Sponsored Projects Office

University of California, Berkeley
1608 4th Street, Suite #220
Berkeley, CA 94710-1749

Principal Investigator: Ching-Yao Chan
Sponsor: Contra Costa Transportation Authority
Prime Sponsor: U.S. Department of Transportation Federal Highway Administration
Project Title: Contra Costa Transportation Authority's (CCTA) for the USDOT Automated Driving System Demonstration
Period of Performance: June 16, 2021 to April 30, 2026
Total Amount: $1,044,987

Please accept the enclosed proposal submitted on behalf of The Regents of the University of California Berkeley campus. Should this proposal be selected for funding, award documents should be issued using the information provided below. Please contact the undersigned if you have any questions or need additional information regarding this proposal.

Endorsed for The Regents of the University of California by:

Peter Gudlewski
Contract and Grant Officer

Phone: (510) 643-3391
Fax: (510) 642-8236
Email: peter.gudlewski@berkeley.edu

AWARDS SHOULD BE MADE TO:	CHECKS SHOULD BE MADE PAYABLE TO:
The Regents of the University of California	**The Regents of the University of California**
Sponsored Projects Office University of California, Berkeley 1608 4th Street, Suite #220 Berkeley, CA 94710-1749	CHECKS SHOULD BE SENT TO:
email address for electronics awards: spoawards@berkeley.edu	Contracts & Grants Accounting Attn: Elizabeth Chavez, Interim Director University of California, Berkeley 2195 Hearst Avenue, Room #130 Berkeley, CA 94720-1103 Telephone: (510) 643-4246 Fax: (510) 643-8997 Email: CGAawards@berkeley.edu
Main Office: (510) 642-0120 Fax: (510) 642-8236 Website: http://spo.berkeley.edu	

USDOT ADS Grant
Proposal to Contra Costa Transportation Authority (CCTA)

California PATH of University of California at Berkeley (PATH) is a project team member of the **Contra Costa Transportation Authority's (CCTA) ADS Demonstration Program** for the USDOT Automated Driving System Demonstration Grant Application. The application was submitted in 2019, and CCTA was awarded with a grant. This document reflects an updated scope of work, in accordance with the revised budget.

UC BERKELEY (PATH) SCOPE OF WORK

The list of tasks below is structured to describe the technical work that PATH will perform. The numbering of tasks is different from that in the integrated proposal submitted to USDOT by CCTA.

TASK 1: EXPERIMENTAL DESIGN

The PATH team will develop an Experimental Plan, to ensure the capture of data sets that achieve the project goal. In the Experiment Plan we will identify the experiment's operational condition(s) and the data that needs to be collected to characterize those conditions with the following objectives (1) collecting all data required to perform its evaluation, (2) ensuring the quality of the data, (3) storing data for processing, and (4) archiving data for transfer to USDOT.

The CCTA Team has proposed three demonstration projects:

PROJECT 1 - Rossmoor First Mile/Last Mile Shared Autonomous Vehicles, Walnut Creek, California

- Increase transit accessibility for the elderly community using shared autonomous vehicles (SAVs). Data gathered will be used to develop and evaluate safety performance measures.

PROJECT 2 - County Hospital Accessible Transportation, Martinez, California

- Provide on-demand, wheelchair accessible, autonomous vehicle (AV) shuttle service to people who don't have transportation. Gather data to develop and evaluate safety performance measures and to provide accessible transportation to public health facility improving quality of life and medical appointment absenteeism

PROJECT 3 - Personal Mobility on I-680 Corridor, Contra Costa County, California

- Prepare the corridor for future CAV. Install new and upgraded vehicle-to-vehicle infrastructure (V2I) and vehicle-to-vehicle (V2V) such as DSRC and 4G/5G communications, to accommodate both CAV technology and implementation of innovative operational strategies.

CCTA will offer a platform as the data gathering gateway.
Data will be gathered from different subsystems such as:

- AWS Nissan SAM

- AWS Verizon
- Caltrans TMC
- Olli
- Nvidia
- Telegra

In this project, CCTA will interact with all partners who are providing vehicle-based and infrastructure-based data. The data will be managed by CCTA and stored in a cloud-based platform, such as Amazon Web Services, where authorized team partners can access, read, download, and/or process the data. PATH will access and acquire the needed data through CCTA.

In this first task, we will create an experimental design plan that includes the following components:

- Based on the operational scenarios, we will work with team members to define the data plans. The design of experiments needs to take into account the volume of data, the conditions of data collections, and the relationships of raw and derived data to the evaluation metrics for ADS performance assessment. Data collection protocol will be generated.
- We will participate in a baseline (test-run) data collection period before the regular data collection is activated. As described in the main proposal, some preliminary testing will be carried out at GoMentum Station. The test run allows us to examine the data elements and issues in data collection procedures, to ensure the data acquisition system works properly and to verify the data elements are captured and uploaded into CCTA correctly.
- As data collection is underway for the duration of the operations of ADS demonstration, we need to ensure data collection is compliant with the predefined protocol. We will work with CCTA and project partners to have scripts automatically check the data collection status. If disruption or abnormality happens, there will be alerts issued and logged for later diagnosis and reference.
- In the meantime, we will monitor the operational conditions to check if any local conditions that may change over time and lead to effects on ADS demonstration. For example, roadway closure or reconfigurations may cause traffic patterns significantly. During this period, the data are continuously processed and reviewed, thus giving us an update status of ADS operation as well as an opportunity to verify the quality and volume of data elements being collected. If we detect any inadequacy or abnormality in data, the problem will be rectified expediently to minimize any disruption to the data collection process.

To maximize the quality of data to be captured that will ultimately inform USDOT AV policy, we will adopt several approaches in our experimental design that are unique and comprehensive:

- Diversity in driving environment; where we include ample daily data in urban setting, congested and free-flow, local streets, arterial and freeway driving environment.
- Diversity in vehicle operation; for example, in this project, three AV operations that serve different purposes are part of the demo program.

- Diversified selection in high-risk cases; where ADS interact with regular traffic and other road users frequently.
- Diversity in time of the day, weather and lighting conditions.

In order to maximize the value of data and to investigate the distribution and intensity of intended vehicle interaction scenarios, we plan to select a set of strategic locations where data will give us most diverse and varying operating conditions. These locations will include intersections, junctions, and passenger pickup and drop-off areas. The demonstration routes will be inspected carefully to determine the worthiest locations. These strategic locations offer the most dynamic and challenging operational scenarios and conditions that will provide the most valuable data sets.

In a later subsection, we present a more detailed description of data elements that we expect to capture and deliver in this project. We will ensure the quality of data and address the challenges and risks associated with maintaining the database; providing smooth and robust data downloading, storage, and archiving processes; protecting the privacy of data; and facilitate reliable and robust access to the database.

Task 1.1: Developing Outline of Data Structure and Contents

We believe that the vehicle-based data are most significant in revealing the safety implications of AV operations. The list given below represents a super set of data elements that can potentially be acquired from integrated vehicles. Other than the raw data, derived and extended variables can also be defined and extracted. The data types and formats will be defined in data dictionaries. The creation of these data dictionaries will be done through coordination with CCTA and project partners and team members as described above. Furthermore, data processing tools will be developed to inspect the quality and integrity of data elements as they are received and accumulated. Moreover, data filtering and aggregation will be carried out. Mode detailed discussions are given in a later section on data processing and filtering.

<u>Task 1.1.1 Vehicle-Based Data Elements</u>

The NOFO identifies one of its primary goals to be collecting data regarding the interactions of AVs with other road users in order to enhance understanding of the safety implications of the AV usage and to support future decisions about what kinds of regulations would be appropriate to ensure safe implementations of AVs. Several kinds of data are needed from the AVs being field tested:

(1) Data describing the motions of the AV, updated at intervals of 1 s or faster, referenced to an accurate time reference:

- location in lateral/longitudinal coordinates and referenced to local digital map
- speed
- direction of motion
- steering commands/actions
- acceleration/braking commands/actions
- vehicle malfunction flags

- event flags for emergency response maneuvers (steering or braking above threshold values, or takeovers by onboard or remote human operators) and crashes
- video camera (and audio if available) data streams associated with each event flag (starting at least 15 s before event flag and continuing until vehicle motion is stabilized)

(2) Data describing the traffic environment surrounding the AV, updated at interval of 0.1 s, referenced to an accurate time reference:
- signal phase and timing (SPaT) information vehicle has about traffic signal it is approaching
- location, relative speed (and heading angle if available) of vehicle(s) detected in vicinity of AV
- location, relative speed (and heading angle if available) of cyclist(s) detected in vicinity of AV
- location, relative speed (and heading angle if available) of pedestrian(s) detected in vicinity of AV
- location, relative speed (and heading angle if available) of other obstacles identified as potential hazards detected in vicinity of AV
- traffic signage and lane marking detected in the reachable vicinity of ADS
- HD map in the driving area
- Reporting on general weather and lighting conditions (especially any obscurants or lighting conditions that impede sensor capabilities) – updated only when they change.

(3) Human-machine interaction that relates to:
- how well the passengers on board input and receive information from the interface
- how well the intent or operational status of ADS is understood by passengers
- how does disadvantaged users' interface with ADS and the difficulty or issues experienced
- how does the users rate the comfort, trust, and sense of safety of ADS?

(4) Written (or oral) reports by onboard operators and/or remote mobility manager in SAM (Project 3) about any noteworthy observations that they can record (with reference time stamps) about:
- every disengagement of the automation system, with the reason for the disengagement
- every crash, with explanation for precursors and reasons
- any unexpected maneuver of the vehicle
- strong steering, braking or acceleration maneuvers
- problems encountered in interactions with external road users
- problems encountered by or with passengers
- observations about causes of any malfunctions or failures.
- every pull over/ stop on shoulder
- long hover beyond a threshold on road /at intersections

We will comply with the request of USDOT and make recommendations to provide the data components that are deemed necessary. All other data elements that are not requested by USDOT will be discarded.

Task 1.1.2: Infrastructure Data

In addition to the vehicle-based data, we expect to receive infrastructure-based data through the roadside sensor and communication setup that CCTA plans to install. As explained in Section 2.2 of the main proposal, CAVs are expected to be equipped with Dedicated Short- Range Communication (DSRC)-based or cellular-based On-Board Unit (OBU) that communicates with traffic signals through V2I and other nearby vehicles through V2V and/or V2X for detection of other moving objects.

Task 1.1.3: Traffic Operations and Environment Data

Furthermore, the CCTA team will also incorporate traffic condition data, including wait time in highway entrance/exit, density per highway lane (e.g., carpool lanes versus ordinary lanes and at different times of the day/days of the week), available parking spots in streets, and average time for red traffic lights. It is also an intent to identify road environment data such as potholes on the roads, highway signs and lanes status, and any road hazards (e.g. construction areas, closed lanes, etc.).

The data collected will be subjected to the same data quality process defined jointly by PATH in the other data categories. The captured data from infrastructure is essential to the evaluation and implementation of the designated application. The PATH team expects that the infrastructure data will assist the assessment of the performance of the AV systems.

Task 1.2: Data Content Summary

In summary, through coordination with CCTA team and USDOT, the PATH team expects to analyze several categories of data:

(1) Raw data and processed variables of data sets on test vehicles
(2) Infrastructure-based data
(3) Environment and operation data, such as weather and traffic data, that are relevant to the assessment of test conditions and should be captured for the evaluation of test results
(4) Trip summaries for test vehicles
(5) Data log, including data quality measures and data history, such as periods of recording, incidents of data missing, video and image issues, etc.

TASK 2: DATA ACQUISITION TESTING AND VERIFICATION

In this project, all three demonstration projects we are proposing involve the use of Level 3 or greater ADS technology. Project 1 will test low-speed (up to 25mph) passenger shuttle, Project 2 medium-speed (up to 50mph) in local urban streets, and Project 3I high-speed (up to 65mph) on highways.

Given the diversity of operating environment, PATH team will coordinate with CCTA and all stakeholders to establish an integrated approach to efficiently carry out the data collection tasks. In addition to requirements of data for later analysis, the team will also suggest a sub-set of data elements for operation by wireless network connection for real-time monitoring. Subsequently, a pre-testing data effort will be carried out to verify the validity of data collection processes.

PATH will work with CCTA and other project partners to go over the data elements identified in the experimental plan. In the process, we will review carefully how the data elements will be mapped onto the data analysis tasks and whether the performance metrics for AV performance assessment.

Task 2.1 Preliminary Testing of ADS platform

The initial testing will take place at GoMentum Station. Once data become available our team will examine the data elements and issues in data collection procedures, to ensure the data acquisition system works properly and to verify the data elements are captured and uploaded into CCTA correctly.

Task 2.2 Pre-Demonstration Testing

Once the infrastructure and ADS platforms are ready on the demo sites, we will proceed with the pre-demonstration testing phase. Data from the test operation in the field will be uploaded data through CCTA to the cloud-based platform. At the conclusion of this phase, reporting on the quality of data will be reviewed – a critical evaluation point on the progress of the project. The data collection plan can be modified to reflect any issues identified in this stage for refinement of data collection plan.

In order to substantiate ampleness and diversity of test data, the PATH team will work with CCTA to recommend pre-demonstration tests in the strategic locations and driving scenarios as described in the experimental plan.

Through coordination with CCTA, the technical and managerial processes for archiving of data on vehicles and from infrastructure will also be verified during this testing. This is necessary to make sure that no data losses occur, and if there are losses, identify the causes and assess its significance. This allows the team to identify any technical limitations, and to ascertain the efficiency and effectiveness of the interactions between the ADS platform team, the data evaluator and the logistics project team.

Task 2.3 Modify Data Collection Plan

Pursuant to the outcome of the task above, the project team will assess the effectiveness of the data collection plan in generating the quality and quantity of data needed to provide high confidence that the full demonstration test will be able to produce the required data. The team will evaluate not only the data acquisition system, but also the test the automation systems, and will consider remedies for any problems. Particular emphasis will be placed on seeking adjustments to operational procedures that can be implemented with minimal impacts on schedules and costs, in preference to hardware or software changes that are likely to have larger impacts.

TASK 3: SUPPORT FOR V2X APPLICATION DATA ACQUISITION

In this project, V2X systems will be installed to facilitate and enhance the operational safety and efficiency of ADS. In selective locations, signal phase and timing information will be broadcast and received by ADS vehicles. Roadside monitoring sensors and on-board sensors on other vehicles will provide inputs to ADS for detection of other moving objects through V2V and/or V2X. PATH will support the collection of data and the subsequent evaluation.

It is understood that CCTA will have other vendors install and equipment necessary communication, computing, and system verification of the required devices. Therefore, in this task, PATH will provide assistance and support to CCTA and its vendors to ensure proper data elements are captured for the vehicle-to-others (V2X) functions. PATH will work collaboratively with the partners to extract and incorporate the data collection plan related to V2X applications.

V2X may encompass vehicle to intersection controller, vehicle to work zone, vehicle to pedestrians, and vehicle to network. The concepts of vehicle-to-others (V2X) lend strong support to the operations of AV tremendously, especially when the vehicle-based sensing and perception capabilities are limited. For example, pedestrian presence may be feasible with the advancements of computer vision technologies. However, the intent of pedestrian movements and crossing at crosswalks are still very challenging. A pedestrian-vehicle communication system will alert the approaching vehicles and minimize the risks and hazards that will be extremely helpful encountered in urban environment.

TASK 4: DATA ANALYSIS AND PERFORMANCE ASSESSMENT

The total numbers and types of AVs to be included in Project 1 and Project 2 are relatively small, several AVs in Project 1 and one AV in Project 2. For project 3, the number of vehicles is yet to be determined. For this data analysis task, we expect the tools and procedures that we develop will be applicable to different platforms and invariant to the total volume of data. However, there will be constraints on available resources and project schedule limitations. If we choose to conduct more in-depth and detailed analysis on certain operation scenarios, we will have to limit the breadth of the study and select a subset of data if the vehicle number turns out to be significantly large. If we choose to carry out analysis on a relatively large number of vehicles or driving scenarios, then the depth of investigations may be limited. We will work fully cooperatively with the CCTA team to decide the best approach for meeting the project objectives.

Task 4.1: Data Logging

Data logging methods and sensor configurations will be tested for adequacy to capture

(1) normal operations, such as periods of recording, data elements collected, list of data files, recording disruptions if any, vehicle trajectory, vehicle operation mode (manual or automated, etc.
(2) abnormal events, such as incidents, hazardous conditions, unusual events, special situations, etc.

Specific for each use-case, a hazard list will be compiled and normal operational modes defined. Required variables, needed to detect, identify and assess hazards will be listed and the configuration of the data collection process will be evaluated. This will include logs of the autonomous driving software as well as hardware sensor information from the CAN bus.

Furthermore, for logging of incidents and events during a data collection session, which are not captured automatically through the system, on-board operators and chaperones will be debriefed. Using an operator’s log, they will answer standard questions and add free-form notes. The goal is to evaluate if during the session unusual situations in the environment occurred, the system showed behavior outside of the normal modes of operation or the operator deviated from the planned procedures. Examples are: stops through the police or a construction site, oscillating or erratic steering behavior, interference with operations through pedestrians or animals or a fallen down and re-attached sensor.

PATH will work with CCTA to implement data logging as the data are streamed into CCTA. The logging should be reported periodically to avoid redundancy information and to ensure surveillance. But if abnormal conditions happen, additional records should be immediately added sequentially to the logging file. For example, in normal condition, a periodical recording (every 5 minutes, 10 minutes, or 15 minutes) about the date, time, weather, road type, location, ADS status, hardware storage status (full or not), airbag status, etc., can be recorded to the logging file. If abnormal conditions occur, in addition to all the fields recorded under normal condition, additional information such as erratic steering, emergency break, long halting, stop on shoulder, vision images, GPS & IMU data, etc., will also be added. Some scripts will be developed to use vision images to carry out the surveillance about unusual scene, e.g. crash, pull over, erratic traffic lights, etc., if real time streaming is feasible.

Task 4.2: Data Processing, Filtering, and Screening

We anticipate that the volume of data will become considerably large over time, and proper processing techniques and reduction of data elements will be employed to extract meaningful data elements while keeping the data base under a manageable size.

Other than the raw data, derived and extended variables can also be defined and extracted. The data types and formats will be defined in data dictionaries. The creation of these data dictionaries will be done through coordination with CCTA. Furthermore, data processing tools will be developed to inspect the quality and integrity of data elements as they are received and accumulated. Moreover, data filtering and aggregation will be carried out. Mode detailed discussions are given in the data processing and filtering session below.

We will utilize the methods to monitor, screen, and filter the data sets:

(1) Eliminate data segments that are repetitive operational situations: For example, there will be certain routes that are taken by the ADS on a daily basis, due to similar starting and ending road segments. These will be eliminated unless the indicators used for monitoring the operational and data acquisition status reveal significant events or irregular operations.
(2) Capture only driving situations of high values: Using vehicle trajectory data and geo-fencing techniques, specific locations such as intersections, road junctions, roundabouts, and high-pedestrian density areas can be identified. The data sets from these locations will be maintained and stored at a relatively high ratio.
(3) Utilize operation monitoring variables to capture irregular and unusual events: For example, longitudinal and lateral acceleration values may reveal situations of hard braking and sudden lane change, which deserve to be further review to decide on the validity of data attributes. Frequently occurred driver takeover or interference at certain locations or road segments may provide hints of special operational characteristics to be reviewed.

(4) Combine data variable filtering with computer vision methodologies to slim down data sets: All of the above techniques can be combined with video and image processing techniques to identify operation scenarios of high interest. For example, there have been a large body of literature on pedestrian detection in recent years. Significant research activities at Berkeley DeepDrive involve the developments of image processing for pedestrian recognition and pedestrian interaction with vehicles. Many of the open-sourced methods can be employed for this project.

Use computer vision processing techniques to calculate distribution of situations, based on visual appearance: In recent work, a research project (*Testing and Verification of Safe Network-Based Driving Algorithms* by S Hornauer, C-Y Chan, S. Yu) conducted at Berkeley DeepDrive developed a technique to identify the confidence level of video and image contents, which can be employed to carry out preliminary filtering of data for a next round of evaluation.

Task 4.3: Data Analytics and Performance Assessment

Data analytics tools will be developed to extract relevant information about vehicle interactions from the massive set of raw data and estimating the measures of performance and matching them up with onboard operator logs

Especially data for risk and hazard analysis, needed to ensure the operational safety of the vehicle, will be extracted. Systematic approaches such as the Systems-Theoretic Processes Analysis (STPA) can serve as reference on which data to extract. Test-cases will be designed to validate the extraction routines. Extracted data will support analysis of *functional safety*, *safety of the intended function* and *safety in use*.

In order to evaluate the safety attributes of the AVs, some of the following performance metrics could be used:

- Categories of failure modes (e.g., disengagement and accident);
- Severity of each failure (e.g., reaction time in the cases of disengagement, speed and locations when the accident happens and involvement of other road-users)
- Number of accidents per mile driven, in order to compare the safety of AV with the safety of human-driven vehicle;
- Number of faults in the machine learning system (responsible for the perception tasks and planning and control tasks) such as faults in object detection, road surface detection, and faults in localization and mapping;
- Number of faults in the computing system, such as faults in data communication;
- Number of faults that can't be classified.
- Variation of vehicle control (e.g. change in speed and position between two or three successive time units)
- Airbag status (in use or not)
- Relative distance to leading vehicles and rear vehicles on current lane and adjacent lanes (too small values indicate hazard driving conditions).
- Number of times going beyond the road boarder, or time duration driving on shoulder (this can be obtained from ADS or vision images)

- Number of emergencies stops

After the extraction of data segments corresponding to unusual situations from an AV, we will perform a multi-step analysis of those data. For each unusual situation, the following steps will be taken (1) Identify the location, date, time of an unusual situation, and extract the AV trajectory and perception information up to 10 seconds prior and up to 5 seconds after the event. (2) Classify the unusual situation using the onboard sensing data, such as road blocks, incidents, malfunctioning traffic signals, etc. Possible types of such situations include incidents, near-misses, violations, deadlocks and disengagements.

Disengagements will have specific causes, which are expected to be documented in the AV operator's log. Our goal is to separate critical disengagements from noncritical. Critical disengagements are those whose absence would lead to a hazard. Noncritical disengagements fall into two categories: unnecessary disengagements and those initiated by the safety driver due to AV inefficiencies.

Task 4.4: Data Visualization

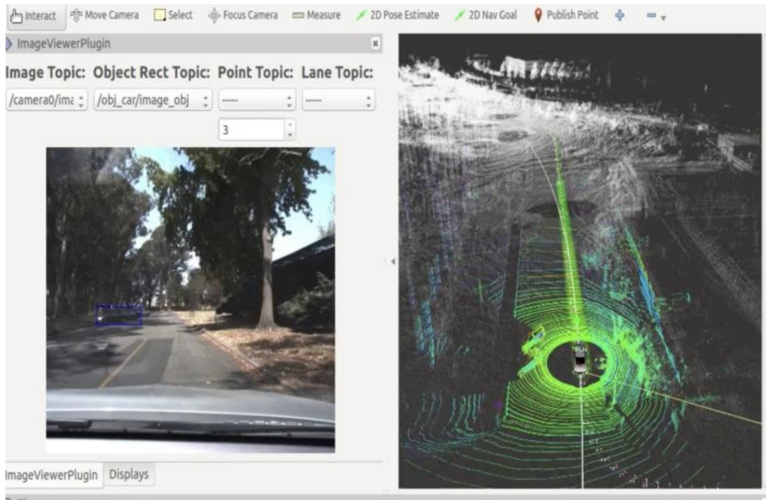
Data visualization will be implemented on three levels:

(1) visualization of the variety of data, e.g. location types (highway or urban), weather conditions (sunny or rainy), incident types (crashes or disengagement), etc. The visualization can be represented by statistic graphs, such as timeseries plots, correlation charts, pie charts and Venn diagrams.

(2) 2D and/or 3D visualization of the scene. Normal situation can be represented in 2D. For example, AV trajectories can be displayed on a map. Possible interactive map solutions include Google Maps, Google Earth, Mapbox. Maps will also be used to display the locations of unusual situations and their hotspots. 3D visualization will be used for unusual situations. This visualization will display scene snapshots and scenario reconstruction with agents surrounding an AV and identified from the onboard camera data, as described in Task 4.3.

One example for illustration is the use of Rviz, a 3D visualization tool for data collected with ROS. We have in-depth experience with the use of Rviz, using it for visualization of image data, lidar data, GPS and IMU data at synchronized time step. For example, see the illustrated figures below.

- 3D view of ego-vehicle and surrounding environment
- Identification of other road users
- Speed, acceleration and trajectory information based on time series



(3) Visualization of the analysis results. The analysis of the traffic efficiency and safety will be presented in various ways, 3D graphs, heat map, histograms, correlation lines, etc.

Task 4.5: Monthly and Quarterly Updates and Summary Reports
Monthly and quarterly summaries will be generated to report the status and progress of data analysis.

Task 5: Data Analysis Report
In this task, the PATH team will prepare a summary report on the following aspect as a conclusion of data analysis:

Task 5.1 Data Collection Summary Report
In this part of reporting, we will provide a summary of:

- Reporting on the demonstration plan, including all ADS vehicle platforms, the data acquisition system through CCTA, the operation scenarios, and the data collection plan for all scenarios, as well as logs of any modification and enhancements of the deployment plan.
- Reporting on the final set of data elements, including both the vehicle-based and the infrastructure-based data.

Task 5.2 Reporting AV Performance Assessment
In this part of reporting, we will provide a summary of:

- Reporting on statistics of the AV operation data, including hours of operation, corresponding road environment, number of unusual situations, number of disengagements, incidents and near-misses et al.
- Reporting on data analytics and results to define unusual situations that challenges encountered by the AV systems.
- Reporting on the causality analysis and the level of severity of the unusual situations and relevant AV issues for control and deployment.
- Reporting how performance evaluation reveal necessary ADS enhancements

TASK 6: TECHNICAL PROJECT MANAGEMENT AND SYSTEMS ENGINEERING SERVICES

Several partners have been selected for the CCTA ADS Demonstration program. Primary partners currently include:

- AAA – AAA provides support for ADS efforts, including safety analysis, verification and validation activities, and related efforts at the GoMentum station and in the field.
- AWS – AWS has been selected for cloud services and support.
- Nissan – Nissan has been selected to provide automated vehicles and related support.
- Telegra - Telegra has been selected to provide local TMC services, hardware, and software required for gathering infrastructure data from the GoMentum station signal laboratory, Rossmoor V2X infrastructure, City of Martinez V2X infrastructure, and the infrastructure within a 2 mile radius of I-680 in San Ramon.
- Verizon – Verizon has been selected for data collection, edge computing, processing, and related support.

A number of other partners will be involved as well including some not yet determined. Public partners will also be involved, including Contra Costa County, Caltrans, Metropolitan Transportation Commission, the cities of Martinez, San Ramon, Walnut Creek, and others. PATH will provide support for project management and coordination and review of vendor and partner activities. In addition, PATH will provide systems engineering technical support and the integration of systems engineering with Agile systems management practices.

This task (Task 6) will be provided on an as-needed, fixed level of effort basis not to exceed 465 hours of effort.

Task 6.1: Technical Project Management

Provide technical project management and technical support/oversight for partner contracted efforts.

Task 6.2: Partner and Stakeholder Coordination

Under the direction of CCTA, provide coordination and technical support for efforts by AMG, CCTA, and other participating partners and stakeholders.

Task 6.3: Partner Relationship Management Support

Under the direction of CCTA, provide partner relationship management support. Assist maintaining positive, productive partner relationships and escalation and early resolution of issues.

Task 6.4: Systems Engineering Documentation

Collaboration with partners, CCTA, AMG, and other project stakeholders to support development of the systems engineering documentation required for the program. Examples include:

- Development of system user needs and requirements, including gathering and defining user needs, defining system requirements, prioritization of requirements, user needs and requirements selection, and preparation of user needs and systems requirements documentation in accordance with standard Systems Engineering practices as needed.
- Development of a concept of operations for the ADS/ATMS integration efforts. This may include coordination with stakeholders, identification of system components and data elements, system operating parameters, usage scenarios, data analysis, communication processes, system characteristics, roles and expectations, and mapping of operational needs to system requirements as needed.

Task 6.5: Systems Engineering Technical Support

Technical support for development of systems engineering efforts, including design and design review services.

Task 6.6: Agile Support

Assistance with Agile, iterative development approaches, including assistance with Scrum or other agile methods, backlog management, iteration definition, task management, or other related support.

Task 6.7: Other Systems Engineering Support

Other systems engineering efforts, support, and documentation as needed, such as systems engineering management plan, system architecture, design, integration, testing, implementation, analysis, and evaluation efforts.

Task 6.8: System Integration Support

Provide technical support for system integration and ATMS/ADS integration efforts.

Task 6.9: Center-to-Center Communications Support

Provide technical support for center-to-center communications.

Task 6.10: Partner Deliverable Review Support

Provide review of partner provided deliverables to ensure deliverable meet contract performance requirements.

Task 6.11: Design Review Support

Provide design reviews of vendor provided design documentation and efforts.

SCHEDULE

A preliminary schedule is given in the table below. The exact schedule and duration of each task will be adjusted to match the overall project schedule determined by CCTA. In the execution phase, the schedule may be further revised to be consistent with the delivery of project outputs to USDOT.

Task Number	Task Title	Start Month	End Month
1	Experimental Design	1	12
2	Data acquisition testing and verification	13	50
3	Support for V2X Data Acquisition	13	50
4	Data Analysis and Performance Assessment	41	58
5	Reporting	43	59
6	Technical Project Management and Systems Engineering Support	1	59

COSTS

A preliminary cost estimate is given in the table below. The costs include coverage of personnel salary and benefits, equipment, supplies, university fees, indirect overhead (57%), as well as travel to attend project meetings with USDOT and CCTA.

Task Number	Task Title	Costs (Budget from CCTA Share)	Budgeted Amount from Cost Share Funding	Explanatory Notes
1	Experimental Design	$69,264	$69,264	Ching-Yao Chan, Peggy Wang Salary/Benefit - BDD Project
2	Data acquisition testing and verification	$105,804	$105,804	Ching-Yao Chan, Peggy Wang Salary/Benefit - BDD Project
3	Support for V2X Data Acquisition	$185,468	$185,468	BDD data and vehicle Project , Supplies and Services
4	Data Analysis and Performance Assessment	$459,890	$459,890	Ching-Yao Chan, Peggy Wang, Hao Liu Salary / Benefits
5	Reporting	$114,562	$114,562	Ching-Yao Chan, Peggy Wang, Hao Liu Salary / Benefits

6	Technical Project Management and Systems Engineering Support	$110,000	$110,000	Ching-Yao Chan, Peggy Wang Salary / Benefits
	TOTAL	**$1,044,987**	**$1,044,987**	

KEY PERSONNEL FROM CALIFORNIA PATH

Team Members and Roles (See detail in individual CVs and linked web pages)

Team Member	Role	Duties
Dr. Ching-Yao Chan	Safety Assessment Lead and UCB Principal Investigator	Oversight of PATH work; Coordination and interaction with partners and USDOT;
Ben McKeever, P.E.	Program Manager	Safety and mobility evaluation; Policy issues; Coordination and interaction with partners
Brian Peterson	Data Scientist and Software specialist	Technical project management, systems engineering, data architecture design, data analysis, and software development
Dr. Peggy Wang	Research Engineer	Human factors; Human-vehicle interface; Statistical analysis
Dr. Hao Liu	Research Engineer	Data processing and analysis

ORGANIZATIONAL QUALIFICATIONS: University of California PATH Program

See the separate qualification document.

CURRICULUM VITAES (CV) / RÉSUMÉS / BIOSKETCH

Ching-Yao Chan, Ph.D., P.E.
Program Leader, Safety Research, California PATH, Headquarters
TEL: 510-665-3621 (office), E-Mail: cychan@berkeley.edu

SUMMARY:

Dr. Ching-Yao Chan is a Research Engineer and the Program Leader for the Transportation Safety Research Area at California PATH (Partners for Advanced Transportation Technology) of the University of California at Berkeley. He joined PATH in 1994. Prior to joining Berkeley, he worked in the automotive industry and consulting services. Dr. Chan has more than 25 years of research and project management experience, spanning from vehicle automation, driver assistance systems, risk analysis and safety assessment of transportation systems. In recent years, his research has been focused on advanced vehicular safety systems and mobility solutions, based on wireless communication, sensing, and automation.

Dr. Chan led and managed research projects that won prestigious awards, including the Best of ITS Research Award from ITS America in 2004 and the award of Excellence in Applied HOV Research from the Transportation Research Board's HOV System Committee in 2008. He was the recipient of the 1998 SAE Forest R. MacFarland Award for his outstanding contributions to engineering education.

PROFESSIONAL EXPERIENCE:

•**University of California, Berkeley, California PATH Program,** Richmond, CA
May 1994 – present, Program Leader and Researcher
•**Forensic Technologies International, Inc**., San Francisco, CA
January 1991 – May 1994, Senior Engineer
•**Automotive Technology International**, Denville, NJ
October 1988 – December 1990, Director of Advanced Concepts
•**Breed Automotive Corporation**, Boonton Township, NJ
February 1988 – October 1988, Senior Engineer

EDUCATION:

•B.S., Mechanical Engineering, National Taiwan University, 1981
•M.S., Mechanical Engineering, University of California at Berkeley, 1985
•Ph.D., Mechanical Engineering, University of California at Berkeley, 1988

PROFESSIONAL AFFILIATIONS:

•Visiting Professor, University of Tokyo, JAPAN, May 2006 – Jan. 2007.
•Visiting Scholar, INRETS (now IFSTTAR, French National Transportation Research Institute), 2004
•Instructor and Author, Professional Seminars, SAE, 1995-2005, on Occupant Restraint and Crash

Sensing; Publication of Professional Tutorial Video and Book on Crash Sensing 2000.
•Invited Lecturer, for General Motors Company, Ford Motor Company, Honda America, Association for the Advancement of Automotive Medicine, and American Bar Association, Japan ASME, Japan SAE, and numerous research and academic institutions
•Associate Editor, International Journal of ITS Research
•Professional Engineer, California, since 1994

SELECTIVE PROJECT/ WORK EXPERIENCE:
•**Deep Learning for Autonomous Driving.** Conducting research projects and managing data and infrastructure projects in the Berkeley Deep Drive (BDD) consortium for deep learning technologies.
•**Mines ParisTech "Drive for All" Foundation.** Managing PATH's participation in this global consortium for autonomous driving in urban environment.
•**Automated Driving Systems Research with Automotive Research and Testing Center (ARTC) and Industrial Technology Research Institute (ITRI).** Collaborative research on driver-machine interaction and driving automation.
•**California Regulations for Autonomous Vehicles.** Providing PATH's technical advisory to California Department of Motor Vehicles (DMV) in establishing regulations for automated vehicles.
•**Foresighted Driving for Networked Travelers.** Responsible for experimental design of this Connected Vehicles project that provides traffic queue alerts based on cellular communication.
•**CAMP V2V Interoperability and Scalability Testing.** Managed this CAMP (Automaker Consortium) project on Vehicle- to-Vehicle (V2V)-Interoperability and Scalability.

SELECTIVE PUBLICATIONS:
See http://www.path.berkeley.edu/ching-yao-chan-publications for a complete list.
•X-M. Chen, et al, "Bionic Decision-Making Analysis During Urban Expressway Ramp Merging for Autonomous Vehicle," *TRB Annual Meeting*, Paper #17-3483, January 2017.
•P. Wang, et al, "Vehicle Collision Risk Prediction at Intersections based on Comparison of Minimal Distance between Vehicles and Dynamic Thresholds," *TRB Annual Meeting*, Paper #17-2683, January 2017.
•W. Zhan, C. Liu, C-Y Chan, M. Tomizuka, "A Non-Conservatively Defensive Strategy for Urban Autonomous Vehicle," *IEEE ITS Conference*, Rio De Janeiro, Brazil, November 2016.
•L. Lu et al., "A Cellular Automation Simulation Model for Pedestrian and Vehicle Interaction Behaviors at Unsignalized Mid-Block Crosswalks, "Accident *Analysis and Prevention*, Vol. 95, Part B, pp. 425-437, Oct. 2016.
•Y. Li, et al., "Develop Right-Turn Crash Warning System at Arterial Access Considering Driver Behavior, "IET *Intelligent Transport Systems,* ISSN 1751-9578, September 2016.
•L. Lu, et al., "Application of SFCA Pedestrian Simulation Model to the Signalized Crosswalk Width Design, "Transportation

Research Part A, Policy and Practice, Volume 80, pp. 76-89, October 2016.
•X. Li, C-Y Chan, Y. Wang, "A Reliable Fusion Methodology for Simulation Estimation of Vehicle Sideslip and Yaw Angles, "IEEE

Transactions on Vehicular Technology, Vol. 65, No. 6, pp. 4440-4458, June 2016.
•P. Wang, et al., "Trajectory Prediction for Turning Vehicles at Intersections by Fusing Vehicle Dynamics and Driver's Future Input Estimation, "*Transportation Research Records*, No. 2602, 2016.
•X-M. Chen, et al, "Bionic Lane Driving Decision Making Analysis for Autonomous Vehicle Under Complex Urban Environment,"

Transportation Research Records, No. 255, 2016.
•C. Nowakowski, S. Shaldover, C-Y Chan, "Development of Behavioral Competency Requirements to Determine the Readiness of Automated Driving Systems for Public Operations", *TRR* No. 2559, 2016.
•P. Wang, et al, "Minimum Sample Size Study Based on Time Series Analysis of Traffic Flow Data at Intersections, "Advanced in Transportation Studies, Nov. 2015m Issue 37, pp. 65-67.
•C. Nowakowski, et al., "Development of California Regulations to Govern the Testing and Operation of Automated Driving Systems," *Transportation Research Records* 2489, pp. 137-144, Jan. 2015.
•X. Li, W. Chen, C-Y Chan, "A Reliable Multi-Sensor Fusion Strategy for Lane Vehicle Positioning Using Low-Cost Sensors," Proceedings *IME, Part D,* Vol. 228, No. 12, pp. 1375-1397, October 2014.
•Li, X.; Song, X.; Chan, C-Y, "Reliable Vehicle Sideslip Angle Fusion Estimation Using Low-Cost Sensors," *Measurement,* Vol. 51, pp.241–258, October 2014.
•Y. Du, Y. Wang, C-Y Chan, "Autonomous Lane Change Controller," IEEE Intelligent Vehicles Conference, June 2015.

Book and Book Chapter
•F. Bu, C-Y Chan, "Adaptive and Cooperative Cruise Control," *Handbook of Intelligent Vehicles*, Feb. 2012, ISBN-13**:** 978-0857290847.
•C-Y. Chan, "Occupant Restraint Systems," McGraw-Hill 2006 Yearbook of Science and Technology.
•C-Y. Chan, "Fundamental of Crash Sensing for Automotive Air Bag Systems," Society of Automotive and Aerospace Engineers (SAE), February 2000, ISBN 0-7680-0499-3.

CURRENT & PENDING SUPPORT

Status (currently active or pending approval)	Source (name of the sponsor)	Project Title	Start Date	End Date
PENDING	Contra Costa County (CCTA)		7/1/2021	4/30/2026

Budget

COMPOSITE BUDGET: ESTIMATE FOR ENTIRE PROPOSED PROJECT PERIOD
5/1/2021 to 4/30/2026

From: To: BUDGET CATEGORY	5/1/2021 6/30/2021 Year 1	7/1/2021 6/30/2022 Year 2	7/1/2022 6/30/2023 Year 3	7/1/2023 6/30/2024 Year 4	7/1/2024 6/30/2025 Year 5	7/1/2025 4/30/2026 Year 6	TOTAL
PERSONNEL: Salary and fringe benefits(less tuition)	$	$113,096	$121,550	$175,941	$121,478	$117,019	$649,085
TRAVEL	$	$	$	$	$		$
MATERIALS & SUPPLIES	$	$	$234	$394	$720	$ 650	$1,998
EQUIPMENT	$ -	$ -	$ -	$ -	$ -		$ -
CONSULTANT	$ -	$ -	$ -	$ -	$ -		$ -
SUBRECIPIENT(S)*	$ -	$ -	$ -	$ -	$ -		$ -
OTHER DIRECT COSTS (ODC)							
Tuition	$ -	$ -	$ -	$ -	$ -		$ -
Server Maint.	$ -	$ -	$ -	$ -	$ -		$ -
GAEL Insurance	$ -	$ -	$ -	$ -	$ -		$ -
UCRP Assessment:	$ -	$ -	$ -	$ -	$ -		$ -
TOTAL DIRECT COSTS	$	$113,096	$121,784	$176,335	$ 122,198	$117,669	$651,082
Indirect (F&A) Costs F&A Base *MTDC*	$	$ 113,096	$ 121,784	$176,335	$ 122,198	$117,669	$ 651,082
Indirect (F&A) Costs* 60.50%	**$**	$68,423	$73,679	$106,683	$ 73,930	$71,190	$393,905
TOTAL ESTIMATED COSTS PER YEAR	**$ 0**	$181,519	$195,463	$283,018	$196,128	$188,860	
TOTAL ESTIMATED COSTS FOR PROPOSED PROJECT PERIOD							**$ 1,044,987**

Budget Justification

The Budget Justification will include the following items in this format.

Personnel

Principal Investigator Ching-Yao Chan, PhD: Dr. Chan, at the University of California at Berkeley, will be the Principal Investigator (PI) of this project and will provide overall direction and oversight of the project including drafting and dissemination of results. Dr. Chan will commit approximately 4% effort in this project for the whole term of the project period. Fringe benefits for Dr. Chan are calculated at the Academic rate.

Staff Engineers: Ben McKeever is an experienced program manager who will support PI Chan in evaluation, reporting, and partner coordination during the duration of the project and will commit approximately 13% during this period. Benefits at the Staff rate. Brian Peterson is a skilled project manager, systems architect, and data scientist who will provide technical project support and support PI Chan in data analysis and software development. Benefits at the Staff rate. Brian will commit approximately 8% during this period (with a higher percentage I the first year of the project).

Assistant Research Engineers: Pei Wang will assist in research and will take direction of duties and research efforts from Dr. Chan. Benefits for Pei will be at Academic rate.
Will commit approximately 40% during this project period.

Assistant Research Engineer: Hao Liu for data processing and analysis. Benefits will be at Acamedic rate. Will commit approximately 20% in Year 5.

Below is a table of hour rates for each person described above:

		A	B		C	D	E	F
Name	Monthly Pay	Monthly Pay	Benefits	Benefits Name	University Indirect	Full Rate	Hours Per Month	**Full Hourly Rate**
		Anticipated rate when project starts	%		%	**D=A*(1+B)*(1+C)**	173	**=D/E**
Ching-Yao Chan	$15,783	$15,783	35.90%	Academic	60.50%	$34,425.80	173	**$198.99**
Ben McKeever	$13,933	$13,933	45.90%	Staff	60.50%	$32,626.84	173	**$188.59**
Brian Peterson	$15,930	$15,930	45.90%	Staff	60.50%	$37,303.20	173	**$215.63**
Peggy Wang	$9,600	$9,600	35.90%	Academic	60.50%	$20,939.47	173	**$121.04**
Hao Liu	$ 9,600	$	35.90%	Academic	60.50%	$20,939.47	173	**$121.04**

		9,600						

Fringe Benefits.

The composite fringe benefit rates for fiscal year 2020-21 have been published. See below. FY 2021 rates should be applied to UC personnel costs that will occur during this time period. Projected rates (FY22-FY25) are estimates for planning purposes, only (e.g., multi-year budgeting, financial aid planning, contract and grant proposal submissions, etc.) and are subject to change.

	Approved Rates		**Projections for Planning Purposes**			
CBR Rate Group	**FY20**	**FY21**	**FY22**	**FY23**	**FY24**	**FY25**
Academic	36.50%	**35.90%**	35.90%	35.40%	34.40%	35.50%
Staff	45.50%	**45.90%**	43.80%	42.80%	42.80%	42.80%
Limited **(includes Postdocs)**	17.40%	**16.40%**	14.40%	14.00%	12.20%	14.70%
Employees with No Benefit Eligibility	5.60%	**5.50%**	4.20%	5.30%	5.40%	4.40%
Students (Graduate and Undergraduate)	2.40%	**2.40%**	2.60%	2.80%	2.30%	3.00%

For more information, please see: http://www.spo.berkeley.edu/policy/benefits/benefits.html

Travel

Materials and Supplies

Disposable supplies will be purchased annually at the rate of ($0, $0, $234, $394, $720 and $650 per year). Total allocation of supplies will be $1,998.

Equipment

No equipment is slated to be purchased

Other Direct Costs

N/A

Indirect (F&A) Costs

The indirect costs are $ 393,905 based on University negotiated rates with the relevant federal authority and are applied using the modified total direct cost (MTDC) formula. The indirect cost rate applied for this project is 60.50% for the duration of the project for an on-campus project. The indirect cost rates are available online at:

http://spo.berkeley.edu/policy/fa.html