Utah's Cooperative Automation Demonstration: A Data-Driven Safety Evaluation

Part 1: Project Narrative

A Proposal in Response to

USDOT Automated Driving System Demonstration Grant

Notice of Funding Opportunity (NOFO) Number 693JJ319NF00001

March 21, 2019

Utah Department of Transportation (Lead)

University of Utah

University of South Florida

Leidos, Inc.

State of Utah

GARY R. HERBERT
Governor

SPENCER J. COX
Lieutenant Governor

DEPARTMENT OF TRANSPORTATION

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March 21, 2019

U.S. Department of Transportation
Federal Highway Administration
1200 New Jersey Avenue, SE
Mail Drop E62-204
Washington DC 20590

Attn: Sara Tarpgaard, HCFA-32

Dear Ms. Tarpgaard:

SUBJECT: Proposal in response to Notice of Funding Opportunity Number 693JJ319NF00001, "Automated Driving System Demonstration Grants"

The Utah Department of Transportation (UDOT), in conjunction with the University of Utah is pleased to offer the attached proposal, ***Utah's Cooperative Automation Demonstration: A Data-Driven Safety Evaluation***, in response to Solicitation 693JJ319NF00001. UDOT is dedicated to innovation and the deployment of new technologies to benefit the travelers throughout the state of Utah and across the nation, and is a leader in deployment of new transportation technologies. We are excited to offer this innovative demonstration.

UDOT believes that cooperative automation, the synergy of vehicle automation and connectivity, is the key to achieving our agency's vision to "*Keep Utah Moving*" by enhancing mobility and increasing safety. Cooperative automation promises to remove the driver error that keeps us from our *Zero Fatalities* goal, and will facilitate improved transit service, ride sharing and vehicle efficiency toward enhanced mobility. Our research proposal will advance cooperative automation and provide useful data and insight in this forward-looking effort.

Utah is currently ranked as the fastest growing state in the nation, with population increasing rapidly in both the urban and rural areas. The population growth in our state will be accompanied by challenges in maintaining mobility, safety and access to real-time information. Innovation in transportation is a core value in our Department as we work toward meeting the needs of the future. For over twenty years UDOT has been known as an innovator in transportation technology, with a culture for open data sharing. The University of Utah has often been our partner in developing and deploying those innovations. Our proposal builds on this great history of innovation and partnership, and further capitalizes on our more recent accomplishments as we demonstrate Level 3 capabilities on an operational connected vehicle corridor and continue our research into public trust of automation with an extended Level 4 low-speed shuttle deployment.

We believe that Utah offers unique characteristics, extensive ITS infrastructure, and connected vehicle experience that can be leveraged to support successful demonstrations of cooperative automation. Our proposed demonstration of Level 3 vehicles will occur on Redwood Road in Salt Lake City, a state-owned arterial and the nation's first fully-operational vehicle-to-infrastructure connected corridor. This connected corridor has been actively communicating with city buses since November 2017, and has produced important data about system reliability. This corridor is part of our statewide fiber network, is supported by a centrally controlled traffic signal system that connects nearly 100 percent of Utah's 1990 statewide traffic signals (including state-owned and municipal-owned signals), and uses an award-winning traffic signal performance metrics system that produces granular data on system performance. Demonstrating Level 3 capabilities on this corridor will be an unprecedented opportunity for learning and data generation, and will address a significant public need.

Our proposed deployment of a Level 4 autonomous shuttle, with a focus on evaluating public trust and access, is an extension of a shuttle deployment project already underway to evaluate the capabilities of these vehicles for first-mile, last-mile transit solutions and measure public interest in these systems. Additional research and data gathering will provide insights into public trust in ways that have not yet been accomplished in the United States.

While the infrastructure is important, the pioneer spirit that Utah residents bring to the table is how we get the work done. We also have one of the lowest median ages of any population in the country, making our citizens, partners and Universities ripe for innovative collaboration. Utah has a low unemployment rate, high fiscal responsibility and a nimble and well educated work force. The possibilities are astounding!

We are poised to successfully deliver the projects listed within this grant application. We have assembled a broad group of project participants and stakeholders who will both contribute to and benefit from this work. We feel that data sharing is the future of transportation and will share the data, information, and lessons learned from these projects with interested parties. The work done within these projects will help revolutionize the transportation landscape as we know it, helping to solve longstanding transportation challenges such as first mile/last mile trips, integration of connected and autonomous vehicles, and development of cooperative automation systems.

With my signature, below, I authorize UDOT to enter into a cost reimbursement agreement for work described in this proposal, and stipulate that our offer is predicated on the terms and conditions described in the Notice of Funding Opportunity.

Sincerely,

Carlos M. Braceras, P.E.
Executive Director

CMB/BL/dej

Summary Table	
Project Name/Title	Utah's Cooperative Automation Demonstration: A Data-Driven Safety Evaluation
Eligible Entity Applying to Receive Federal Funding (Prime Applicant's Legal Name and Address)	Utah Department of Transportation 4501 S 2700W, Salt Lake City, Utah 84119
Point of Contact (Name/Title; Email; Phone Number)	Blaine D. Leonard, P.E. Technology & Innovation Engineer bleonard@utah.gov / 801-887-3723
Proposed Location (State(s) and Municipalities) for the Demonstration	Salt Lake County, Utah
Proposed Technologies for the Demonstration (briefly list)	Level 3 Automated Vehicles, Level 4 Autonomous Shuttle, Connected Vehicle applications, Data Sharing portal for public sector, private sector and industry
Proposed duration of the Demonstration (period of performance)	4 Years
Federal Funding Amount Requested	$ 4,420,631
Non-Federal Cost Share Amount Proposed, if applicable	$ 1,212,742
Total Project Cost (Federal Share + Non-Federal Cost Share, if applicable)	$ 5,633,373

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1. EXECUTIVE SUMMARY

a. Vision, Goals, and Objectives

Automated driving systems (ADS) are expected to effectively eliminate human errors and increase road safety, in particular when enhanced with the connected vehicles technologies (Li and Kockelman, 2016), i.e. cooperative automation. Although methods (e.g., Funke et al., 2007; Gordon et al., 2010) have been proposed to estimate the expected safety benefits of integrated ADS into the nations' on-road transportation systems, most methods are based on simple assumptions or computer simulation and few are validated with field demonstrations with full scale **automated vehicles (AV)**. Especially, field demonstrations are even more valuable in estimating ADS benefits in complex AV applications such as integration with **connected vehicles (CV)**, arterial operations with signalized traffic signals and services for demand response ridesharing, in which AV performance can hardly be estimated with simple simulations. Further, the benefits of AV will only be realized when the public has sufficient trust in these new systems. USDOT Secretary Chao remarked in February 2019 that "the promise of automated vehicles will never be realized if the public does not have confidence in the safety, security and privacy of these new emerging technologies".

Our team is proposing a groundbreaking ADS demonstration using Level 3 (L3) vehicles on public signalized arterials and a Level 4 (L4) shuttle on private campus in Salt Lake City, Utah. The L3 component will involve multiple automated, connected, and human-driven vehicles with coordinated signal timing and AV trajectory optimization. The L4 component will also involve measurements of trust on vehicles with and without a human operator present, which will be compared with those of the L3 component. A set of broad pilot tests will be conducted before the demonstration to examine the key components of the demonstration. These will, incrementally, produce data and results, minimizing the risk as the pilots become increasingly complex. The demonstration serves the following seven project objectives:

a) Studying ADS's safety performance on a public road network. This project will sequentially demonstrate ADS under two scenarios: i) with three L3 AVs only; and ii) in an environment that involves both AVs and CVs. By demonstrating ADS on a public road network, this project will offer a unique opportunity to study the interaction between AVs and **human-driven vehicles (HV)**, indicate how they affect each other and how they respond to each other, and measure the level of safety that can be achieved in a mixed-traffic environment.

b) Conducting cooperative automation demonstration by integrating ADS with connected vehicle (CV) technology. This project will leverage the 11-mile long, 30-intersection, Redwood Road CV corridor in Salt Lake City as the testbed, to demonstrate how to integrate ADS into existing transportation systems safely on public roads and address how this deployment can be scaled for broader application across the nation. These demonstrations will leverage the important development already accomplished with the USDOT-funded Cooperative Automation Research Mobility Applications (CARMA) platform, and further expand that open-source software platform. This work will also enable platooning of L3 AVs on an arterial to demonstrate the extra benefits from reduced headway and increased control responsiveness.

c) Developing metrics to measure ADS's traffic safety performance, and collecting the demonstration data in real-time and sharing data with the public. Particularly, this project will investigate how driving styles of AVs impact decision-making, trust, and acceptance of AVs both for the human operator and for drivers in other HVs. Metrics will focus on safety and driver response.

d) Developing input/output user interfaces on the ADS and allow users with varied abilities to input origins and destinations, communicate route choices, and access ADS information. For the L3 demonstrations on Redwood Road, a user interface will be developed to allow the rider to select a destination (which may be along Redwood Road or on one of several cross-streets) and to access the ADS operational data. For the L4 demonstration, an existing user interface will communicate with riders and allow them to initiate travel.

e) Evaluating the public's trust in automated vehicle systems. The benefits of AVs will not be realized unless the public trusts, and will use these new systems. A UDOT project already underway is assessing the level of trust of the general public (through focus groups), and of those who ride a L4 shuttle system in Salt Lake City, and evaluating how their trust levels may change based on an experience in an AV. Extending that cognitive psychology effort, this project will further evaluate trust in a scenario where a human operator is not recognizable or physically present on the vehicle, an important step toward a fully autonomous future. Then, using data from L3 vehicles operating in live traffic, further information will be gathered from drivers and riders in the mixed-traffic scenarios.

f) Testing applications with great potential to service transportation-challenged populations. The L4 shuttle demonstration will evaluate the functionality of an AV to serve various populations in an actual deployment setting, including the utility of an automated ramp, the ease of use of wheelchair securement, ride quality, and the route schedule flexibility that might be needed to serve groups that need longer transit dwell times. We also seek to understand the attitudes that these populations have toward this novel mode of transportation.

g) Sharing data, information and lessons learned with the AV community and the public. The data gained from these proposed deployments will be very valuable to other researchers, deplorers, agencies, and the public. Inherent in this project are specific plans to share data through open data portals, present findings in various forums, work proactively with the USDOT to provide information in formats useful to their efforts, and interact with the media so the public will learn from our work.

The remainder of our proposal, including the information contained in Parts 2 through 6, will demonstrate that we have a robust project plan focused on achieving unique objectives and collecting a rich data set, that we have assembled a project team capable of executing the plan successfully, and that this project will meet the goals, objectives and requirements set forth by the USDOT. We look forward to a collaborative and productive relationship with the USDOT on this project.

b. Key partners, Stakeholders, and Team Members

A project of this nature will require a broad set of key players, supporters, and stakeholders. The Utah Department of Transportation (UDOT) Traffic Management Division, with Blaine Leonard serving as the Project Lead, will lead the ADS demonstration efforts. As shown in Fig. 1, UDOT's academic partners at the University of Utah (UU) and the University of South Florida (USF) will be responsible for much of the research and development work on this project, supported by the experienced private consultant and CARMA developer, Leidos. Other private sector partners include AutonomouStuff, EasyMile, and Narwhal and they will provide L3 AV, L4 AV, and CV technical support. Stakeholders, who will periodically review work progress, include the Utah Transit Authority, Salt Lake City, Wasatch Front Regional Council (the local MPO), SunTrax - Florida Department of Transportation (FDOT,) AAA Foundation for Traffic Safety, University of Maryland, University of Illinois Urbana-Champaign, Center for Urban Transportation Research, Traffic Technology Service, Inc., and Toyota.

Fig. 1: Overview of the project team

c. Challenges, Technologies, and Anticipated Performance Improvements

<u>Public arterial application challenges</u>

Despite increasing deployment of low level ADS, real-world *<u>AV applications on public roads with signalized intersections are rare</u>*. Technologies for existing pilot deployment of ADS applications are highly classified commercial secrets of top AV companies (e.g., Waymo, Uber). Few public agencies have conducted ADS demonstrations on public roads due to challenges such as handling traffic signal systems, multi-modal surrounding traffic (motor-vehicles, pedestrians and bicyclists), and needs for lane changing, turning and stop and go maneuvers. Hence, operations of AVs on arterials is much more complicated than on freeways. To address those challenges and lead the ADS demonstrations from the perspective of the public sector, this project plans to enhance safety of L3 AV operations on signalized roads by integrating CV and platooning technologies. Based on the receipt of Signal Phase and Timing (SPaT) messages, AVs can detect a more complex driving environment, optimize trajectories, and enable proactive controls. With platooning, the AV fleet can virtually form one longer vehicle, which has increased safety and mobility benefits and decreased control complexity. In addition, despite the numerous published studies reports on optimizing traffic signal plans under a CV environment and the few demonstrations on closed courses, no field demonstration of cooperative AV on public roads has been accomplished yet. This project will focus on a first-ever effort to combine CV-based real-time signal control and assessment of AV safety performance in live traffic on a long corridor.

Vehicle automation challenge

This project aims to address the challenges of lane changing and turning by enhancing AV with CV. UDOT began deploying connected vehicle technology in 2014, and in November 2017 began full operation of a vehicle-to-infrastructure (V2I) system along Redwood Road, in Salt Lake City. The CV corridor is a state-owned arterial that is 11 miles long and Dedicated-Short-Range-Communications (DSRC) radios were installed at intersections to broadcast both the SPaT and the intersection geometry (MAP) messages. Leveraging this operational corridor, we propose to deploy three L3 AVs in a succession of pilot tests and a final demonstration. This project will use three L3 AVs integrating the state-of-art made-in-USA AV platform (provided by AutonomouStuff) and nationally leading AV control algorithms (provided by USF on high-level control, AutonomouStuff on low level control and Leidos on Carma for CV integration) that have been validated with field experiments. These AVS are capable of making complex maneuvers (e.g. longitudinal car-following, lane-changing, turning, parking, and responding to signals, signs and unexpected objects) needed for operating in the fully automated mode on public roads with mixed traffic.

Data Openness Challenge

AVs produce tremendous amounts of data during operation, which raises a significant challenge in how to effectively collect, process, and share this data in near real time. In addition, there is no standard or mature metric to measure the safety performance of AVs. Existing metrics used in industry like “miles-driven” and “frequency of human intervention” only capture coarse aggregated information while missing much of the detailed microscopic dynamics that are critical to safety for not only AV but also surrounding vehicles. To enable the real-time data sharing, this project has created a *“3+3” data structure*. The first “3” represents objective measures that include three layers (raw data, object-oriented data, and safety metric data) and the second “3” indicates subjective survey data. More detailed illustration of this 3+3 data structure will be given in Section 2.b. As public agencies using open source software and hardware platforms, we will be able to fully share the data from the pilots and demonstration, allowing others to make full use of the data sets.

Anticipated Performance

It is anticipated that demonstration results will validate the safety performance of L3 AVs on signalized corridors. One unique feature of this project is to study how HVs would behave in response to AVs in mixed traffic and quantify the safety improvement of AVs with enriched real-time information from environmental CVs. With our preliminary simulation studies (Giasi et al., 2019, Ma et al., 2017, Yao et al.,2018), the safety benefit of AV alone is around 10% at a low AV penetration rate (based on the inverse time-to-collision surrogate measure), while the safety benefit may increase up to 50% when the penetration rates of CVs and AVs are increased. Further, the associated mobility and fuel consumption benefits can reach up to 10% and 25%, respectively. We will design the field demonstrations based on these preliminary simulation settings to test how much of the estimated safety and other associate benefits of ADS can be realized in real world.

The benefits of automation, including safer performance, will only be realized if public users become comfortable with these systems. The L4 demonstration will produce significant data and insight about public trust and how attitudes can be impacted. Our demonstration will build upon research currently underway, including public focus groups, ridership surveys, and cognitive psychology trust evaluations, to understand public attitudes. This research on public attitudes will continue into the L3 pilot tests.

d. Geographic Area or Jurisdiction of Demonstration

The proposed ADS pilots and demonstration will be conducted in Salt Lake City, UT with the L3 component operating on the Redwood Road connected vehicle corridor in Salt Lake City, a UDOT-owned arterial. The L4 component will be conducted on the University of Utah campus on a route connecting a well-used transit site to several key campus buildings. This route has already been used for an earlier demonstration project, so operational and rider opinion data already have been established as a baseline.

e. Proposed Period of Performance

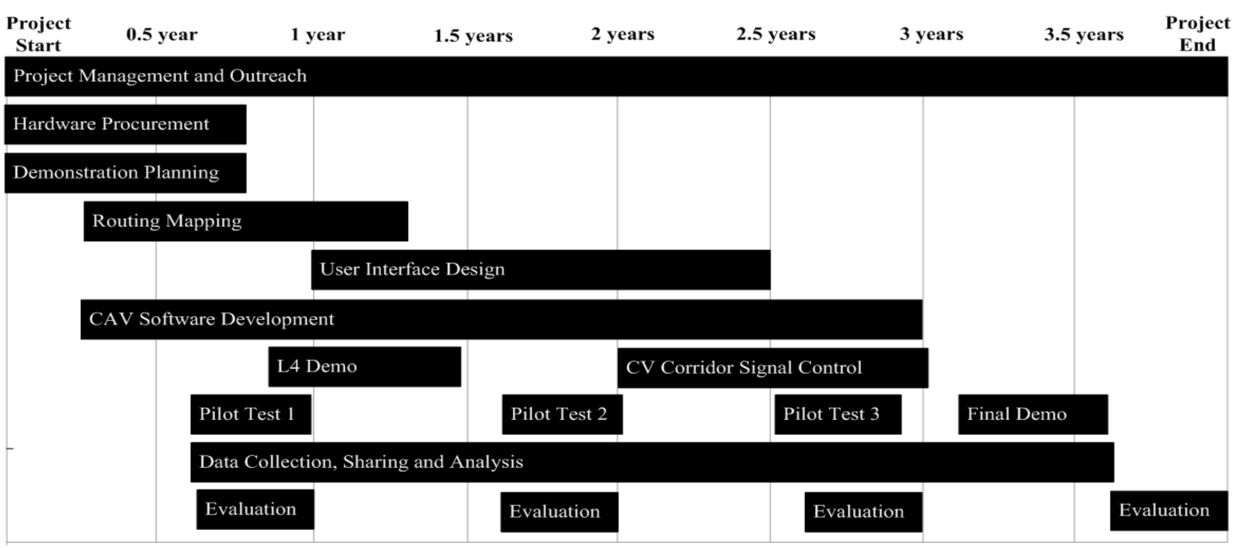


Fig. 2: Proposed period of performance

2. GOALS.

a. Safety

This project aims to evaluate the safety impact of L3 AVs in a mixed traffic environment with options for CV communications and on-demand shared mobility services. We will propose a set of safety measures on detailed multi-source sensor data from AVs for the AV fleet and surrounding HVs, bicyclists, pedestrians and other physical barriers. Particularly, by demonstrating AVs on the public road, this project will investigate how driving styles of AVs impact decision-making, trust, and acceptance of AVs both for the human operator and for drivers in other HVs.

Experiments will be conducted on both AVs and benchmark HVs on the CV corridor. The measurements from the AV and corresponding HV experiments will be compared to identify safety benefits and challenges in various traffic scenarios (e.g., light and heavy traffic), road geometries (e.g., segments, intersections) and vehicle connections. The extra benefits from communication-based AV control (e.g., joint signal timing and trajectory control, integrating CVs and AVs, and AV platooning) will be investigated in the corresponding testing scenarios.

b. Data for Safety Analysis and Rulemaking

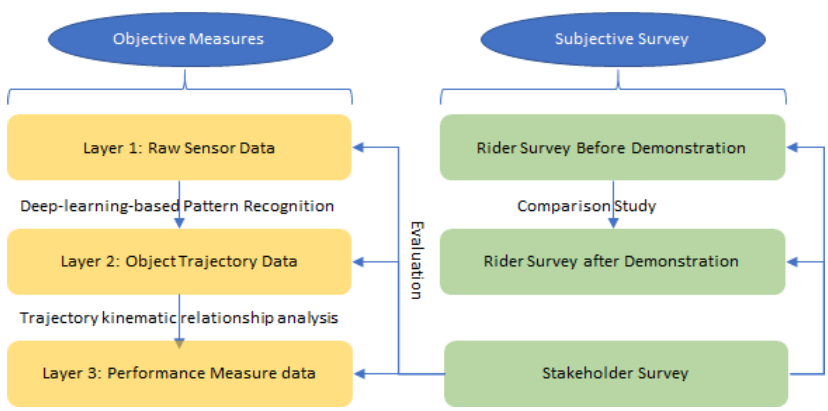


Fig. 3: Illustration of 3+3 data structure.

This project holds the spirit of full and comprehensive data sharing for an unprecedented amount of multi-layer AV safety data on a public corridor with signalized intersections. Since the majority of the AV fleet use the open-source-code-based ADS platforms integrating the USDOT CARMACARMA, the AutonomouStuff platform and the USF high-level software, this project does not have any technology or proprietary issues preventing sharing of any data collected in the entire course of the project. The comprehensive datasets will be shared in a "3+3" structure described in Fig. 3. It contains three layers of objective measures derived from AV sensors and three layers of subjective survey data on feedback from AV riders before and after demonstrations and the stakeholders.

For the objective measurement data, the first layer contains raw streaming sensor data from Lidars, Radars, Global Navigation Satellite Systems (GNSS) and cameras equipped on AVs. The raw Lidar data, raw video data, and raw data will be generated at a rate of 100GB/hr, 10GB/hr, and 5GB/hr, respectively. The GPS and IMU data is relatively small.

The second layer contains the object-oriented trajectory data extracted from the first layer raw sensor data with the deep learning based pattern recognition module in the USF AV software. This module will fuse the raw trajectory data to identify and object (including CAV themselves) trajectory data in real time to assist AV driving control. The identified object will be classified into different types (e.g., different types of vehicles, bicyclists and pedestrians). Their geometries, locations and kinematic states will be recorded. Further, the CV data (SPaT, BSM, and MAP data) and the traffic signal data (Automated Traffic Signal Performance Metrics, indicating vehicle arrival time, etc.) will be stored in this layer. This data layer will be much smaller compared with the raw data set (e.g., <100 MB/hr).

The third layer contains performance measure data on safety and other aspects via processing the second layer data. A safety data processing module will extract safety performance measures in real time by analyzing kinematic properties from comparing the AV trajectory with environmental object trajectories and other barriers' geometries. The FHWA surrogate measures may be used to construct the safety performance measures including Gap Time (GT), Encroachment Time (ET), Deceleration Rate (DR), Proportion of Stopping Distance (PSD), Post-Encroachment Time (PET), Initially Attempted Post-Encroachment Time (IAPT) and Time to Collision (TTC) (see https://www.fhwa.dot.gov/publications/research/safety/03050/09.cfm). In events of risky conditions of AV disengagements, near collisions, the corresponding data (including incident type and causal factors) will be flagged for further safety analysis. In addition to safety measures, mobility and fuel efficiency measures can be collected. This data layer will be the smallest objective dataset (e.g., <10 MB/hr).

For the subjective survey data, our research team will conduct surveys of both riders and stakeholders. The before-and-after comparison of survey data from both the L3 and L4 operations can help us understand the public perception of AVs and evaluate whether the demonstrations can increase their confidence and trust in using the technology. Evaluations of human response and trust, performed by cognitive psychologists, will provide some rigorous insights. In addition, survey of L3 riders will provide us valuable guidance on how to improve the user interface designs.

All data will be fully made accessible to USDOT via the UDOT Traffic Operation Center web portal. The anonymized data will also be made available to the public. The project outcomes will assist rulemaking and policy development by answering the following critical questions: 1) how can AVs' safety performance be more effectively measured; 2) what are the current technology bottlenecks in operating AVs safely on public roads with L3 or greater level of automation; 3) what kind of infrastructure is required to support the operation of AVs; 4) what is the current public perception of AV technology and how can we increase users' confidence and trust in using it; and 5) what kind of public benefits will AV technology bring? More specifically, data produced by this project will inform standards development, vehicle functionality, and comprehensive safety metrics.

c. Collaboration

The ADS demonstration efforts will be achieved by a collaborative environment among state and local governments, universities, and private partners. Blaine Leonard from

UDOT will serve as the Project Lead, assisted by the Co-PIs including Xianfeng Terry Yang (UU), Joel Cooper (UU), Xiaopeng Shaw Li (USF), and Chris Stanley (Leidos). Other key project members include Cathy Liu (UU) and Robert Bettini (USF). Peter Jager (UDOT) and Chris Siavrakas (UDOT) will perform project management responsibilities, with support from other UDOT personnel. The team will conduct early coordination with law enforcement, local public agencies, industry, transportation-challenged populations, and stakeholders to conduct the proposed demonstrations. AV vendors including AutonomouStuff (L3) and EasyMile (L4) will work closely with the team to set-up ADS platform at the early stage of the project. Leidos will support the implementation and expansion of CARMA platform. Narwhal will lend expertise in the V2I elements of the project. The team members will meet regularly with the stakeholders for project evaluations. Table 1 summarizes the partners of this project and explains their roles. The team members and stakeholders come from different regions in the US, well representing the national-level interests and impacts about this project.

Table 1: List of stakeholders and partners

Category	Entity	Role	State
Government & MPO	Utah Department of Transportation	Project Lead	Utah
	Utah Transit Authority	Stakeholder	Utah
	Salt Lake City Government	Stakeholder	Utah
	SunTrax- Florida DOT	Stakeholder	Florida
	Wasatch Front Regional Council	Stakeholder	Utah
Industry	Leidos, Inc.	Subcontractor	Virginia
	AutonomouStuff, LLC.	L3 AV vendor	Illinois
	EasyMile, Inc.	L4 shuttle vendor	Colorado
	Narwhal, Inc.	V2I support	Utah
	Toyota	Stakeholder	California
	AAA Foundations on Traffic Safety	Stakeholder	D.C.
	Traffic Technology Service, Inc.	Stakeholder	Oregon
Research Institution	University of Utah	Subcontractor	Utah
	University of South Florida	Subcontractor	Florida
	University of Maryland	Stakeholder	Maryland
	University of Illinois Urbana-Champaign	Stakeholder	Illinois
	Center for Urban Transportation Research	Stakeholder	Florida

3. FOCUS AREAS.

a. Significant Public Benefits

Improve traffic safety

The proposed ADS demonstration will provide comprehensive metrics to quantify the improvement of traffic safety by AVs. As stated in Section 2.b, one primary goal of this project is to collect 3+3 data for supporting safety assessment. This project will help the public better understand AV's safety benefits when they run in a CV environment. More details about the demonstration design is described in Sections 4 and 5.

Increase the public's confidence and trust of L3 and L4 AVs

A myriad of studies have used online surveys to assess public opinion and perception towards AVs. In many cases, these survey participants have not been a passenger in an automated vehicle. Building on research already in progress in Salt Lake City, our team will evaluate opinions, attitudes and actions by public riders in our L3 and L4 AVs. We will assess how the experience of riding may impact their attitudes. Our studies will shed light on what kinds of actions we can take to increase public confidence in AVs and their willingness to make AVs part of their daily travel. Co-PI Joel Cooper will perform evaluations of rider behavior and conduct before-and-after surveys of the participants. Survey data will also help the team better design the user interface and control functions of AVs, in response to the riders' needs.

Reduce congestion and increase traffic speed

Using microscopic simulations, many existing studies have reported the increased road capacity by AVs. This is mainly due to the shorter vehicle gap in the AV platoons when AVs communicate with each other. Notably, the portion of increased capacity is more significant on freeways than local streets, and it is affected by penetration rates and platooning of AVs in the traffic stream (see our study Ghiasi et al., 2017). For example, 50-70 percent of AVs on roads could contribute to about 50 percent capacity increase in the optimistic scenario. However, capacity increase would be marginal when the AV market penetration is below 15 percent, e.g., in the near future.

One unique feature of this project is to conduct ADS demonstration on an 11-mile long CV corridor. With efforts in a prior project, UDOT has developed a software package that can adjust intersection signal timings according to the arrival time of CVs. Hence, the CV corridor would have the capability of conducting real-time traffic signal optimization using CV data. In addition to the AV fleet, this project will involve another twenty CVs equipped with DSRC onboard units (OBUs) to provide auxiliary data to AVs. Then the proposed control algorithm will function to change phase green durations, adjust signal coordination plan, and send advisory speed to AVs. The demonstration will enable the possibility of reducing urban congestion when L3 or greater level AVs are operated with small penetration rates.

b. Addressing Market Failure and Other Compelling Public Needs

Gaps in integrating AV and CV technologies

In recent years, AV has captured substantial interest from the industry. Tech companies have expended great efforts and funds to develop vehicle automation functions. Those automated vehicles utilize a certain number of safety-critical control functions to assist the operation of vehicles, without direct driver input. On the other hand, CV systems, with V2V and V2I communications, is capable of providing real-time information, such as traffic signal status, traffic congestion warning, alerts about vehicle movements, etc., to enhance safety, mobility and environmental efficiency. The integration of AV and CV technology, to achieve cooperative automation, is particularly important when operating AVs on the local roadways. However, these vehicle types will require some dedicated infrastructure development (e.g., roadside units and data backhaul) on the roadways, which is beyond the capability of private companies.

An AV often relies on an internal mapping function to determine location and uses its onboard sensors to capture changes of traffic signal states and movements of other vehicles. This limits operations of AVs to “reactive” control conditions and makes “proactive” control impossible, limiting AVs’ safety performance. Despite the fact that integration of AV and CV technologies would yield significant safety improvements, industry still lacks adequate incentives to develop CV capabilities, and lacks confidence that public agencies will deploy necessary infrastructure. This project brings a great opportunity to facilitate the collaboration between governments (e.g., UDOT) and AV vendors (AutonomousStuff, and EasyMile), with collaboration from academic institutions and multiple stakeholders to demonstrate the benefits of cooperative automation. The outcome of this project directly addresses the current market failure in integrating AV and CV technologies. It will also offer a better understanding about what level of government investment and rulemaking could help advance safer operations of AVs.

Insufficient investment to support particular groups

One main benefit of AV is to increase transportation accessibility for individuals with disabilities. In the U.S., there are more than 57 million people who have a disability. The most recent nationwide transport survey indicates that six million individuals with disabilities have difficulty in getting transportation. AVs are designed to reduce those transportation obstacles. However, private sector investment has not proven sufficient to develop relevant functions or systems to support the AV usage by individuals with disabilities. This project will address such compelling need with a focus on developing more accessible control systems that allow multiple communication formats (e.g., visual, audible, haptic), and on demonstrating features such as automatic ramps and wheel chair securements.

c. Economic Vitality

Our project team will comply with federal buy-America requirements and apply resources toward US-based companies. For example, all three L3 ADS platform are built on American brand vehicles including Chrysler Pacifica and Lincoln MKZ hybrid. Project team members are US companies, including AutonomouStuff, Leidos, and Narwhal. During pilot tests and demonstrations, the team will hire professional drivers, who are U.S. citizens, to help operate the AVs. Data generated from this project will be shared with the public and project outcomes will directly support the U.S. industrial and research communities.

Although the vendor of the L4 shuttle, EasyMile, is not a US company. However, its staff is based in Denver and UDOT will use state funds to lease the shuttle for demonstration. EasyMile was selected after soliciting proposals from six companies and determining that EasyMile’s system best fit the current needs of UDOT.

d. Complexity of Technology

<u>Demonstration of L3 technology</u>

The demonstration will use three Level-3 (L3) AVS, as shown in Fig.4, with DSRC OBUs for communications with RSUs at the signalized intersections. USF will provide one existing L3 AV based on a Lincoln MKZ hybrid. It s furnished with a set of hardware platform, including two Velodyne Lidars, one Delphi Scanning Radar kit (including 2 SSR2 short range Lidars and one ESR 2.5 long range Lidar), one Mobileye 630 development kit, one Novatel navigation unit, one FLIR 3.2 MP camera, one Spectra industrial computer with three monitors, one Savari DSRC on board unit, and customized by-wire control system. Two additional AVs will be provided by AutonomouStuff, built on made-in-the-USA Chrysler Pacifica vehicles, with by-wire control boards, sensor platforms (e.g. Lidar, Radar, Cameras, GPS and a high resolution navigation unit), a computational unit, data storage device, and the basic Autoware control.

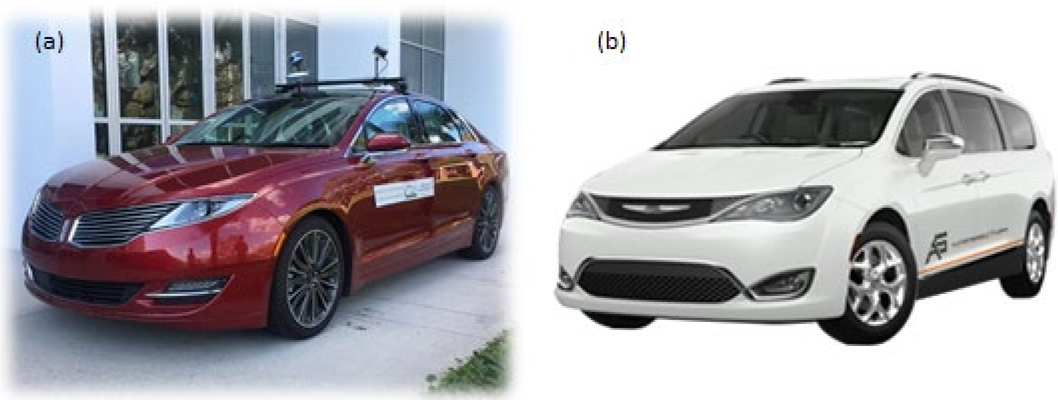


Fig 4: The types of AV platforms used in demonstrations: (a) USF Lincoln MKZ hybrid, and (b) AutonomousStuff Chrysler Pacifica (right).

Fig. 5: Screenshots of L3 AV experiments in mixed traffic with HDVs: (a) lane changing, and (b) trajectory smooth at a traffic signal.

In addition to the basic AV platform, USF has developed prototype L3 AV high-level control software in previous studies, enabling necessary longitudinal and longitudinal controls, including longitudinal cruising, car-following, lane keeping, lane changing, protected turns and communications with CV infrastructure. This software is built on ROS and Autoware and can be integrated with CARMA. While a driver is required to sit in the vehicle to respond when needed, this software is able to support pure automated driving on designated routes with mixed traffic. This software has been tested with multiple field experiments with different settings. For example, the aerial photographs in Fig. 5 show field experiments with relatively complex longitudinal and latitudinal controls interacting with mixed traffic and communicating with RSUs on arterials.

Table 2. Advantages of the USF AV platform

Features	Existing public platforms	USF AV platform
Longitudinal control	Linear control models with more frequent AV disengagements (transferring from the AV to the human driver)	Nonlinear control models to minimize disengagement while improving the control smoothness
Latitudinal control	Only on fixed planned lane changing course without dynamic interactions to HDVs	Dynamic lane changing course for reliable lane changes in mixed traffic with HDVs; fail-safe mechanism to abort lane changing in response to aggressive human drivers
Arterial applications	None	Real-time signal control using CV data; data driven based trajectory smoothing coordinating with signal timing in mixed traffic

The USF developed platform has several features more advanced than existing AV control platforms from public agencies, as summarized in Table 2. Further, Leidos, a developer of CARMA, has rich experience in conducting public road tests of AVs. For example, the Speed Harmonization project led by Leidos (also involving the USF team for the core algorithm development; see Part 2) contains a series of public road AV tests. These unique features enable conducting the first AV demonstration on public arterial roads.

Demonstration of L4 technology

The testing and deployment of low speed, L4 automated shuttle has become more commonplace over the past two years. UDOT is currently demonstrating an L4 shuttle in nine locations in northern Utah and researching 1) the utility of these vehicles as part of a transit system, 2) the operational constraints and characteristics of these vehicles, and 3) the public attitudes about autonomous vehicles and how integrating with a shuttle may impact those attitudes. As part of this project, we propose to extend the lease of this AV shuttle and perform additional research on public trust. Previous work focuses on trust in a vehicle which still has a human "operator" available on board. The proposed extension of this work will evaluate the level of trust when a human is not noticeably on board (disguised to be a regular passenger), or not present at all. This is a key, and unique, aspect of public trust of automated vehicles. Another aspect of the research will focus on accessibility issues - the functionality of an automated wheelchair ramp, the use of chair restraints, and ride comfort. Raw sensor data will also be collected for assessing safety performance.

e. Diversity of Projects

This project will leverage an existing CV corridor in Salt Lake City for ADS demonstrations. In 2017, UDOT operationalized a connected vehicle corridor with a conditional transit signal priority system using DSRC V2I communication. The corridor, shown in Fig. 6, is Redwood Road, a UDOT-owned arterial corridor that stretches 11-miles and includes 30 signalized intersections. For this demonstration, UDOT will install ten additional RSUs on arterials crossing the CV corridor to create a CV network. Operating L3 AVs on this live corridor represents a unique approach, and will be different from other demonstrations that have been done and will be proposed. Having data from these demonstrations will provide opportunities for analysis and learning that are unprecedented.

The L4 shuttle will be operated in a non-street, pedestrian environment at a low speed (e.g., 15 mph). Although other demonstrations have been done with L4 shuttles, the unique and diverse approach of this project will be the rigorous assessment of public trust and the focus on accessible functionality.

Fig. 6: The CV corridor

f. Transportation-challenged Populations

Many seniors, people with disabilities or medical conditions and children often encounter challenges traveling independently. AVs present a unique opportunity for these transportation-challenged populations to travel freely and independently. A portion of our project will focus on accessibility of L4 shuttles (ramps and securement) and the usability of passenger interfaces on the L3 demonstration.

g. Prototypes

The L3 AVs used in the proposed demonstration builds upon hardware provided by AutonomouStuff (regarded as the leading company worldwide in providing CAV hardware platforms) and customized software including ROS, Autoware and CARMA (which has been well tested in field experiments). The software takes advantage of the USF platform that has several advantages over the existing public platform on longitudinal and latitudinal control and communications (see Table 2), which have been validated with field experiments (see Fig. 5). A driver will be seated in each AV and ready to takeover when needed during experiments and demonstrations to ensure the safety of operations. The platform has an audio warning system to inform the driver to takeover as soon as an emergency is detected. All the vehicles will be operated in a familiar environment (e.g., a test track, a sub-section of the CV corridor and several neighboring road segments) with a high-resolution map before the tests and demonstrations. These protocols will ensure the operations of the prototype L3 AVs safely and reliably, and set the stage for expansion beyond a prototype environment.

4. REQUIREMENTS.

a. Research and Development of L3 and Greater Technologies

The passenger car AVs used in the demonstration are L3 vehicles, with software developed by the USDOT, USF, and AutonomouStuff (CARMS, ROS, and Autoware). We will also develop customized software on the Autoware and CARMA platforms to enhance the data collection methods for this project, including object classification (e.g., differentiate different types of objects including heavy-duty and light-duty vehicles), prediction of moving object trajectories, and model-predictive control based smart path planning. The developed AVs shall have automated car-following, lane changing, turning and parking functions and are able to complete designated routes in the automated mode in normal conditions. An in-vehicle driver will monitor oeprations and prepare to respond. The low-speed shuttle used in the proposed demonstration is an L4 vehicle capable of full autonomy within the designated operational design domain.

b. Physical Demonstration

This project is committed to conduct a physical ADS demonstration in Salt Lake County with three L3 AVs and one L4 autonomous shuttle. The L3 demonstration will leverage the existing CV corridor operated by UDOT and evaluate the safety performance of L3 ADS on a public signalized arterial. The L4 demonstration will occur in a public space, likely at the University of Utah, with volunteer riders. Details of each phase of the demonstration is described below.

L4 autonomous shuttle demo

UDOT is currently demonstrating an L4 autonomous shuttle, leased from EasyMile, in nine locations in northern Utah and researching 1) the utility of these vehicles as part of a transit system, 2) the operational constraints and characteristics of these vehicles, and 3) the public attitudes about autonomous vehicles and how integrating with a shuttle may impact those attitudes. As part of this ADS demonstration project, the team will extend the lease of this L4 shuttle and perform additional research on public trust and safety performance. Previous work focuses on trust in a vehicle which still has a human "operator" available on board. The proposed extension of this work will evaluate the level of trust when a human is not noticeably on board (disguised to be a regular passenger), or not present at all. This is a key, and unique, aspect of public trust of automated vehicles. Further comparison of survey of L3 and L4 demo participants will enable the study of users' attitudes about AVs. Another aspect of the L4 research will focus on accessibility issues - the functionality of an automated wheelchair ramp, the use of chair restraints, and ride comfort. The developed safety metric will also be placed to assess its safety performance.

L3 Pilot Test 1: on a testbed

Before bringing the L3 AVs to a public signalized road for demonstration, it is essential to pre-evaluate the effectiveness, stability, and safety of the vehicle automation system on a testbed and examine the vehicle performance after integrating with CV technology. In response to such a need, UDOT will establish the testbed on a Utah Division of Motor Vehicles (DMV) driving test site. The site has one intersection with traffic signal control devices and UDOT staff will install a DSRC RSU at the intersection to support V2I communications. In addition, L3 AVs will be installed with DSRC OBUs and a customized software will be added into their on-board ADS platform for receiving SPaT information from the RSU. For system performance evaluation, the project team will particularly examine the AVs' capability of automated car-following, platooning lane changing, left/right turning, parking, and stopping when encountering red lights. The testbed will offer a closed environment for driving test and allow the team to identify, analyze, and fix the potential technical issues in the ADS. The proposed period of testing is 2 months and corresponding safety data will be stored on the data-sharing platform.

L3 Pilot Test 2: on a public road with shared-mobility service

With the first pilot tests, the project team will be ready to bring the L3 AVs to the UDOT owned CV corridor for testing. As this 11-mile long corridor crosses both urban and suburban areas in Salt Lake County, the AVs will be operated in a variety of communities having different driving environments. In this test, the project team will be able to evaluate those AVs' safety and operational performance on car-following, lane changing, left/right turning, and stopping with red signal. Notably, since 100% CV environment cannot be achieved at this stage, the automated maneuver of permitted left-turning would yield high crash risk when AVs rely on on-board sensors (e.g., Lidar) to detect opposing through traffic. Hence, the developed vehicle automation algorithm would focus on addressing the case of protected left-turning and right-turning. Conflicts with pedestrians might be encountered when AVs are making right-turns. The proposed testing period is two months (4 hours per day and 5 days per week) and resulting data will be collected for sharing. Control algorithms in the automated driving platform may be updated if data analysis reveals the necessarily.

Pilot Test 3: L3 AV platooning and CV-based signal optimization

When integrating AVs with CV technology, one of the main benefits is the capability of enabling AV platooning and speed harmonization along signalized arterial roads. As revealed in the literature, operating speed harmonization for AV platoons can potentially improve intersection capacity and reduce AV travel time along consecutive intersections. However, two main research tasks have to be completed to support this pilot test. The first task is developing a platoon operation algorithm that integrates AV trajectory control with the V2V communication platform. The algorithm will be built upon the customized ADS platform and more details will be illustrated in Section 5.a. To facilitate the progression of AV platoons in a designated green band, AV speed harmonization would require an optimization of vehicle speed profile and traffic signal plan. Recognizing the data from three L3 AVs shall not be enough to support real-time traffic signal optimization, this project will adopt 20 additional CVs to create a more "connected" environment. Through prior project efforts, UDOT has developed a type of carry-on suitcases that contains all required devices (e.g., OBU, Linux unit, etc.) for V2I communications. Any regular vehicles with such carry-on suitcases will become CVs and will be able to send CV safety message to the RSUs at intersections. Hence, this project would create a unique field testing scenario that allows the team to perform real-time signal optimization using CV/AV data as input. Such a test will also address the critical question "would AVs will be operated more safely in a CV environment?"

Final L3 demonstration

After the completion of the pilot tests, the project team will obtain reliable ADS systems for the final demonstration. In addition, to support the AV routing design based on input destinations, UDOT will install ten additional RSUs on arterials crossing CV corridor to create a small CV network. The demonstration is proposed to last 4 months and the L3 AVs will be operated under four different scenarios: 1) AVs are operated independently on the CV network and have different destinations on the network; 2) AVs are operated as a platoon along the main CV corridor, while the platoon may disperse later if AVs have different destinations; 3) AVs are operated with additional CVs on the network and the real-time signal optimization function is activated; and 4) AVs are operated as shared vehicles and would serve the requested demands on the CV network. Notably, demonstration under the fourth scenario will be supported with a set of key functions, including an onboard user interface that shows the information of SPaT, vehicle speed, routing plan, destination, etc., a mobile app that allows passengers to send service request, and a cloud-based control platform that determine the dispatch plan of the AVs. The research team will compare the vehicles' safety performance under different operation scenarios.

c. Data Sharing and Accessibility

Data collection

The data collected in the demonstration are in the 3+3 structure described in Section 2.b, including three layers of objective measures and three layers of subjective survey data. Notably, the first layer of the objective measures, raw streaming data, can amount up to 200GB per hour (based on our previous field experiments). While it is infeasible to transmit the data in real-time, we will store and share the data in near real-time. We will adopt high-speed hard drives to store the obtained raw data temporarily, and our staff will upload the data to the server manually after each day of pilot test and demonstration. In the second and third layers, the data size is likely less than 200 MB per hour, which enable real-time uploading and sharing with 4G wireless communications. On the CV corridor, UDOT has already installed a fiber optic network to connect intersection signal cabinets to the server in the Traffic Operation Center (TOC). Information such as SPaT, CV trajectories, and roadside detector data can be transmitted in real-time. To take advantage of such data collection facility, this project will further install a wireless trans-modem on the AVs for sending the object-oriented data to the signal cabinets. Then the server in the TOC will be able to collect the data in real-time.

Subjective data will consist of survey data from demonstration participants and other research regarding their perception, level of confidence, and trust of both L3 and L4 AV technology. Feedback and evaluation reports from stakeholders will also be recorded.

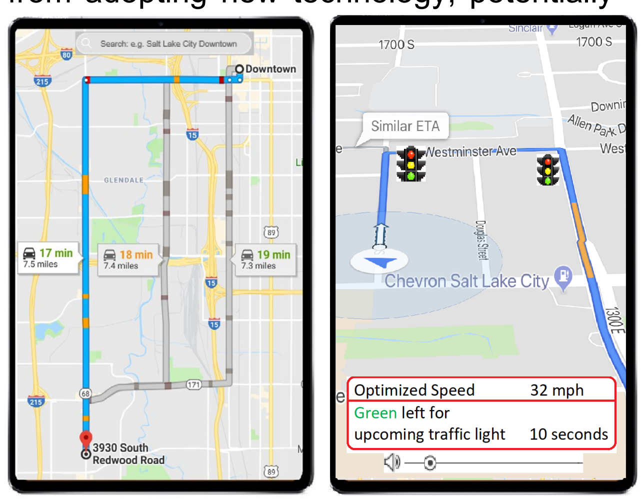
Data storage and sharing

The team will leverage UDOT TOC's server for both data storage and sharing. Based on the above collection plan, to minimize the potential operational cost and maximize access convenience, this project proposes to store all obtained data in the TOC of UDOT. To ensure the data accessibility, UDOT will ensure all data on the TOC's server will be kept for a minimum of five years after the award period of performance expires. All data produced by our pilot tests and demonstration (after anonymization) will be open for sharing to both USDOT staffs and the public. Users can choose to request the CV related data and second and third layers of AV data from UDOT TOC's web portal. It shall be noted that the first layer of data may contain some private information such as vehicle plate number and pedestrian faces. Before sharing the data to the public, all information related to private identity will be removed. As the TOC platform already contains a mature data sharing module, this project will devote more efforts on expanding the existing web portals. More detailed information regarding the data sharing approach will be described in Section 5.c.

It is worth noting that this team has an established record in sharing cutting-edge AV experiment data. For example, the data generated from the preliminary field experiments (see Section 3.d) for the complex AV lane changing operations in mixed traffic have been shared at the open access Github platform (https://github.com/sgzzgit/Autonomous-Vehicle-Lane-Change-Experiment-Data). UDOT openly shares signal metric data at https://udottraffic.utah.gov/atspm.

d. User Interface Development

The pilot test will further enhance AV capability to effectively interact with human reasonably seeking for the AV service. Recent research aimed at redefining the driving experience largely focused on healthy, able-bodied individuals. This bias can lead to designs that exclude a broader population from adopting new technology, potentially exposing certain drivers to undue risks. We will design a user interface inside the AVs for vehicle control inputs/outputs to enable functional independence and mobility by the elderly and people with disability. Acknowledging the fact that these individuals may experience intellectual, developmental, cognitive, or sensorimotor limitations when interacting with the AVs, our user interface will be carefully designed on the basis of perception-cognition-action, in support of this sector of our population. The input/output user interface on the ADS will be created with physical and cognitive assistance to ensure safe driving environments for individuals suffering from physical disabilities and cognitive impairment. At the minimum, the in-vehicle display (e.g. iPad) will allow users to input a destination, and will visualize



(a) (b)

Fig. 7: The user interface design

the routing, SPaT info, current speed, suggestive/optimized speed, mapping information, etc. The user interface will adapt to user specific requirements in terms of size, color and number of items on the screen, and support a wide range of output modes, including graphics, sound and speech.

Three main application interfaces are essential to the facilitation of AV operation. These three interfaces include a situational awareness interface, a travel planning or forecasting interface, and a real-time detailed view of a specific trip. These interfaces have been sketched, displayed and described below.

Situational Awareness - Map View

The view allows users to locate various elements involved in their AV travel from his or her surroundings. The map will represent: i) traffic conditions on the major roads; ii) Incidents or events in the vicinity; and iii) other riders who have requested the shared AV service. The user could tap on the icons (e.g. events, riders) on the map to see the details such as other riders' profile and communicate with them, if needed. These are just some examples of the information pertaining to the AV trips that could be added to a map display to allow users to make informed decisions about their trip.

Trip Prediction - Forecast View

Fig. 7(a) shows a mock-up of the forecast view. The forecast view is intended to show the user the current and future status of the route of their chosen. Once the user input their destination, the forecast view will display the suggested route, and estimated time of arrival.

Real Time - Travel View

Fig. 7(b) includes a mock-up of the travel view. This view is intended to be used by the user once he/she has decided on a specific route to choose and ready to embark on the trip. When the AV is en-route, this view shows the current speed, suggested speed and the SPaT information of the upcoming signalized intersection. When designing the user interface, the research team will ensure the physical and cognitive assistance, augmentation and control needed for the mobility challenged population. We will learn from our potential user base to determine inclusive design features that will ensure safe, independent, and comfortable mobility. To this end, we will involve a customer research effort including conducting surveys and focus groups to understand how the application platform can best meet their functional and aesthetic needs for various groups of population.

e. Applicability across the Nation and Outreach Activities

While the proposed demonstrations are focused on finite corridors, all the work proposed in this project can be scaled up for deployment in other locations. Further, all of the data can be used to evaluate other corridors and applications. The safe operation of L3 AVs on the signalized arterial, four hardware components, L3 vehicle automation system, user interface, CV communication devices (RSUs and OBUs), and traffic signal controllers, are fully coordinated in the demonstration. On the AVs' operation platform, the customized software package can support various operational tasks such as vehicle sensor data processing, object recognition, vehicle trajectory and maneuver control, routing design, etc. On the TOC side, a real-time signal optimization algorithm can function to adjust intersection signal timing and coordination plans based on the CV/AV data. Hence, with the support of local government agencies such as state or local DOTs, the developed technology can be easily transferred for implementation on other similar types of roadways. With the demonstration efforts led by UDOT, this project can be viewed as a role model in establishing collaborations among government agencies, research institutions, and the industry, which is essential to fill the current gap of deploying CAV technology.

To share demonstration status, results, and lessons learned with other jurisdictions and the public, this project will include a set of outreach tasks. First, the relevant control algorithms will be presented at international conferences (e.g., TRB annual meeting and Automated Vehicle Symposiums) and be published in journals (e.g., Transportation Research series and IEEE Transactions on ITS). Second, UDOT and UU will organize workshops in Salt Lake City starting from the second year of this project. The practice-oriented sessions will attract practitioners and engineers in both government agencies and companies. Project outcomes such as the developed system framework, procedures of field deployment, and corresponding benefits and costs will be shared with the attendees. A research-oriented session will be hosted by UU and USF for facilitating technical exchange and knowledge transfer. Scientists from universities, national/regional research centers, and company owned research labs will be invited to attend. Third, more detailed information related to the proposed demonstration will be shared with the project stakeholders. Last, the project team will outreach to both local and national media to report the ongoing pilot tests and demonstration during the project period. Such efforts will bring more useful information to the public and help future AV users better understand the technology.

5. APPROACH.

a. Technical Approach to Implement and Evaluate the Demonstration

The project objectives can be achieved by conducting the following ten tasks.

Task 1. Project Management and Outreach. Blaine Leonard from UDOT will serve as the Project Lead, assisted by the Co-PIs including Xianfeng Terry Yang (UU), Joel Cooper (UU), Xiaopeng Shaw Li (USF), and Chris Stanley (Leidos). Other key project members include Cathy Liu (UU) and Robert Bertini (USF). Project management responsibilities will be performed by Peter Jager (UDOT) and Chris Siavrakas (UDOT), with support from other UDOT personnel. The PI and Co-PIs of this project will jointly manage the progress of each project tasks, monitor the potential risks which are pre-identified, and conduct outreach activities.

Deliverables: Project management plan, project evaluation plan, quarterly_project progress reports, risk register and management form, annual budget reviews, summer workshops, media outreach activities, and final evaluation report.

Task 2. Hardware Procurement. We will purchase the hardware platforms for two L3 AVs from AutonomouStuff that are ready to operate on public roads in light traffic. These vehicles shall have all needed sensing, by-wire control, onboard computing and communication devices equipped. AutonomouStuff will also provide basic software support including integration with ROS, Autoware and CARMA.

Ten additional RSUs will be installed on corridors crossing the Redwood Road CV corridor and integrated into the CV system. UDOT will oversee the procurement and installation of the devices and Narwhal will install, test and integrate the system.

Deliverables: Two L3 AVs, additional RSUs on corridor.

Task 3. Demonstration Planning. This task will plan the demonstration route, stops, service frequency, mode connection, scenarios, and data to be collected and shared. We will examine the traffic sensor data and transit ridership data on the CV corridor to identify which routes have appropriate traffic and rider demand for the demonstration. The L3 demonstration plan will follow the structure of three pilot tests and one final demonstration, as described above. The L4 shuttle route will be selected, reviewed, and submitted for NHTSA approval.

Deliverables: both L3 and L4 demonstration plans.

Task 4. Route Mapping. After the routes are determined, the USF team will work with AutonomouStuff and UDOT to conduct the mapping. AutonomouStuff has enabled CARMA as a software option for its Automated Development Research Platforms. Their manufactured L3 driving platform will rely one a pre-completed routing mapping service. UDOT already maintains and regularly updates an HD 3d map system (with centimeter-level accuracy) for all Utah state roads in Salt Lake City. Leveraging this in-house map, the USF team and AutonomouStuff would collaborate on converting and expanding the existing map to support localization of AVs in operations.

Deliverables: Route mapping for supporting L3 AV operations.

Task 5. Interface App Development. The three main application interfaces (i.e., a situational awareness interface, a travel planning or forecasting interface, and a real-time detailed view of a specific trip; detailed in Section 4.d) are essential to the facilitation of AV operation. Co-PI Cathy Liu from UU will lead the efforts on developing the user interface which can offer accessibility to potential users with disabilities.

Deliverables: use interface app design and related software development.

Task 6. AV Software Enhancement. The USF team will enhance its existing L3 AV software platform. First, they will work with Leidos to integrate CARMA into the existing Autoware-based software platform to enhance its communication capabilities for signal coordination, platooning and cooperative lane-changing. USF and Leidos have already collaborated on multiple FHWA AV related projects (e.g., Speed Harmonization Fundamental Research, Connected and Automated Vehicle Analysis, Modeling and Simulation). These collaborations have yielded a set of models for AV trajectory control, platooning, merging and lane-changing that can be incorporated to the existing AV software platform via integration with CARMA. Note that most of the developed models have been validated by field experiments, either on closed testbeds or public roads.

Secondly, we will upgrade the existing feature-based object identification module to one with deep learning to reduce detection errors and increase vehicle classification capability. We have used deep-learning based software in an ongoing FHWA project for video-based vehicle identification and classification (see Part 2), which will be adapted to fuse both video and Lidar data on AV for object identification.

Thirdly, the predicted control module of the existing software can be enhanced by integrating the USF team's recent algorithm developments on AV prediction-based motion control in complex mixed traffic environment (involving non-cooperative human driven vehicles and AV coordination with traffic signals).

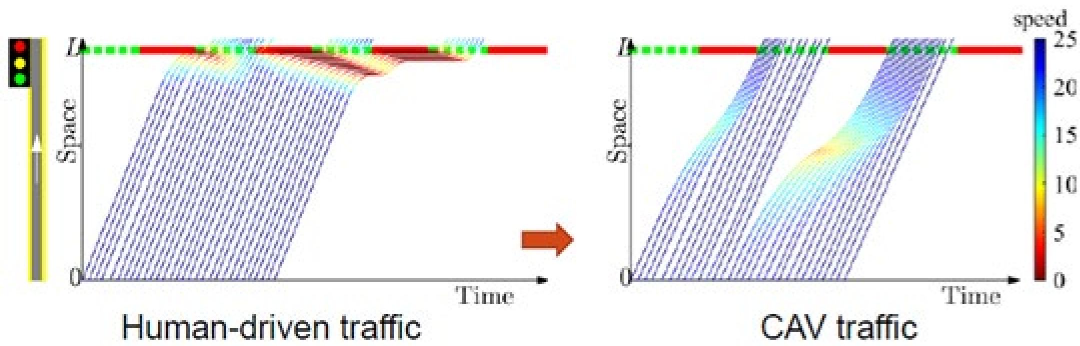


Fig. 8 comparison of human driven traffic and AV traffic

Fourthly, the USF team has analyzed AV platooning in mixed traffic (Ghiasi et al. 2017) and developed efficient models for platooning formation (Li and Li, 2019), which will be integrated to the software platform for platooning applications in the demonstration. A routing module will be developed per riders' OD demand selections at the user interface app. Algorithms will be developed to plan for the optimal AV assignment, routing and pickup/drop-off scheduling of the demand to maximize the service quality.

Overall, these enhancements will increase the performance of the software for the proposed demonstration. The figure below illustrates the smoothed (and thus safer, faster and more energy efficient) trajectories with the proposed AV control platform compared with HV traffic on one signalized road section.

Deliverables: The improved AV software platform; installation of the platform on the test AVs; configuration of the software for mapping, test routes and scenarios; integration with the user interface app.

Task 7. CV Corridor Signal Control. One key component of this demonstration is to design optimal signal timing plans for supporting the CV corridors. The primary input of the proposed control models will be trajectory data of all vehicles. Since CVs and AVs might only account for a portion of the total traffic, it is critical to estimate the trajectory of HVs at the first step. Grounded on the calibrated car-following model, we will utilize vehicle insertion procedure for such a need. Notably, the estimation accuracy is only acceptable when the CV penetration rate is above a 10% threshold, which is suited for our project.

The traffic signal control will be executed at both higher and lower levels. At the higher level, we will develop a signal coordination model, by optimizing signal phase plan and offsets of each intersection to facilitate the movement of traffic along the entire corridor. The lower level control function (Yang et al., 2019) aims to make real-time adjustment of signal timings, grounded on the software package developed by UDOT. Given the estimated HVs trajectories and collected CV trajectories, the control objective at the local level is to minimize the intersection delay based on the queue length at each time interval. To solve the problem in real-time, we will leverage quadratic programming technique. The output of these two traffic signal control models will be the optimized SPaT for the incoming signal cycle and intersection RSU would broadcast it to the approaching AVs.

Deliverables: Enhanced software for supporting real-time signal controls, tests of the resulting SPaT messages.

Task 8. Pilot Tests and Demonstration. As detailed in Section 4.b, this project will conduct demonstrations of both L3 and L4 AVs. Particularly, the demonstration of L3 AVs will be supported by three pilot tests, which aim to evaluate the functionality of sensors and control software. The relevant data will be collected in real time for sharing (see Section 4.c).

Deliverables: L3 and L4 physical demonstrations in Utah and data produced.

Task 9. Data Collection, Sharing and Management. As described in Section 4.c, the data collected in the demonstrations are in the 3+3 structure, including three layers of subjective measures and three layers of subjective survey data. The first layer of objective measures and survey data will be uploaded to UDOT TOC server on a daily basis and the second and third layers of object measure data will be collected and shared in real-time. UDOT will also expand their current web portals to support the on-line data analysis. Chuck Felice, of UDOT, will manage the data collection, storage and sharing portions of this project.

Deliverables: The data collection, sharing, and analysis platform.

Task 10. Project Evaluation. The overall progress and results of the project will be subject to periodic evaluations by the stakeholders. Our research team will set periodic meetings with the stakeholders to report our project progress every year. In addition, we will organize an onsite event for them to evaluate the on-going demonstration. A quantitative assessment instrument and associated rubrics will be developed, referencing the innovativeness (e.g., heurism, novelty, departure from prior approaches, etc.), theoretical utility (e.g., integrative capability, parsimony, explanatory coherence, predictive potential, etc.), practical utility (e.g., convenience, efficiency, applied potential, values added in problem-solving, etc.), and completion (e.g., fulfillment of project objectives) rating criteria. Any indications of flagging or inferior ratings will provide a basis for mid-project focus group inquiries to facilitate recommended methodology adjustments.

Deliverables: Evaluation report by the survey of stakeholders.

b. Approach to Address Legal, Regulatory, Environmental, and other Obstacles

Utah is an ideal location to demonstrate cooperative automation systems, with a supportive legal and regulatory environment, strong experience in vehicle connectivity, and an operational connected vehicle corridor. In early 2019, the Utah Legislature unanimously passed autonomous vehicle legislation which broadly allows the testing and operation of highly automated vehicles on public roads in the state. With this, there will be no state or local legal or regulatory barriers to testing L3 or L4 vehicles on public roads.

For the L3 demonstrations on the test site or Redwood Road, all vehicles will already meet Federal Motor Vehicle Safety Standards (FMVSS), since they will be commercially available vehicles with retrofitted autonomous systems. UDOT is currently beginning a one-year demonstration and evaluation of an L4 autonomous shuttle, with nine different deployment sites. Since the shuttle does not meet the FMVSS, the team is obtaining NHTSA approval for operation at each site. The L4 shuttle demonstration proposed in this ADS Demonstration application will be an extension of the work already underway, with expanded research goals. NHTSA approval will need to be sought and obtained for this additional deployment. Our experience in gaining these approvals for the current project will facilitate the future approval effort.

The L3 vehicles being purchased as part of this proposed ADS Demonstration project are based on commercially available vehicle platforms, assembled in the United States. As such, they will fully comply with the Buy American and domestic vehicle preferences. The L4 shuttle being used as part of this proposed demonstration is from EasyMile, a French-based company. However, it is not being purchased, it is being leased, and the funds for that lease will be state funds as a match to the federal funds provided by this grant. When UDOT sought proposals from L4 shuttle manufacturers for the current shuttle deployment project, no US-based manufacturers responded. However, no federal funds are being used, or will be used, for this shuttle lease.

c. Commitment to Provide Data and Participate in the Evaluation of the Outcomes

The collected data and the compressive sharing plan are described in Sections 2.b and 4.c. This project almost has few technology or proprietary barriers preventing sharing data collected in the entire course of the project. They will be shared in either real time (for moderate and small data sites) or near real time (for huge raw sensor data) after anonymization. In addition to safety data, the associated mobility (e.g., throughput, travel delay) and environment data (fuel consumption and emissions) can be easily extracted with object trajectory data. Dr. Li's team has conducted multiple studies using trajectories to extract safety, mobility and environmental data (e.g., Yao et al. 2018; Li et al, 2018; Zhou et al., 2017; Ma et al., 2017). Further, since one major task is to conduct real-time signal control using trajectories of AVs and CVs, this project will further evaluate the mobility performance by: 1) comparing system performance with and without signal control function; 2) analyze the AV and CV trajectories to obtain corresponding travel times; 3) using roadside sensor data to evaluate intersection performance, and 4) study the intersection videos (available from the traffic monitoring system housed in both UDOT TOC and UU's Utah Traffic Lab) to estimate intersection delays.

d. Approach to Risk Identification, Mitigation, and Management

Risk identification and assessment

At the beginning of the project, the Project Lead, Blaine Leonard, will convene the team to identify potential risks and build a Risk Register. The proposed techniques for risk identification include brainstorming with team members, discussion with stakeholders, review of best practices, and discussion with federal contracting officials. The team will use a risk identification worksheet to examine the existence of risks in ADS development, project collaboration, ADS implementation, ADS demonstration, operation of ADS vehicles in public space and roadways, and data collection, storage, and sharing. A Risk Register will be developed so that each risk can be tracked, monitored and mitigated.

Risk mitigation and management

The use of a Risk Register will facilitate the proactive monitoring of risks throughout the project. The project leadership team will meet monthly to evaluate the progress of the project and consider the various risks. An evaluation will be made about whether each risk is increasing or decreasing in likelihood, whether planned mitigation measures will be adequate, and whether new risks need to be added to the list. Each risk will be proactively managed by instigating appropriate measures or modifying deployment plans. More specifically, some potential risks and corresponding mitigation strategies are summarized as follows:

- Difficulty or delay in developing L3 ADS platform: the team has included some consulting effort from AutonomouStuff to support the platform development;
- Failure in integrating AV and CV software/hardware: the team will develop the system upon USDOT's CARMA platform and its developer, Leidos, Inc., will work closely with the team.
- Occurrence of crashes during demonstration: the team will hire professional drivers to operate the AVs and provide a safety training before letting me on-board; all AVs and CVs will be operated with insurance.
- Existence of personal identity in the collected data: the team will develop the data collection and sharing plan with an IRB approval.

e. Approach to Contribute and Manage Non-Federal Resources (Cost Share).

This project will leverage some non-federal resources to support the proposed ADS implementation, demonstration, and evaluation. The resources include equipment, cash, and staff time. Since 2014, UDOT has already spent over $1.3 million to deploy the CV corridor on Redwood Rd., Salt Lake City. This 11-mile long signalized arterial includes 30 intersections and all of them are installed with DSRC RSUs for V2I communications and a fiber network for real-time data transmission. The traffic operation center of UDOT will also devote several servers for data storage and sharing, and will provide data analysis and support. The traffic monitoring system in the Utah Traffic Lab at UU will provide real-time road videos for extracting vehicle trajectories. UDOT will contribute both staff time and cash for demonstrating the L4 autonomous shuttle in Salt Lake City.

UU will contribute hosting, meals and other potential costs in the stakeholder meetings, and students' tuitions. In addition, USF will contribute over 95k including sending a L3 AV to support the proposed demonstration tasks and covering the student tuition.

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