and Schedule

The current metrics most widely used to evaluate the safety performance of Autonomous Driving Systems (ADS) is the number of miles driven and the frequency of human interventions; both of which are insufficient to demonstrate the safety of an autonomous vehicle. It is obvious that the operation of an autonomous vehicle for hundreds of miles on a rural freeway with limited traffic cannot be compared with operation in a city environment with multitude of interactions with various modes of transportation. Therefore, there is a need to develop additional safety metrics that characterize the safety risk of ADS integration into the transportation system. A detailed review of the literature revealed several resource documents and research related to the development of new metrics and Key Performance Indicators (KPI) related to ADS. A report by VTT Technical Research Center of Finland presents a summary of KPIs developed through a survey of various stakeholders from Europe, US, and Japan to facilitate harmonization in data collection as part of future research activities related to ADS. Additionally, other research reports also propose a number of different metrics on the same topics. In view of the literature findings, the investigators in this research are proposing a list of KPIs related to L3, L4, L5 ADS operation and safety which is shown in Table 2. Table 2 presents the KPIs related to ADS operation, ADS safety, and KPIs specifically related to the use of L3 ADS only.

Safety data communication using 5G and DSRC systems will be conducted under different weather conditions, emulated traffic congestion and interference conditions, and antenna failure. Link configuration, coverage, and communication latency of 5G and DSRC systems will be measured along the routes. All results will be stored and evaluated. It is expected that results from this measurement campaign will give insights into vehicular mmWave LOS/NLOS channel models, which are not fully understood.

Table 2. KPI Related to ADS Operation, Safety, and Use

Vehicle Operation KPIs (L3, L4, L5)	Safety (L3, L4, L5)	ADS Use (L3 only)
No. of instances where the driver must take manual control / 1000 miles	No. of crashes (distinguishing property damage, and crashes with injuries and fatalities), in total and per 100 million miles	No. of instances where the driver must take manual control / 1000 miles
Mean and max duration of the transfer of control between operator/driver and vehicle (when requested by the vehicle)	No. of instances where the driver must take manual control / 1000 miles	Use of automated driving functions (% of miles of max possible use)
Mean and max duration of the transfer of control between operator/driver and vehicle (turning ADS on/off, manual overrule)	No. of conflicts encountered where time-to-collision (TTC) is less than a pre-determined threshold / 100 million miles	Comprehension of user interface (expressed on a Likert scale, e.g. 1–9, low–high)
Emergency decelerations per 1000 miles	No. of instances with hard braking (high deceleration) / 1000 mi	Feeling of safety (expressed on a Likert scale, e.g. 1–9, very dangerous – very safe)
Mean and min time-headway to the vehicle in front in car following situations	No. of false positives / 1000 miles, i.e. instances where the vehicle takes unnecessary collision avoidance action	Interaction with other road users (expressed on a Likert scale, e.g. 1–9, failure–perfect)
Min accepted gap at intersections or in lane changes	No. of instances rated by a human as being of increased risk or not correctly handled by the automated vehicle / 1000 miles	Inappropriate use of automated driving functions (no. of events per 100 miles)
Mean, max, and rate of change in longitudinal acceleration and deceleration	Proportion of time when time-to-collision (TTC) is less than a pre-determined threshold	Requirement of attention and concentration (number of events per 100 mi)
Lateral position variation (st. dev. of distance from the center of the lane) while travelling within a lane	Distribution of TTC at brake onsets	Trust (expressed on a Likert scale, e.g. 1–9, low–high)
Speed variation (st. dev. of speeds) while travelling at constant speed (on link section, single speed limit)	No. of selected traffic violations / 1000 miles of driving	Reliability (subjective perception, expressed on a Likert scale, e.g. 1–9, low–high)
Proportion of correct use of turning indicator/signal		Mental workload (expressed on a Likert scale, e.g. 1–9, low–high)
Mean lateral acceleration during lane change		Feeling of being able to control the vehicle (expressed on a Likert scale, e.g. 1-9, failure-perfect)
		Feeling of frustration (expressed on a Likert scale, e.g. 1–9, low–high)

6. **Conduct Automated Driving System Tests**

As required under current California regulations, the project team will work with an OEM to perform ADS testing on the selected demonstration routes, according to the test parameters and KPIs identified above.

7. **Collect and Share Data with the USDOT**

The Draft Data Management Plan included in Part 3 of this application details the steps this demonstration project will take to collect, package, and share – in real- or near real-time – with the USDOT and the public.

8. **Evaluate Data and Test Results for Safety Performance**

The proposed project will evaluate safety performance parameters using the three described technologies in terms of reliability, latency, speed, time of day, road conditions, NLOS links, V2X and V2P. This task will also provide an estimate of the safety benefits from full deployment, enable the fine-tuning of some of the algorithms and parameters, and identify appropriate directions for ongoing outreach. Finally, collision warning and avoidance algorithms based on real data will be developed, optimized, and tested.

Evaluation of safety metrics

Vehicles with high automation are expected to generate terabytes of data per vehicle per day. Managing and communicating this data is challenging with today's DSRC systems. Extensive simulations based on real data would be conducted to understand the limitations of onboard sensors, 5G and DSRC systems, and harness the benefits of the combined systems (sensor fusion).

Infrastructure assisted collision warning/avoidance system

Infrastructure equipped with sensors, example camera, radar, etc. can provide a bird's eye view of the environment to vehicles in its range. This task will study the feasibility of sensor fusion at the infrastructure to generate driver assist algorithms (L3 or greater automation) and improve situational awareness. Infrastructure-based collision avoidance/warning system will be evaluated and tested.

Design of beamforming algorithms for 5G V2X systems

Due to weather effects and mobility, vehicular millimeter wave (mmWave) antenna elements are subject to random blockages from debris or particles found along the lane of travel. Configuring these arrays in the presence of blockages (which the communication system is unaware of) is crucial for the system operation. This task focuses on the design of signal processing tools for antenna blockage detection and beam-steering in the presence of antenna blockages.

Prototyping and Proof of Concept

Based on the results of the simulations, optimal configurations will be outlined and tested on vehicles.

9. **Outreach**

The proposed demonstration project will include a comprehensive outreach and engagement plan to share the status of demonstrations, results, and lessons learned with key stakeholders, industry leaders, decision-makers, and the public. This public outreach effort will leverage existing regional activities and partnerships with the Sacramento Area Council of Governments, Sacramento Municipal Utility District, the California Air Resources Board, and others to amplify existing work. Communications will include project communications, earned media, social media, and other means of educating stakeholders and disseminating information. Outreach will include 16 meetings with key stakeholders and 4 meetings with the public throughout the life of the project.

Challenges

Four challenges to the proposed demonstration of ADS and connected vehicle technologies have been identified. They include the following:

1. **Compatibility and Interoperability** – The City of Sacramento currently works with three different signal controller manufacturers, which poses challenges for compatibility and interoperability of the various RSUs with each of the different controllers. To reduce the risk of procuring devices that are not interoperable with the various controllers, the project will incorporate device testing into the City's procurement approach and source

election process. Prior to releasing a Request For Proposals to DSRC radio vendors, the project will host a “plugfest” to test vendor equipment with the City’s various signal controllers and ensure compatibility and interoperability.

2. **Standards and Regulations** – The proposed demonstration project will conform to all relevant ITS architecture standards, including CVRIA standards, and connected vehicle resources and guidance published by the FHWA, the USDOT’s ITS JPO, the National Operations Center of Excellence, AASHTO, and others. The project will conform with both the Federal Motor Vehicle Safety Standards and the Federal Motor Carrier Safety Regulations, as well as all relevant state regulations governing autonomous vehicle testing and permitting regulations, as amended in Articles 3.7 and 3.8 of Title 13, Division 1, Chapter 1 of the California Code of Regulations.
3. **5G deployable devices** – The technology for the proposed demonstration using 5G connectivity exists, but commercially available devices are limited. Integration of back-end systems to move and process the data and push the data out to both 5G and DSRC systems will be a challenge. The project team will work with mobile communications providers to ensure support on the 5G subscriber node side and the end user side with phones, modems and routers to get the data to and from vehicles and pedestrians. There are multiple pilot assessments of DSRC technology, such as the USDOT’s pilot in New York City that can be used to develop connectivity.
4. **DSRC Licensing and 5G Permissions** – Obtaining licenses to deploy DSRC RSU’s and permission for a waiver to include 5G in the 5.9 GHz band currently dedicated for Intelligent Transportation Systems (ITS) communications from the Federal Communications Commission (FCC) will be time consuming.

   Obtaining a license from the FCC to deploy DSRC RSU’s involves the following steps:

   ◦ Site Selection, Deployment Design, and Service Planning
   ◦ Procurement and Equipment /Other Certifications
   ◦ FCC Licensing and Site Registration
   ◦ Coordination with Existing Federal and non-Federal Co-Primary Users (e.g., Fixed Satellite)
   ◦ Radio Frequency Analysis and Survey of "Unlicensed" Systems (e.g. Wi-Fi)
   ◦ Revisions to Design and Service Planning

- RSU Site Installation
- Security Credentialing and Service/Application Commissioning
- Service Channel/ Application Configuration Updates and Optimization
- Security Credential Updates
- Ongoing Coordination with New Primary Users
- Ongoing Coordination with New DSRC RSU Sites/Service Providers
- Updates to Radio Frequency Analysis Addressing New Interference

Current FCC rules restrict ITS operations in the 5.9 GHz band to those that use the DSRC standard, and thus a waiver of the rules is necessary to test 5G in that spectrum band. Petitions to obtain such a waiver are currently outstanding by various manufacturers and industry associations, and the process involves uncertainty and unpredictability.

Data Sharing

The project will develop and deploy a cloud-based data management platform and data aggregator framework for autonomous vehicle data collection, storage, analysis, and public dissemination. The City's Traffic Operations Center and the USDOT will have access to the cloud-based storage, which may utilize the City's existing open data portal. Data will be maintained in customized formats and managed in two forms: raw data restricted access and public domain open access (scrubbed of all CBI and PPI identifiers).

Approach to Risk

Automated vehicles are vulnerable to various security and spoofing attacks. As detailed in the Draft Data Management Plan, this project will employ additional layers of encryption for V2X communications to mitigate these data security risks. This project also proposes the use of a subset of the communication antennas for data encryption at the physical layer and will quantify the trade-offs between communication rate-loss, security benefits, and interference to neighboring vehicles. The proposed demonstration will also investigate the simultaneous use of communication and sensing technologies to provide additional degrees of secrecy and resistance to spoofing.