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This report documents the Comprehensive Deployment Plan of the FHWA Truck Platooning Early Deployment Phase II project. It includes important aspects of the Field Operational Test (FOT): (a) technical approach for CACC including system functionality and some initial relevant functional safety considerations; (b) test and experimental design which includes: progressive CACC system performance tests by PATH project team in public traffic; professional truck driver acceptance test between Berkeley and Roly's Trucking at Rancho Cucamonga in Southern California to test how the drivers would experience the behaviors of the CACC trucks in platooning operation; and Operational Readiness Test, which would be the test of the overall system including CACC truck platooning on the test route along Interstate-10 and 20, functionality of the data collection system on the trucks, the real-time monitoring system between the trucks and PATH team at Berkeley, data collection and uploading from Roly's Trucking to the UC Berkeley Data Server; and finally the FOT; (c) Data Management Plan, which include data collection, CACC system and data collection system real-time monitoring, data uploading from Roly's Trucking to UC Berkeley Data System, data health check and correction, meta data calculation, and data sharing with FHWA and the Independent Evaluator; (d) Human Use Plan, which includes IRB application for using professional truck drivers as test subjects, driver recruitment for FOT, questionnaire design for driver's opinion, driver training and testing for qualification of operating the CACC trucks, etc.; (e) Partnership Plan for FOT, including partner group formation, fleet partner coordination, and stakeholder engagement strategy etc. The partnership is important since the FOT test route would cross four states including California, Arizona, New Mexico, and Texas. Therefore, stakeholders of the four states need to be involved for the FOT.

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16. Abstract

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Table of Contents

Executive Summary **1**
Technical Approach for CACC Implementation 1
Data Acquisition and Management Plan 2
Human Use Approval Plan 3
Partnership and Outreach Plan 3
Chapter 1. Introduction **5**
1.1. Background 5
1.2. Purpose 5
1.3. Scope 6
1.4 References 6
Chapter 2. Technical Approach for CACC Implementation **9**
2.1 Overview 9
2.2.1 CACC-Enabled Trucks 14
2.2.2 Drivers 14
2.2.3 Emergency Coordinated Braking Capability 16
2.2.4 Modifications to CACC System since EAR Project 16
2.3 Key Safety Considerations 17
Chapter 3. Approach to Progressive Test and Experimental Design **19**
3.1 System Acceptance Test 20
3.2 Operational Readiness Test (ORT) 22
3.3 Field Operational Test (FOT) 23
3.3.1 Operational Considerations 26
3.3.2 Driver-related Considerations 27
3.3.3 Driver Questionnaires and Fleet Operations Questionnaires 29
Chapter 4. Data Acquisition and Management Plan **33**
4.1 Performance Measures 33
4.2 Data Overview 33
4.3 Data Acquisition System 37
4.3.1 Data Upload from Trucks to PATH Server 38
4.3.2 Truck Mounted Sensors for Traffic Detection 41
4.3.3 On-board Driver Monitoring Systems 42
4.3.4 Remote Monitoring and Data Verification 44
4.4 Data Stewardship 45
4.4.1 Data Owner and Steward 45

4.4.2 Data Access 45
4.4.3 Data Re-Use, Redistribution, and Derivative Products Policies 47
4.4.4 Data Storage and Retention 47
4.5 Data Standards 48
4.6 Data Lists and Metadata 48
Chapter 5. Human Use Approval Plan 49
5.1 Human Subjects Testing Protocol 49
5.2 Certificate of Confidentiality (CoC) 49
5.3 Timeline for Obtaining Human Use Approval 50
Chapter 6. Partnering and Outreach Approach 51
6.1 Project Partners and their Roles 51
6.1.1 Core Team 51
6.1.2 Additional Key Partners 54
6.2 Fleet Partner Coordination 55
6.3 Stakeholder Engagement Strategy 57
Appendix A. Truck Platooning Performance Measures 59
Key Area IDs 59
Priority Levels 59
CACC System Parameters 59

List of Tables

Table 1. Time Gap Settings for ACC and CACC Modes used in EAR project 14
Table 2. Sequence of Events for Test Drivers 29
Table 3. Data Set Descriptions 33
Table 4. Total data size estimates for data collection for each FOT round trip....39
Table 5. Number of hours to transfer data from trucks....39

List of Figures

Figure 1. CACC Truck System Hardware 10
Figure 2. CACC Control System Architecture 11
Figure 3. PATH CACC Truck DVI....13
Figure 4. CACC System Operation Control On the Steering Wheel....15
Figure 5. Relationship among Planned Testing Stages and Tasks....19
Figure 6. Map of Planned Truck Platooning Test Route....24
Figure 7. Data acquisition system installed on each truck: two large data drives are installed; one for CACC engineering data and one for extra sensor data....38
Figure 8. Data uploading using removable SSDs cable-linked with PATH computer at Roly's....40
Figure 9. Three fixed beam lidar coverage scheme, mounted on the tractor only....41
Figure 10. Three wide angle video camera coverage areas, mounted on the tractor only 42
Figure 11. SmartCap Fatigue Levels 43
Figure 12. Scheme for Data Storage, Processing and Sharing with FHWA and IE....46
Figure 13. Team Site Visit Photos at Roly's Facility 56

Executive Summary

This report documents the Comprehensive Deployment Plan of the FHWA Truck Platooning Early Deployment Phase II project. It includes the following plans which are described in more detail below:

- Technical Approach for CACC Implementation
- Progressive Test Plan
- Data Acquisition and Management Plan
- Human Use Approval Plan
- Partnership and Outreach Plan

Technical Approach for CACC Implementation

This section documents the technical implementation of CACC on the four trucks to achieve the functions necessary for CACC operation in the field. It describes the overall system and major individual subsystems. Those subsystems include: the PC-104 engineering control computer using QNX 7.0 as the Real-time Operating System which interfaces with the J-1939 Bus (a truck internal information bus) to get the real-time data necessary for control and to send back the commands for control execution; The CACC algorithm running on the PC-104 computer calculates the desired control commands for engine torque, engine retarder and service brake to achieve the stability of a single truck feedback; the string stability for platooning, based on the sensor detection and perception of the inter-vehicle distances etc.; and other truck information through vehicle-to-vehicle (V2V) communication. The algorithm is essentially the same as the one developed in the previous FHWA EAR Truck Platooning Project with some improvements for functional safety. The subsystems also include other components such as Dedicated Short-Range Communication (for V2V) between trucks, GPS units, Driver-Vehicle-Interface (DVI), added other sensors (fixed beam lidar and video camera), and the Quantum Data Collection System with a 23 TB solid-state drive (SSD).

Progressive Test Plan

The progressive Test Plan includes four stages: CACC system performance test, driver acceptance test, system readiness test, and field operational test (FOT).

CACC system performance test

This test was conducted by the PATH project team during step-by-step implementation of the CACC system on the trucks. During the whole process of the implementation, PATH made sure each individual component and the integrated CACC system behaved technically as expected with the corresponding data analysis. As the implementation progressed, the components implemented earlier were re-tested at later stages. Therefore, after the system integration stage, many components were tested hundreds of times in practice. From the testing at this stage, the team was be able to verify the functionality and reliability of the components and to decide if certain components would need to be replaced with better ones. This stage also provided some clues regarding safety related to CACC functionality.

Driver acceptance test

This would be a round-trip drive of three fully loaded CACC trucks by professional truck drivers between Berkeley and Roly's Trucking at Rancho Cucamonga in Southern California. This would happen after the CACC system integration and PATH internal performance test. This is a very important step since the drivers would need to accept the CACC system before the FOT. If there are flaws and deficiencies experienced by the drivers, the project team would need to revise and improve the system to the drivers' acceptance and satisfaction. The main scenarios to be tested at this stage are:

1. Switch On/Off of the ACC/CACC system.
2. Transitions between manual and ACC/CACC modes.
3. Driver Vehicle Interface (DVI) use for understanding the information displayed, drive-mode and time-gap selection, driver voice recording in case of abnormal situations and including incidents/crashes, and driver's information input such as ID and platoon position.
4. Driver's understanding of the Operational Design Domain (ODD) which defines under what conditions the driver can and cannot use the CACC system, and what the driver can select optionally. In addition, this test would also check the CACC system functionality and performance under the operation of professional truck drivers in extreme road conditions such as long distance up and down grades.
5. Operational Readiness Test (ORT). The objective of this test is to check if the overall system is ready for the FOT. The overall system includes:
   - CACC truck platooning system driving on the test route along Interstate-10 and 20
   - Data collection system on the trucks
   - Real-time monitoring system implemented with a cellular modem link between the CACC trucks in the field and PATH at UC Berkeley
   - Data acquisition uploading from Roly's Trucking to UC Berkeley
   - Data logging and storage at PATH of UC Berkeley

Data Acquisition and Management Plan

The data acquisition includes the data collection from different subsystems. The first part is the engineering data from the J-1939 Bus, which are mainly related to the truck dynamics and its powertrain and drivetrain and data necessary for front scene perception and control purposes. The second part is the V2V communication data which are from other trucks in the platoon. Those data include the standard BSM (Basic Safety Message) I, BSM II and some additional data necessary for truck control to achieve the platoon string stability and active safety. The third part includes some added sensors (such as fixed beam lidar and video camera) in the front and side of the truck to capture the nearby other traffic behaviors. The front fixed beam lidar would also be used for enhancing the perception by built-in fused radar and video camera to handle aggressive other vehicle such as cut-in maneuvers. The fourth part includes the driver monitoring data from SmartCap (EEG data to measure driver's fatigue level) and Jungo system (to measure the driver's attentiveness). An EEG is a test that measures electrical activity in the brain using electrodes attached to the scalp. Those data would be saved on the Quantum Data Collection System, which has an internal process using Linux as the Real-time Operating System and has an SSD with 23 TB storage capacity. The system has been designed to be able to save all the data for a round trip between Los Angeles and Texas. The SSD is also removable so that, after each trip, the SSD would be swapped with an empty one in the internet-connected magazine at Roly's Trucking for automatic data-uploading to the PATH Server.

The data management would be conducted in the following way after the data has been uploaded from the SSD at Roly's Trucking to the PATH Data Server:

1. Automatic initial health checking for completion of the data to find out if there are any significant data errors and inform PATH in case any attention/care is necessary
2. Loading the checked data to Google Drive of UC Berkeley
3. Calculation of (intermediate) Meta-data for the convenience of extensive data analysis at later stages
4. Share the data with FHWA and the Independent Evaluator by uploading the data to US DOT's Secure Data Commons (SDC).

The Data Management Plan also includes the details of the data to be collected, the list of metadata to be calculated and their potential application in later stage data analysis.

Human Use Approval Plan

The first step toward using professional truck drivers in the FOT was to get the approval of the Committee for Protection of Human Subjects (CPHS), the Institutional Review Board (IRB) for U.C. Berkeley. The project team obtained the approval in the first year of the project. This dictates how the project can legally recruit the professional drivers for FOT, how to respect the driver's human rights, how to protect the driver's privacy including driver's real ID, and some collected data related to driver personality and behavior. With those regulations in mind, the project team developed feasible plans for driver recruitment, incentives, questionnaires, training, testing the trained drivers for qualification of CACC truck operation, and obligations during the FOT, which include what the driver must do, what the driver must not do, and what the driver can do optionally.

Partnership and Outreach Plan

The Partnership Plan includes the formation and maintenance of the partnerships through the project performance period. The partnership is critical to the success of the project from the CACC implementation through the FOT. The partnership with Volvo would support the implementation of the CACC system on the trucks, which are mainly the interface with the J-1939 Bus for data reading and control, which required some Volvo truck proprietary information. The partnership with Bendix made it possible to access brake control and the perception data from the kit of the fused radar and video camera. The partnership with state DOTs, law enforcement agencies, and trucking associations in the four states (California, Arizona, New Mexico and Texas), were necessary for the operation of truck platooning on Interstate I-20 and I-20 in those states since (a) the operation of truck platoon will be different from that of traditional trucks, and (b) shorter inter-truck distances needed to be reconciled with the traditional state regulations/law. Additionally, those CACC trucks would have to interact with other traffic and be subjected to the speed-limit and regulation of weigh stations.

Chapter 1. Introduction

1.1. Background

This Comprehensive Deployment Plan is a project deliverable in Phase 2 of the Federal Highway Administration (FHWA) Truck Platooning Early Deployment Assessment Project. For Phase 1 of this project, California PATH and its partners, Volvo, Westat, and Cambridge Systematics[1] developed a concept and proposal for a truck platooning field operational test (FOT) along the I-10 corridor from California to Texas. The project has advanced to Phase 2, aimed at conducting the FOT of truck platooning on the corridor with our fleet partner Roly's Trucking.

PATH and its team have built upon a previous truck platooning effort funded under the FHWA Exploratory Advanced Research (EAR) Program and subsequently tested under U.S. Department of Energy (DOE) funding. For the earlier EAR project, PATH and Volvo designed, developed, implemented, field tested, and demonstrated a three-truck platooning system that utilized Cooperative Adaptive Cruise Control (CACC) technology. That system was test driven safely for hundreds of hours on test tracks and public roads by a variety of truck drivers. CACC is a driver assistance technology that controls the speed of a vehicle while still requiring the driver to steer. The PATH team has refined the system to make it suitable for the Phase 2 FOT.

In Phase 2, the PATH team equipped four new Volvo trucks with CACC technology and a suite of data collection equipment. After the trucks were equipped and tested by PATH, Roly's Trucking planned to integrate the four trucks into their daily fleet operations between terminals in Southern California and Fort Worth, Texas. During operations, the four trucks would be split into a three-truck platoon (all assisted with CACC technology) and a "reference" truck to be driven separately without CACC along the same route at about the same time to provide a baseline for comparison with the platooned trucks. In some cases, when freight demand requires fewer trucks, a two-truck platoon could be used in place of the three-truck platoon. The FOT was planned to run for 12 consecutive months, with data continuously collected and shared with USDOT and their Independent Evaluator (IE) during the test.

1.2. Purpose

The purpose of this Comprehensive Deployment Plan is to describe how the PATH team planned to conduct the 12-month FOT of truck platooning with fleet partner Roly's Trucking and to capture, monitor, report on, and maintain the data and the calculated performance measures that have been identified for the FOT. This document builds on the previous Phase 2 deliverables (see References 8-11) and is an update to the technical proposal submitted at the end of Phase 1 (see Reference 7).

11

1.3. Scope

This document first summarizes the technical approach to the planned FOT including descriptions of the CACC system, trucks, drivers, and some important safety considerations for the FOT. Next, this report presents the experimental design, which cover three stages of testing: system acceptance test (SAT), operational readiness test (ORT) and the FOT. This is followed by the data management plan including a discussion of the data, performance measures, and data management procedures that are critical to the Phase 2 field test. This report concludes by covering the PATH team's approach for obtaining human use approval and building partnerships to ensure a successful project.

As part of the process of developing the Phase 2 Test and Evaluation Plan (see Reference 11) and related deliverables, the PATH team worked closely with the IE to develop the key performance measures and data management plan needed for the Phase 2 field test. PATH also coordinated closely with fleet partner Roly's in the development of this plan to get their concurrence on the experimental design and the data management plan for the Roly's facility. Finally, PATH coordinated with state departments of transportation and law enforcement in each of the states where the FOT was to be conducted including California, Arizona, New Mexico, and Texas, as described in Section 6.

1.4 References

The following documents are provided as references for this Comprehensive Deployment Plan deliverable.

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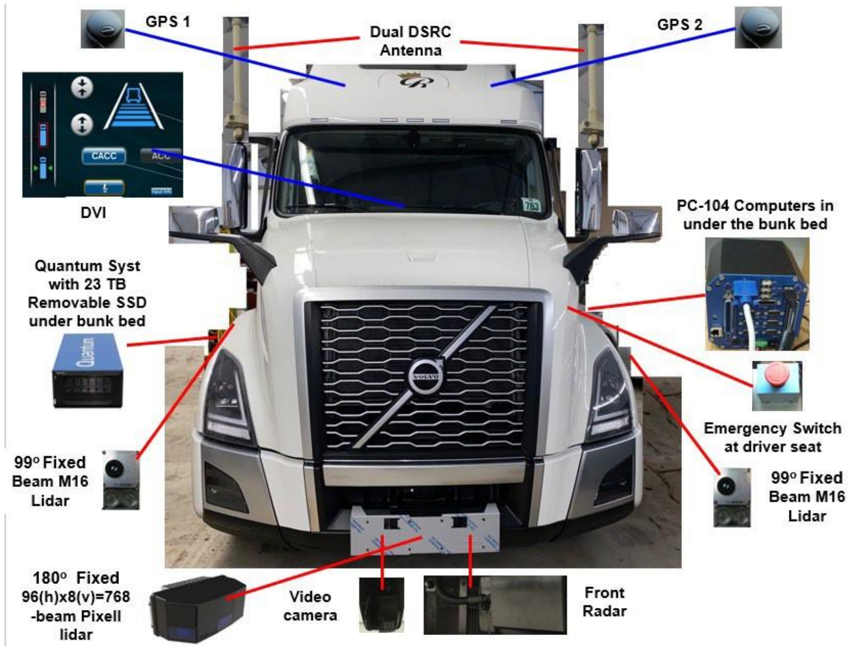
Chapter 2. Technical Approach for CACC Implementation

2.1 Overview

The PATH team enhanced the CACC technology developed under the earlier FHWA EAR project and installed it on four new Volvo model VNL-64T760 trucks purchased by Roly's Trucking. After a period of rigorous testing (see Chapter 3), Roly's planned to integrate these trucks into their daily operations along the I-10 corridor between Rancho Cucamonga, California and Fort Worth, Texas. All of the trucks would be driven by Roly's drivers, three in a platoon and the other independently to serve as a reference truck in the experiment. The trucks were equipped with some additional instrumentation beyond that needed for the basic in-platoon vehicle following control. The additional instrumentation is needed to observe driver behavior and to measure the movements of adjacent vehicles to enhance understanding of the interactions of other traffic participants with truck platoons and to evaluate the safety impacts of truck platooning. All of the data needed to answer the key research questions were to be captured and managed by PATH and shared with USDOT and their IE as described in the Data Management Plan (as seen in Chapter 4) System Description.

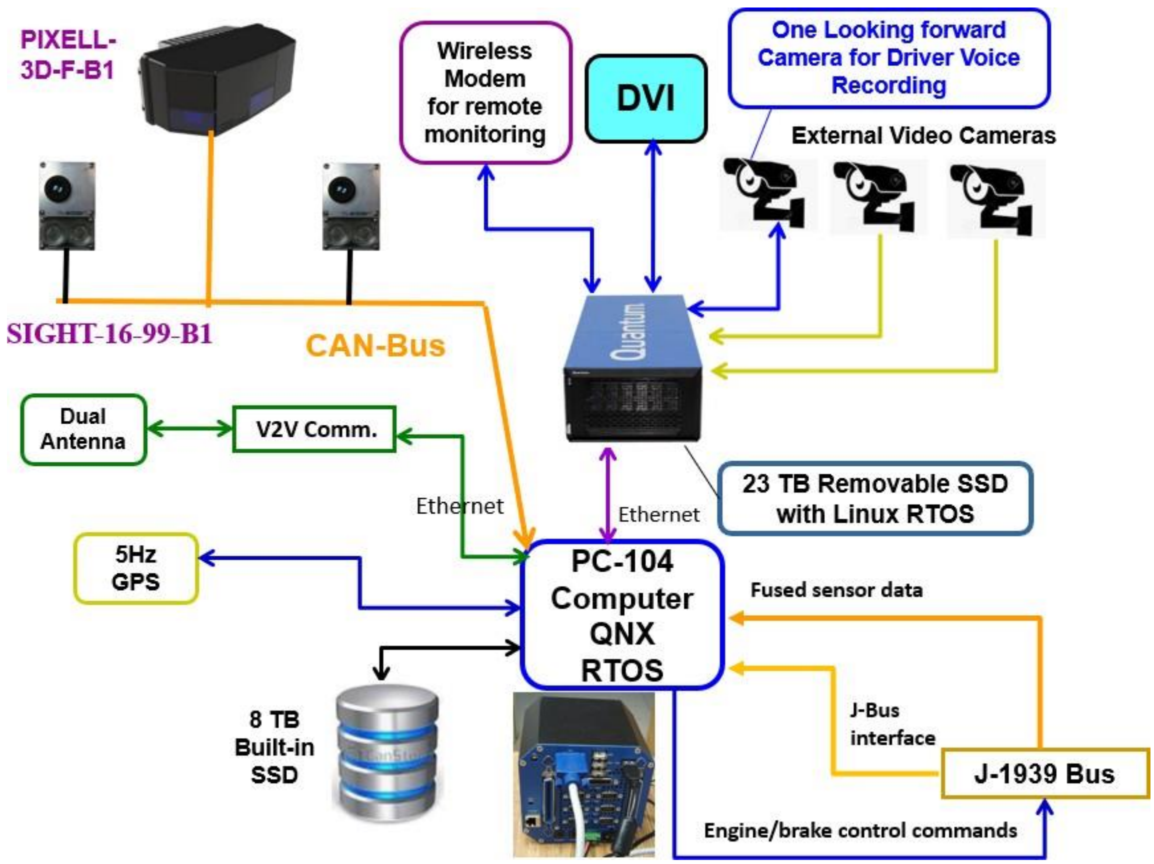
See Figure 1 below. This figure depicts the overall hardware components of the control system and the data collection system. It includes the main control computer, three fixed beam lidar, 5 Hz GPS units and the V2V communication with dual antenna, and the Quantum data collection system with 23 TB solid drive.



Source: Lu, 2022

Figure 1. CACC Truck System Hardware

Figure 2 shows a graphical depiction of the CACC control system architecture for the FOT. The Phase 2 system architecture is composed of two parts: (a) control system anchored by the PC-104 computer with QNX 7.0 as the real-time operating system (RTOS); and (b) data collection system anchored by the Quantum Data Collection system, with an internal computer with Linux as the RTOS as shown below. This figure depicts the overall hardware structure of the control system and the data collection system. It includes the main control computer which runs QNX as the Real-Time Operating System which receives engineering data from the J-1939 Bus, three fixed beam lidar, 5 Hz GPS unit, three video cameras, and the V2V communication with antenna. It is also linked with the Quantum data collection system with an internal processor running Linux as the RTOS. The latter collect video data and runs DVI and real-time monitoring program through the wireless modem. It also receives and saves all the engineering data from the control computer.



Source: Lu, 2022

Figure 2. CACC Control System Architecture

The system architecture components shown in Figure 2 and their intended functions are described below.

1. Control Computer (Computer 1):
    - Industrial PC-104 computer with QNX 7.0 as the RTOS to collect data and determine engine and brake control commands
    - DSRC communication radios and dual antennas
    - Safety Interrupt (or Emergency) Switch
    - A 5 Hz update GPS (Global Positioning System) unit for time synchronization and location determination
    - An X-PC computer (from Volvo) for data processing to fuse the radar and video camera data from the production ACC systems on the trucks for front target detection and tracking
    - 8TB built-in SSD for engineering and sensor data buffer
    - Fixed beam lidar units for detection of short distance aggressive cut-ins by other vehicles. (These were not used in the FHWA EAR project but will be necessary for the FOT.)

- All the components will be directly connected with cables for reliability

2. Data Collection Computer (Computer 2):
   - Quantum Data Collection System with internal processor with Linux as the real-time operating system and 23 TB Removable SSD for storing all the data
   - Continuously recorded video data and driver monitoring data
   - Recorded driver voice data for any special events and abnormal situations
   - Touch-screen computer for driver vehicle interface (DVI)
   - Wireless modem for remote system monitoring

The two computers are directly linked with cables and communicate with each other for synchronization, timestamping, association of data with a specific driver, and for the coordination of all the processes run on them. The supporting software mainly includes the interfaces between the hardware components.

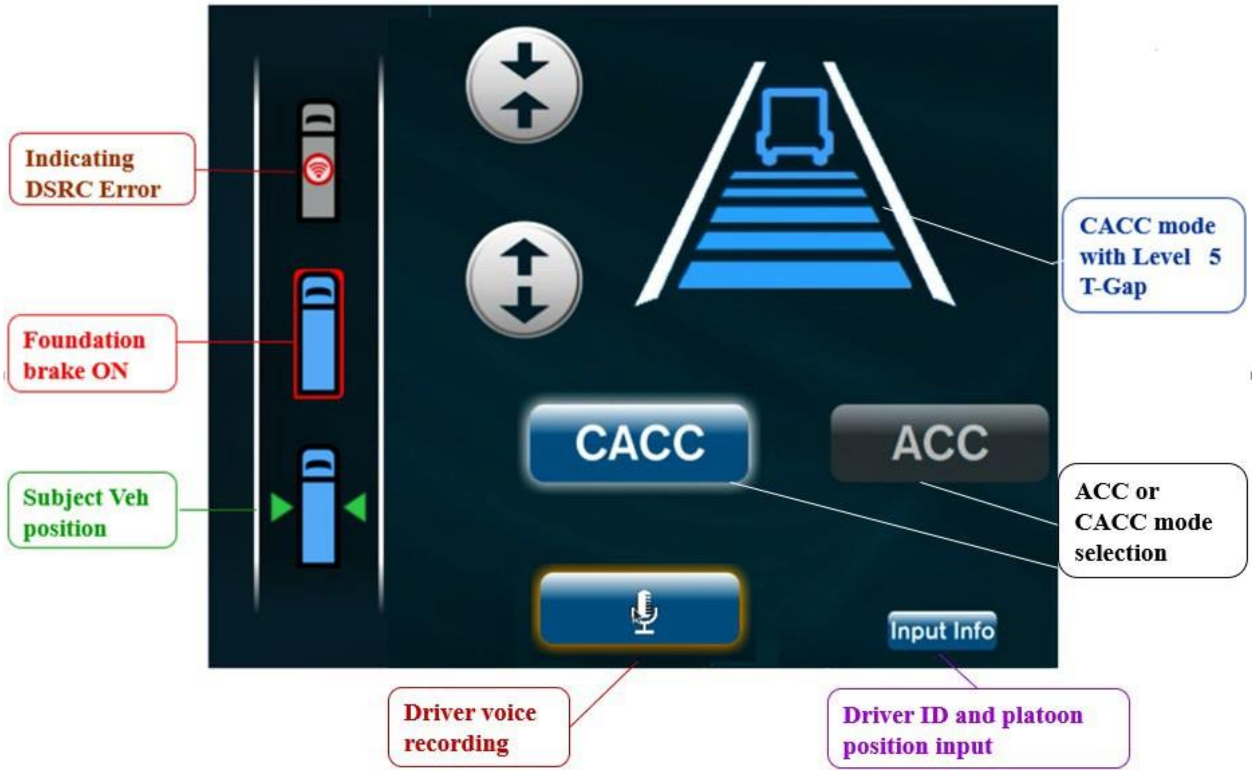
The primary task of the central PC-104 control computer is to support real-time data exchanges, with the PC-104 reading information from the other components and sending back the commands, if applicable, to those components. It also includes the timing and scheduling of the processes running on the PC-104 in real-time like the director of an orchestra, It determines which process needs to run earlier and which one needs to run later and how long it is expected to run. It is also responsible for the management of the data exchange by temporarily storing the data in a database and feeding the data to the control system. All those functionalities of the software have been built in submodules which are running in the RTOS QNX-7. The QNX system was initially developed for real-time and embedded control purposes, with a small kernel for high speed and reliable command execution. It has similar origins to the UNIX operating system.

The data collection tasks are handled by the Quantum Data Collection System which has an internal computer using Linux as the RTOS. It is mainly used for additional sensor data collection, running the DVI, and for remote monitoring as depicted in Figure 2.

The updated design also includes some changes in system hardware and software for system reliability improvement. This includes replacing the previously implemented Wi-Fi connections among different components of the system within the truck with hard-wired cables.

The project team revised the previously developed the DVI to enable the driver to readily understand the state of all three trucks that are driving together and to safely operate in public traffic. Two additional buttons have been added to the DVI as shown in Figure 3: (a) driver's voice recording; and (b) driver and platoon position information input.

See Figure 3, below. This figure depicts the DVI display. On the left panel, it displays the number of trucks involved in the platoon and their fault status. As an example, the two green arrows indicate that this is the display on the third truck, and it has a communication error with the lead truck. The red boundary around the truck icon means that the second truck is using service brake, either by the driver manually or automatically by the control system. On the right panel, the arrow buttons can be used by the driver to select the time-gaps indicated on the upper right – the number of horizontal bars displays the level of the time-gap. The middle CACC and ACC button allows the drivers to select the driving mode. They also indicate the current mode by illuminating the applicable button. The lower left button allows the driver to press and record any voice such as the driver report of any incident and abnormal situations. The lower right button allows the driver to input the Driver ID and current platoon position of the subject truck if the system cannot determine it due to GPS signal errors.



Source: Lu, 2022

Figure 3. PATH CACC Truck DVI

The DVI design principles are simple and intuitive, but also informative. It is believed that such a design is easier for driver adaptation. The preliminary driver behavior tests in the EAR project showed that the DVI design was well understood by drivers. For the Phase 2 project, all drivers were to be trained to fully understand and operate the new DVI prior to driving the CACC-equipped trucks. In addition to the functionalities indicated in the figure, some other DVI features include:

- The left pane shows the number of vehicles in the CACC string (or platoon)
- Green arrow indicates the subject truck
- Rectangle indicates the service brake application of that truck
- Red wireless logo indicates the loss of communication of the truck with respect to the subject truck
- The right panel shows the ACC and CACC mode selection button
- Both ACC and CACC modes have five time gap levels available for driver selection as depicted in Table 1.
- Driver voice recording switch – it will flash when it is ON

- Information input button, which allows the driver to input the unique driver ID and platoon position of the subject truck at the start of each trip segment

See Table 1, below.The numbers shown in Table 1 were the time gaps used in the previous FHWA EAR Truck Platooning project. As a point of comparison, the Volvo default ACC minimum time gap is 2.0 seconds. This number is usually different for different manufacturers. PATH considered using larger time gaps for both ACC and CACC in the FOT, with the plan to make the final decision about gap sizes during the system acceptance testing.

Table 1. Time Gap Settings for ACC and CACC Modes used in EAR project

ACC Level	ACC Time Gap [s]	CACC Level	CACC Time Gap [s]
1	1.1	1	0.6
2	1.3	2	0.9
3	1.5	3	1.2
4	1.7	4	1.5
5	1.9	5	1.8

2.2.1 CACC-Enabled Trucks

The trucks chosen for the FOT are four new Volvo model VNL-64T760 truck tractors with 500 horsepower engines and a 12-gear electronic transmission, engine brake, and service brake. These trucks are similar to the ones used in the previous EAR project.

The four trucks to be used in the FOT were purchased by Roly's Trucking and leased to PATH for the duration of the project. PATH equipped each truck with a CACC system including the major components linked with the Control Computer which are shown in Figure 2. After equipping the trucks, PATH conducted some basic system acceptance tests (SATs) with PATH drivers on local roads and then planned to move to driver acceptance tests using Rolys' drivers. After the driver acceptance tests, the PATH team planned to fine-tune the CACC and add data acquisition systems (as shown in Figure 2) on the trucks and then proceed to the ORT. The testing plans are described in more detail in Chapter 3.

2.2.2 Drivers

PATH planned to work with fleet partner Roly's Trucking to recruit a pool of drivers for the field test. The CACC system can be operated by any professional truck driver with some basic training. PATH discussed with Roly's regarding the best way to attract and select good drivers for the FOT by offering them enhanced status and extra pay to compensate for their additional responsibilities. Based on previous field-testing experience, the training was expected to include several hours of classroom training and several hours of hands-on training and practice driving the CACC-equipped trucks. Following the training, the drivers would be able to freely select driving mode (manual, ACC, or CACC) and time gaps using the DVI. However, the drivers still need to watch out for the traffic on the road and be prepared to take over the control whenever necessary for safety. This decision making was incorporated into the training program. Aside from these factors, there were no additional limits on the drivers.

The CACC platoon control system is activated by the driver using the same DVI interface on the steering wheel control stalk as the production ACC system on the Volvo trucks (Figure 4). The driver was given the choice of five different gap settings, with shorter gaps available when in the CACC platoon control mode, as shown in Table 1. A human factors field experiment (under the EAR project) using similar trucks and this driver interface showed a significant diversity in the preferences of the drivers for gap selection, indicating the importance of providing a reasonable range of choices for the drivers. With this range of choices available for the planned new field test, it would be possible to obtain more extensive data regarding how drivers choose to use the platooning technology under various traffic and environmental conditions. Although PATH tested significantly shorter gaps than these on a closed test track, it is believed, based on a safety analysis, that the minimum time gap of 0.6 s is the shortest that would be prudent to use in mixed traffic on public highways.

See Figure 4, below. This figure depicts the activation buttons of the integrated ACC/CACC system. Pressing the CC button at the top initiates the internal system without activation. Pressing the middle toggle switch/button is for the ACC/CACC activation and setting speed. Push forward and pull backwards on the middle toggle switch to increase or decrease the set-speed.

Source: Lu, 2022

Figure 4. CACC System Operation Control On the Steering Wheel

The default ACC vehicle following control logic built-in by Volvo was purposely deactivated, while retaining the original sensor fusion and target detection logic, and the operation switch on the steering column stalk was to be used for CACC operation. The new ACC control logic was developed for easier integration with CACC and for smoother transitions of the system when it is necessary to switch between different driving modes: manual, CC, ACC and CACC. All the following functions of the original ACC operation were kept for driver's easy adaptation:

- ACC/CACC ON
- ACC/CACC OFF (going to manual)
- Resume: going back to ACC/CACC mode if the control has been deactivated for any reason

The driver could also push down the emergency button on the right side of the seat to deactivate the automatic control mode, which essentially cuts off the physical connection between the PC-104 computer and the J-1939 data bus.

Such a straightforward implementation from the driver perspective is feasible thanks to the real-time access of the operation switch signal information from the J-1939 data bus.

2.2.3 Emergency Coordinated Braking Capability

PATH and Volvo developed an emergency coordinated braking capability using the DSRC V2V communication. It is felt that this capability will be very useful particularly for short time gap operation of those trucks in automatic control mode. It is designed with the following strategy: if any of the trucks uses its service brake, activated either by the CACC or manually by the driver, the following truck(s) will automatically activate their service brake with at least the deceleration level of the preceding truck. For example, if the first two trucks apply service brakes, the third truck will apply the service brake with the maximum deceleration rate of the first two trucks plus an offset. Therefore, during the emergency deceleration process, the three trucks will spread out their following gaps. The offset in deceleration rates is designed to be modest so that it doesn’t cause a safety issue with the following traffic.

This maneuver was quantitatively tested with three CACC trucks (total combination weight of 22,000 kg each) at Crows Landing, a former NASA airfield, located in Stanislaus County, California, with the following scenarios:

- Coordinated service brake for Truck 1 using deceleration commands of 1.0, 1.5, 2.0, 2.5, 3.0, 3.5 m/s^2
- Coordinated service brake for Truck 1 with each of the above service brake commands plus 100% engine braking

The service brake actuation switch signal and engine brake percentage command were transmitted to the following trucks via DSRC. The tests showed reasonably good and reliable performance in the sense that the following two trucks responded to the action of the first truck immediately. The inter-vehicle distance changes between the three trucks have not exceeded 3 meters (all in the positive direction) in testing since adopting a distance regulation strategy to modulate the braking deceleration commands.

2.2.4 Modifications to CACC System since EAR Project

There are three important changes that have improved CACC system performance since the previous FHWA EAR project. The system improvement has been achieved with support from a separate project funded by Caltrans, which is gratefully acknowledged. The technical achievement was accomplished with the support of Volvo Group engineers in Sweden and in the United States. The major modifications include:

Speed control range

Previously, the speed control range was limited to 13 mph and higher due to the transmission control limit. With the newly implemented system modification, CACC operation is available at speeds down to zero, allowing it to be operated in stop-and-go traffic if desired (but the FOT plan assumes operation only at traffic speeds of at least 35 mph). The maximum speed for CACC operation is limited to 65 mph.

Service brake automatic control

With the previous CACC system, automatic control of the service brake would frequently deactivate the control system. This is still a problem for the Volvo VNL 760 truck. This improvement facilitates the operation of heavily loaded CACC trucks on roads with negative grades.

One fixed beam LiDAR Pixell

One fixed beam LiDAR Pixell which has 180^{o} field of view has been added in the front for the detection of short-distance aggressive cut-in maneuvers by other vehicles. Such maneuvers have been observed many times in previous tests. These cut-ins cannot be detected fast enough by the currently used radar sensor due to its limited angle field-of-view. The PATH project team believes that adding such sensors will enhance the safety of the FOT by enabling earlier system detection and response to cut-ins.

Collision Mitigation System

The new VNL-760 Volvo trucks were equipped with a Bendix Collision Mitigation System. Its functions include: (a) a beep warning activated for the driver at lower collision risk levels; (b) automatic braking activated to avoid/mitigate collisions if the risk goes over a certain threshold. The Bendix system runs in the background of the CACC system with a higher level of priority so that the CMS takes over when necessary. PATH believes that this provides the highest level of safety to the overall system.

2.3 Key Safety Considerations

Under the FHWA EAR program project on truck CACC development, PATH researchers incorporated a number of safety considerations in system design and implementation. These safety measures have been expanded upon under the current project in consultation with Volvo safety engineers. A key principle of the PATH CACC system is that it is not designed to replace the driver control. Instead, the CACC system is only a driver assistance system which augments the driver during operation. The driver must still steer the truck and always pay attention to the traffic in front and nearby for safety purposes. The integrated ACC/CACC system was designed for safety in the following three aspects:

- Safety from system-level control
- Safety from driver behavior and interface with the vehicle
- Safety from lower-level vehicle control.

The integrated ACC/CACC typically acts in the following manner: the first truck in the string/platoon operates in ACC mode and the second and third trucks operate in CACC mode. Note that our system is flexible enough to allow the lead driver to operate in manual or ACC mode, depending on their preference and the conditions, but ACC is recommended. The feedback control structure for ACC and CACC are the same. It is only the feedforward part of the two control strategies that are different. ACC depends on front sensor detection and CACC depends on both front sensor detection and information passed by DSRC. Both ACC and CACC have five levels of time gap (T-Gap) selection. The driver selected T-Gap for a given speed reflects the driver’s confidence in the ACC/CACC operation at that specific time and place, taking into account safety factors from the driver’s perspective. The three safety design aspects (system and control, driver behavior and interface, and lower-level control) are important features of the PATH CACC system.

Chapter 3. Approach to Progressive Test and Experimental Design

This chapter presents the overall testing approach and general experimental design developed for Phase 2 of the truck platooning assessment project. The main purpose of the experimental design is to define how the tests will be structured to capture the data that are needed to inform the performance measures that help answer the key research questions. This is not a classical "statistical design of experiments" approach that would be followed for a tightly controlled experiment because it is intended as a naturalistic driving test to capture real-world use of the system. Another reason for the experimental design is to explain how human subjects (study participants) will be involved in the project in order to obtain human use approval (see Reference 10). PATH has planned for three stages of testing that will involve professional truck drivers (human subjects) in the project: SAT System Acceptance Tests, ORT and FOT. These are described at a high level below.

Each of these different stages of tests are associated with different tasks in the project work plan (see Reference 7), as shown in Figure 5. Each stage of testing is denoted by a blue box. This figure schematically shows the sequence of CACC development followed by System Acceptance Tests (Engineering development verification in Task 5.10 and Driver acceptance test in Task 5.11), followed by the Operational Readiness Test in Task 7.2 and the Field Operational Test in Task 8))

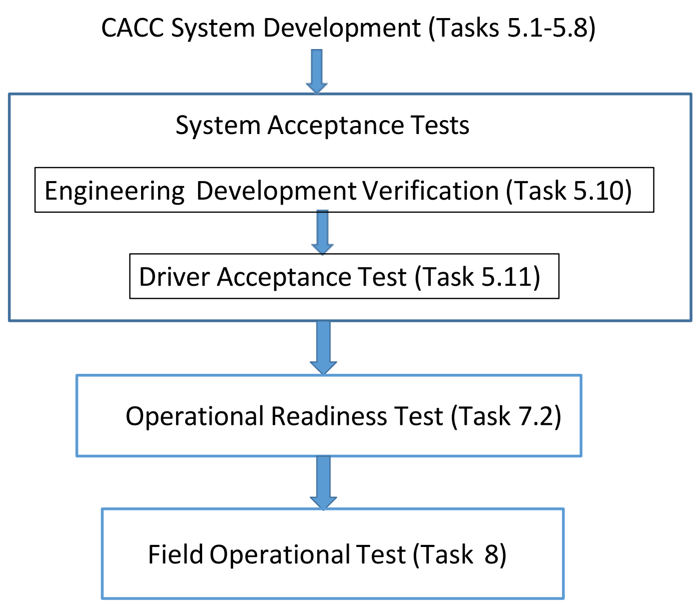


Figure 5. Relationship among Planned Testing Stages and Tasks

3.1 System Acceptance Test

The System Acceptance Test (SAT) includes two major subcomponents: engineering development verification and Driver Acceptance Test (DAT). The main portion of the SAT is a technical verification of the primary engineering development work - implementing the CACC control system on the four new Volvo trucks. This CACC control system was already developed and tested extensively on an earlier set of three Volvo trucks, accumulating hundreds of hours of safe driving experience by multiple truck drivers on public roads and closed test tracks, so the focus of the SAT testing is on the integration with the new truck platform and on the changes that were made for the FOT.

The SAT would first be conducted on closed test tracks and then culminate with public road testing in and near the San Francisco Bay Area. These engineering tests would be conducted using PATH drivers for a range of traffic conditions and road grades that approximate the conditions expected for the FOT between southern California and Texas to the extent possible (with the exception of the higher truck speeds that are not legal in California). Although the early testing during the implementation and debugging of the CACC control system was done using truck tractors only, the majority of the SAT (including the DAT) was done with trailers to provide the most realistic testing conditions, and trailers loaded within the range of typical loads that Roly’s Trucking hauls between California and Texas. The engineering data acquisition system was used to collect a full set of diagnostic data on the performance of the CACC system.

After proper technical performance has been verified by means of these local SATs, the next step would be the DAT using drivers from Roly’s Trucking. The purpose of the DAT is to test the usability of the system with real world drivers. The results of the DAT would be used to make final refinements on the system to ensure good usability by regular truck drivers based on considerations such as:

- Overall dependability of the truck platooning system as perceived by drivers
- Ease of understanding how to use the system (activation, deactivation, making adjustments, recognizing potential problems)
- Driver interface ease of use, especially touch screen usage and visibility under a wide range of ambient lighting conditions
- Driver training procedures and questions that arise during training
- Identifying potential driver misunderstandings or misuses of the system by riding along with the drivers
- Driver comfort and confidence in system in response to cut-ins
- Driver comfort with system response on road grades
- Any issues associated with long-duration driving with the system
- Driver preferences regarding changing positions within the platoon (how frequently they prefer to change positions)
- Driver interactions with the SmartCap headband system and Jungo driver monitoring system to determine if there are any acceptance or usage issues.

Some of this data would be collected during post-trip questionnaires and interviews with the drivers, some collected by PATH staff as they ride along with the drivers, and some assessed through post-trip analysis of the engineering data. The DAT would allow us to collect data from four drivers and treat that data as if it were collected on a typical FOT round-trip, although this test would cover an 850-mile distance (round trip between PATH in Richmond and Roly's in Rancho Cucamonga). That is, PATH should be able to gather Jungo event email alerts, perform basic quality control (QC) checks on camera aim and operation, event sensitivity and validity, and collect data for post-hoc analysis after the trip is complete (including full-trip video). Westat would develop aggregation and visualization tools to quickly see the data collected from the Jungo and SmartCap systems with time-based and/or location-based plots of distraction and fatigue data for purposes of QC and exploration of the collected data by vehicle, by driver and by multi-truck-trip. This test would allow us to see those tools in action and to confirm that the knitting together of video and digital data are feasible and working properly.

As part of the DAT, drivers would also answer interview questions regarding the acceptability of both the Jungo system and the SmartCap system. These questions address potential concerns about comfort, privacy, hygiene, and effort required to use the systems. The DAT would also provide an opportunity to collect data from both systems, understand the drivers' comfort with us collecting this data and to verify the content, format, QC, and reduction post-processing routines to be used on the data as it comes in from the FOT.

Because the DAT would be the first time that drivers will be using the CACC system for more than a few hours at a time, it was important to make the DAT a long-distance drive, so that any potential problems that may not arise during short-distance drives can be identified. In particular, PATH would monitor the system closely for any potential safety issues such as the system not responding appropriately to cut-ins or drivers not disengaging the CACC system in dangerous situations. Furthermore, because the intended users during the FOT would be drivers from Roly's Trucking, it makes sense to focus this test on the same population of drivers. This would simplify the driver recruitment process and provide a "dry run" for the recruitment of drivers for the larger test.

The plan for the DAT is therefore structured around a round-trip drive between the PATH development site in Richmond, CA and Roly's Trucking in Rancho Cucamonga, CA. These sites are slightly more than 400 miles away from each other. With the California truck speed limit being 55 mph, and the route including some portions in both San Francisco and Los Angeles urban area traffic, these drives should take between 8 and 10 hours each way, providing a good representation of long-haul driving. Since many truck drivers on this route (mostly on I-5) drive significantly faster than the 65 mph speed limit of the platoon, it also gives the drivers a similar experience to what they should expect on the field test route, where the CACC-equipped trucks would be limited to 65 mph, even though the speed limit for trucks in Arizona and Texas is 75 mph.

The steps in conducting this test would therefore be as follows:

1. Develop detailed test protocol for approval by U.C. Berkeley Committee for Protection of Human Subjects (CPHS), the Institutional Review Board (IRB) for this project. This includes the driver recruitment process at Roly's Trucking, the recruitment documentation and release form, the data acquisition and retention procedures, and the pre-trip and post-trip questionnaires.

2. Recruit drivers for this test using documentation about the test provided to Roly's for them to distribute to their drivers, followed by a visit to Roly's headquarters by a PATH staff member to meet with drivers and sign up volunteers.

3. Four volunteer drivers fly to the Bay Area for training and familiarization with the truck CACC system at PATH and answer the pre-drive questionnaire. All four volunteers drove from PATH in Richmond to Roly's in Rancho Cucamonga, accompanied by four PATH staff in the respective passenger seats, who would observe their use of the system, answer their questions about the system, and manage the onboard data acquisition system to ensure that test data are being recorded properly. The PATH staff would encourage the drivers to change positions in the platoon and to alternate between driving in the platoon and in the reference truck role if the drivers do not decide themselves about changing positions, to try to ensure that each driver experiences each driving role. The drive would be scheduled to include a mixture of daylight and dark conditions to identify any important differences in driver preferences and to check for any problems with display visibility or brightness.

4. After arrival at Roly's (the same day or next day, depending on specific arrival time of day), the trucks would be shown to Roly's management and operations staff as well as other drivers who would be potential volunteers for driving in the subsequent FOT. PATH staff would use this occasion to sign up drivers for the FOT.

5. The four original drivers and PATH staff drive the return trip from Rancho Cucamonga to Richmond, again aiming for a mixture of daylight and dark conditions. After arrival, the drivers fill out the post-trip questionnaires to capture their opinions about the CACC system, specifically to identify any recommendations for changes that should be made prior to the FOT. The drivers then make the return flight to their home base at Rancho Cucamonga.

6. The PATH staff document their notes (including event timing) on issues they observe during the test that point toward additional changes that should be made to the system. They also analyze the engineering data recorded during the tests to identify any technical issues associated with the performance of the CACC system or the driver monitoring and data acquisition systems. The Westat staff analyze the driver monitoring data to identify any issues that need to be resolved with those systems in preparation for the FOT.

The data collected and lessons learned from this test would be documented in the SAT Results Report to FHWA and used to guide modifications that need to be made to the systems prior to the FOT. All system modifications resulting from the DAT findings would be made prior to the start of the ORT.

3.2 Operational Readiness Test (ORT)

The ORT would be conducted as a "dress rehearsal" for the FOT, combining all the elements needed for the FOT to make sure that they work as planned. Demonstrating that they work as planned would be a vital input to the "Go/NoGo" decision that FHWA needs to make before the FOT data collection can begin. First, PATH would provide USDOT, the IE and any other interested parties an opportunity to ride along in the CACC-equipped trucks on a to-be-determined segment of freeway near the Roly's facility. This would give USDOT and the IE an opportunity to experience how the trucks operate in mixed traffic while in platooning mode and ask questions to the PATH team. If USDOT is comfortable with how the trucks perform in this initial demonstration, then PATH and Roly's would commence with the full ORT as outlined below.

The ORT would involve driving the three-truck platoon and reference truck on the round trip between Rancho Cucamonga and Fort Worth, with full use of not only the CACC control system but also the engineering data acquisition and driver monitoring systems. Data collected during the ORT would be shared with USDOT and the IE after the test is complete. The drivers who were previously trained in use of the system for the DAT would be assigned to drive the trucks for this test, and the FOT questionnaires would be administered to the drivers and fleet operations staff to determine whether the questions are formulated properly to elicit clear responses. The details of the test route, vehicle operations, and driver-related considerations are described in the next section, covering the FOT.

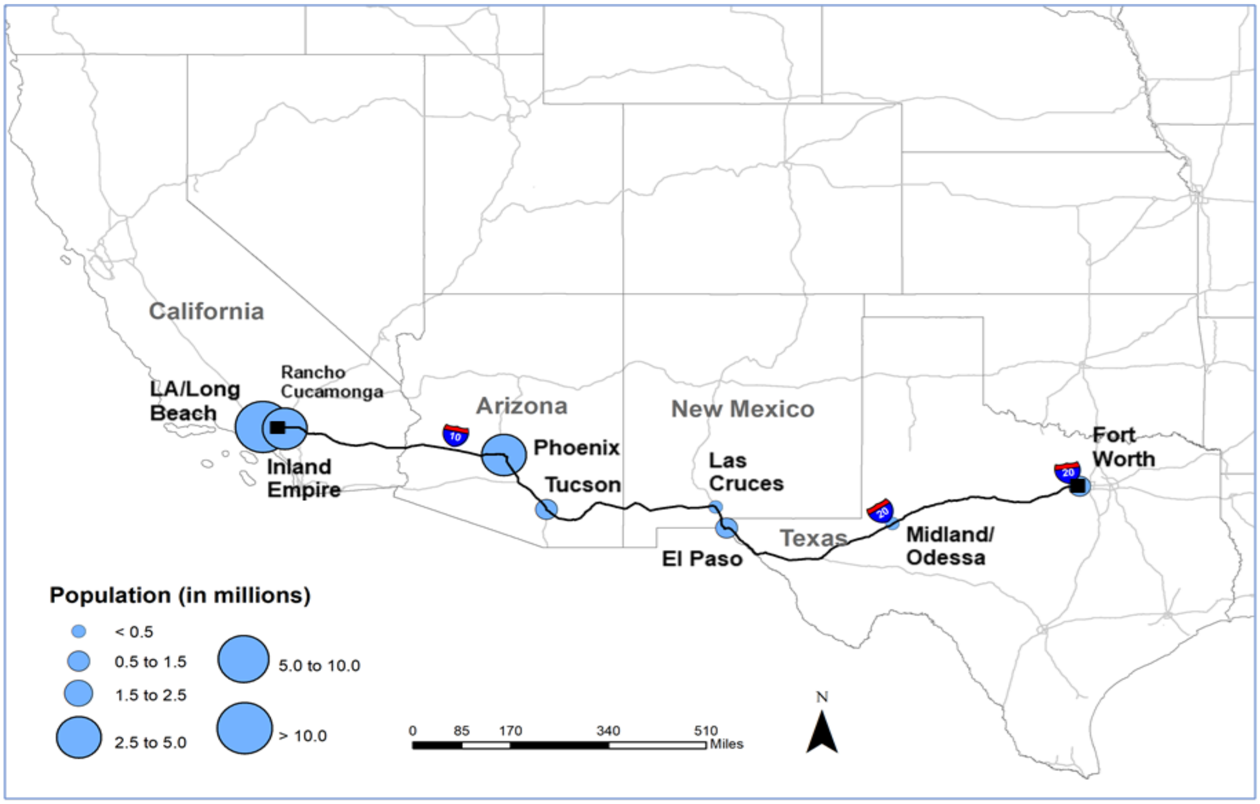
The analysis of the data from the ORT would be focused on ensuring that the CACC control, driver monitoring, and data acquisition systems are working correctly under the full-scale FOT conditions and that the drivers and fleet operations managers are able to conduct the necessary platoon driving and data management operations. Drivers and fleet operations managers would be interviewed after the ORT to get their opinions on all aspects of the system. This would be a qualitative rather than quantitative assessment, focused on:

- Identifying technical failures that need to be fixed
- Identifying performance problems that need to be fixed
- Identifying driver concerns that need to be addressed
- Identifying fleet operations problems that may require modifications to the experimental plans
- Identifying limitations in the questionnaires that need to be remedied before the questionnaires are used on the participants in the FOT.

3.3 Field Operational Test (FOT)

The FOT has been designed to produce authoritative data about the applicability of truck platooning in a real-world long-haul trucking application with minimal disruption to the normal truck fleet operations. It is based on providing the fleet operator partner in the project, Roly's Trucking, with four instrumented truck tractors capable of driving in platoons that they can integrate into their normal interstate freight operations. The selected test route is a 1,400-mile trip that includes a segment of the I-10 corridor between Roly's main terminal in Rancho Cucamonga, California and west Texas, and then a stretch of I-20 to Fort Worth (see Figure 6). This route is the busiest shipping route for Roly's Trucking, which runs dozens of trucks between southern California and Texas daily, carrying freight from a variety of origins in southern California to a variety of destinations around the Dallas-Fort Worth Metroplex, which means that there would be some naturalistic variations in the actual truck origins and destinations from one week to the next.

See Figure 6, below. This figure is a map of the southwestern US, with the FOT route indicated by a line following the path of I-10 from southern California, through Arizona and New Mexico to western Texas, where the route shifts to I-20 to Fort Worth. The urban areas of southern California, Phoenix, Tucson, Las Cruces, El Paso, Midland/Odessa and Fort Worth are indicated by dots of varying size representing their population categories.



Source: Lu, 2022

Figure 6. Map of Planned Truck Platooning Test Route

An important aspect of the experimental plan in the FOT is the use of one of these trucks as a “reference” truck that would be driven individually along the same route at about the same time as the truck platoon to provide a baseline for comparison with the platooned trucks. The reference truck would be dispatched simultaneously with the platooned trucks, or within a few minutes of the dispatch of the platooned trucks. PATH worked with Roly’s on the FOT dispatching protocols, which need to be flexible to adapt to varying freight movement requirements. For example, in situations when the eastbound loads are not all starting from Roly’s headquarters but some of them need to be picked up from different locations in Southern California, the dispatcher could arrange for all four trucks to meet at a rest stop near Coachella (about 90 miles east of Roly’s headquarters) to initiate the platooning trip. If there are significant variations in the loading of the trucks, the sequencing of the trucks in the platoon would generally be based on keeping the heavier ones toward the front and lighter ones toward the rear, but the sensitivity of the sequence to truck loading still needs to be determined. These dispatching and coordination details would be settled with Roly’s based on the practical experience gained in the ORT and early FOT trips.

PATH suggested the following strategy to guarantee such sequencing:

1. The initial sequencing would be arranged by the fleet operator based on the tonnage of the freight.

2. Once the CACC trucks are in a close proximity with DSRC available, the comparison of the total weights of the trucks will be available, so the displays can be used to indicate the would-be position of the truck platoon. The drivers may need to swap positons if necessary.

The drivers of the reference truck and the platooning trucks would be instructed to travel at the same speed and stay within a few miles of each other during the trip. PATH explored options for using the drivers' cell phones (in hands-free mode) to coordinate the position of the reference truck with the platoon during the trips, so if the reference truck gets too far separated from the platoon the drivers can call each other to stay in closer proximity. The dispatcher can also monitor the positioning of the four trucks during the trip and help them stay together. This means that all four trucks would experience the same traffic and weather conditions, and because they have the same data collection capabilities direct comparisons can be made between the platooned and non-platooned truck driving in multiple dimensions (measures of performance for the comparison are discussed in Chapter 4 and Appendix A):

- Fuel consumption
- Truck driver behavior, including attentiveness and fatigue
- Interactions with surrounding traffic and their safety implications
- Travel time between same origin and destination (considering time to get the platoon assembled at the origin).

This type of comparison is possible because Roly's Trucking dispatches multiple trucks per day along the same I-10 route between southern California and Texas; they are able to coordinate the dispatching times of the eastbound trucks so that they can be driven in two- or three-truck platoons plus the reference truck can be driven independently. The preferred configuration is a three-truck platoon, so those would be dispatched whenever possible. However, on some days (especially for the westbound return trips) the demand from Roly's customers may not support that many truck dispatches at one time, or one of the trucks may be unavailable, or not enough of the drivers from the FOT cohort may be available. In these cases, a two-truck platoon would be dispatched instead, so PATH expected to naturally acquire data on two-truck platoons to compare with the data on three-truck platoons without deliberately planning for two-truck platoon dispatches.

The experimental design includes keeping track of the extent to which the normal truck departure times would need to be modified to facilitate these coordinated departures, since that represents a potential disbenefit to the fleet operator. The westbound return trips may not be as well coordinated for simultaneous departures because of the pattern of Roly's trucking operations, but they believe that it should be possible to do coordinated platoon scheduling for at least some major portions of the return trips, and they planned to schedule the westbound movements of these trucks to maximize the opportunities for platooning. Even though this may limit the total amount of platoon driving time and mileage that can be accumulated in the test, it provides important knowledge about some of the practical constraints on use of platooning in real-world trucking operations that have asymmetrical traffic patterns and moderate rather than huge volumes of truck traffic on specific routes.

Estimating the fuel consumption impacts of the truck platooning requires considerable care in the comparison of the fuel consumption data measured on the platooned trucks and the reference truck. During our previous test-track experiments using the SAE J1321 gravimetric fuel consumption measurement method (the industry "gold standard"), PATH was able to calibrate the fuel injector measurements (available during the real-world field test on the trucks) against the gravimetric measurements, so PATH would be able to use the fuel injector signals that are recorded from the trucks as the basis for fuel consumption comparisons. These need to be further normalized for differences in the loading on the trucks, using the truck mass estimates available in real time from the truck transmissions. The fuel injector measurements from the trucks in each of the positions within the platoon can then be compared with the fuel injector measurements from the reference truck to determine the savings associated with the platooning. The original calibration work was accomplished in collaboration with DOE and Transport Canada, while testing the truck platoon at Transport Canada's Motor Vehicle Test Centre and is described in an SAE paper (see Reference 3).

The overall design of the experiment is aimed at understanding how truck platooning fits into a long-haul trucking operation, and the implications for the fleet operators and drivers. As such, it is not like a tightly-controlled test track test, in which experimental conditions are carefully controlled, because that would defeat the primary purpose of the project, which is to collect naturalistic real-world operational data. Therefore, the fleet managers and dispatchers and drivers would be encouraged to do their jobs as close to normally as possible, while still enabling the collection of data that can be used to assess the impacts that the truck platooning system has on their work.

3.3.1 Operational Considerations

In order to obtain a comprehensive set of data to reveal the real-world impacts of truck platooning, several important operational considerations must be accounted for in the experimental design. These include

- Planning for a full year of operation in order to collect a large quantity of data representing a full range of weather conditions for this route (while recognizing that as a southern route it is not likely to encounter much snow or ice).
- Including both daytime and night-time driving, to understand whether driver preferences for gap selection or other aspects of platoon operations may vary based on lighting conditions.
- Focusing on a fixed-route freeway operation to have good road geometry and road conditions, limiting the variability associated with operations on multiple types of roads.
- Within the interstate environment, using a route that includes significant grades as well as flat sections, and a mix of urban and rural traffic conditions so that platoon operations can be tested under these important variations. While most of I-10 is fairly flat, some modest grades are expected when passing through some of the higher elevations such as San Gorgonio Pass in California, the Sacaton Mountains in southern Arizona, the Peloncillo Mountains in southern New Mexico, and the Davis Mountains in Texas. Urban freeway driving conditions are expected when passing through the Phoenix, Tucson, El Paso, and Midland/Odessa regions on the way toward Fort Worth.

The Operational Design Domain (ODD) constraints for the truck CACC system do not need to be defined precisely (with a few exceptions) because this is a Level 1 driver assistance feature, so the ultimate decision about when and where to use CACC remains with the drivers, who will continue to perform the balance of the dynamic driving task even when CACC is active. The CACC system has been tested successfully in heavy rain and high wind conditions on the test track, but the drivers may prefer to drive manually under those conditions. The system is not intended for use on snowy or icy roads, so the drivers will be trained to avoid using it under those conditions. The system is designed for use on the normal range of freeway grades, but the drivers may prefer to not use it on the steeper positive or negative grades. The system is capable of operation in moderately congested traffic, but experience with a prior test indicated that drivers prefer to not use it when traffic becomes congested because of the extra workload associated with managing frequent cut-in maneuvers by other drivers, so operations for the FOT were specified to be limited to when the freeway speed is at least 35 mph. There are some locations (e.g., near interchanges in New Mexico) where manual driving is required because of state guidelines so these types of restrictions were incorporated into the training materials. The drivers would be able to use voice communication to coordinate their decisions about when and where to disengage and re-engage CACC control.

In the end, one of the important learning opportunities from the FOT was expected to be the improved understanding of the range of conditions in which long-haul truck drivers prefer to use the system (and the conditions in which they prefer to not use it).

3.3.2 Driver-related Considerations

In addition to the operational characteristics of the FOT, there are a number of considerations that relate to the drivers and their use as human subjects in the experiment. These include:

- Incorporating structured questionnaire-based interviews with drivers and dispatchers at Roly's Trucking to learn about their subjective attitudes and experiences with the platooning system before, during, and after the field testing. This would allow us to understand driver and dispatchers' perception and how they may change with growing familiarity with the system.

- Obtaining objective, state of the art measurements of driver drowsiness (fatigue) and attentiveness to their driving related tasks. PATH selected a dry EEG technology (SmartCap) for our fatigue measures because directly monitoring brain activity is recognized as the "gold standard" for determining levels of drowsiness and this technology has been used successfully in Australian applications over the last decade. Measuring driver distraction/attentiveness would be accomplished by using a Jungo system that collects video data of the driver's face using a camera fitted with infrared illuminators as well as video of the road ahead. This allows data to be collected during the day and at night. The face and road ahead video data would be synched and processed in real time using artificial intelligence algorithms developed by Jungo. Outputs include the driver's distraction events, head pose, eye closures, and gaze direction estimates. Data from the DAT and ORT would be used to fine tune these parameters.

- Designing this as a formal human subjects experiment because of the importance of truck driver behavior considerations in the assessment of truck platooning. This includes collecting baseline data about their driving behavior (especially vehicle-following gap preferences) before they experience the CACC system. This means that the drivers who drove for the DAT and ORT (discussed in Sections 2.1 and 2.2, respectively) would not be suitable subjects for this experiment, so additional drivers need to be recruited for this test.

The truck driver behavior research questions are fundamental to the project, especially because these have not been possible to answer in closed test-track tests and previous limited-duration field tests with truck drivers. The experiment has been designed to collect longitudinal data on each individual driver to understand time and experience related trends, while also collecting data to reveal variations across the driver population. PATH's previous small-scale field test indicated a potentially significant relationship between amount of prior truck driving experience and level of comfort with the shorter available CACC gap settings, so the intent is to explore this in more depth by recruiting test drivers with differing levels of driving experience and comparing the results for those different experience levels.

Roly's Trucking would have a dedicated pool of drivers assigned to the test trucks, and in order to obtain a large enough sample of different drivers this pool would rotate four times during the testing period so that each driver has three months of driving time. In order to provide for situations in which not all of the trained drivers are available to drive at the same time (illness, vacations, hours of service constraints, turnover), each cohort would include six drivers, based on Roly's recommendation. PATH expected about 20 to 24 drivers to participate in the study, based on four sequential cohorts of five to six drivers each, which would give each cohort about three months of driving time. These drivers would be assigned primarily to the CACC trucks throughout their three-month period of FOT driving, and because the dispatching of those trucks needs to be coordinated for the FOT, the driver assignments also need to be coordinated. The detailed scheduling would be done by the Roly's dispatchers since this is part of their normal job.

Each driver would have opportunities to drive in each of four different roles: platoon leader, first follower, second follower, and reference truck driver. For the first platooned trip by each cohort of drivers, each driver would be required to spend some time in each role so that they can gain a minimum of experience with each. For subsequent trips, they would have flexibility in the choice of roles since different drivers are likely to have different preferences. It's important to learn about their relative preferences and any measurable differences in their behavior in these different roles. The findings would be useful in the future for fleets that use platooning systems so that they can understand whether (and if yes) how frequently, to alternate driver assignments among the different roles. The decision about how frequently the drivers should rotate among the different driving positions (or whether that should be left entirely to the discretion of the drivers on each trip) would be made after the DAT to ensure that it is compatible with driver preferences.

The longitudinal measurements of each driver's behaviors and attitudes are at least as important as the comparisons among the different drivers, so the experiment has been designed to reflect that. Each driver would begin the FOT doing baseline driving (under manual speed control or using ACC) in one of the instrumented trucks (i.e., four reference trucks) so that their behavior can be measured during a complete round trip on the test route before they have experienced the platooning system. They would then be introduced to and trained in use of the CACC platoon control system.

The platoon driving would span the balance of the duration of the field test so that PATH can observe any long-term trends in driver preferences for different gap settings or any potentially unsafe behavior trends such as complacency or reduced attentiveness. When the drivers are driving the independent reference truck, their car following behavior and their selection of gaps in the ACC mode would also be examined to see whether their experience driving in platoons may be leading them to choose shorter gaps than in their original baseline driving. It is therefore important that they have the freedom to choose their preferred ACC gap setting. They were expected to use ACC in the reference truck because this would enable them to choose speeds up to 65 mph, the same as the CACC trucks, but if they use manual control through the accelerator pedal their maximum speed would only be 62 mph, which would make it difficult to keep pace with the platoon. Roly's drivers are currently limited to driving no greater than 65 mph, whether in manual mode or ACC mode, so this 65-mph speed limitation should not be new to them.

The driver opinions about their experience using the platooning system would be solicited by questionnaires twice during their period of test driving, once after their first round-trip with the CACC system and again at the end of their driving period. The trucks would also be instrumented for driver voice recording and the drivers would be trained to push a button to make a voice recording about any anomalies or troubling situations that they encounter during their drives. These systematic investigations of driver behavior should reveal important insights into the safety and driver acceptability of partially automated truck platoon driving.

Although Roly’s Trucking uses team driving on some of their runs (two drivers per truck, rotating between driving and sleeping to keep the truck in continuous motion), they prefer to test the platoon operations with one driver per truck, stopping when the drivers approach their hours-of-service limits. This reduces the number of drivers who would need to be recruited and trained compared to the situation for team driving.

In summary, each cohort of test drivers was expected to proceed in the sequence of events described in Table 2 during their participation in the FOT.

Table 2. Sequence of Events for Test Drivers

Stage/Duration	Description	Round Trips (per driver)
1 – up to 1 month	Recruitment of drivers, signing consent forms, initial questionnaire	0
2 – 1 week	Baseline manual and ACC driving, without using CACC	1
3 - 2 days	Classroom training, driving instruction on the road, then testing to verify they are qualified to drive with CACC	0
4 – 12 weeks	FOT driving using CACC (or manually in certain situations), and alternating with driving reference truck in ACC mode	12
5 – 1 day	Final debrief and filling out final questionnaire	0

3.3.3 Driver Questionnaires and Fleet Operations Questionnaires

The engineering data about the technical performance of the platooning system and the driver monitoring data are described in Chapter 4 of this report. The other important data to be collected in this field test are the data from the questionnaires to be answered by the fleet operations staff and drivers at Roly’s Trucking. These are designed to answer research questions about driver preferences regarding use of the platooning system and about the operational advantages (and potential disadvantages) of platooning for truck fleet operations. The numbers of the specific performance measures associated with some of the questions are shown in parentheses after those questions.

Because most of the drivers at Roly’s are native Spanish speakers, and some may not be proficient in English, PATH planned for Spanish translations of the questionnaires as well as English versions. The Spanish responses would be converted to English, initially using automatic text translation software, but this would be checked by Spanish-speaking students who are available for hourly employment, since the translation software is not always accurate.

The driver questionnaires seek some basic demographic information but concentrate primarily on the drivers' opinions about their use of the system. Examples of the types of driver demographic data and driver opinions PATH intended to collect are provided below.

Driver demographics:

- Age
- Gender
- Number of years of long-haul truck driving experience
- Number of years at Roly's Trucking
- Prior use of ACC or other driver assistance systems
- Understanding of truck platooning prior to training.

Driver opinions about use of the platooning system:

- How well they understood the information on the DVI display
- How useful they found the display information
- What additional information they would have liked to have on the display?
- Their preferences among the different gap settings (and reasons for that preference)
- Any concerns about seeing the road ahead when in a following position at different gaps
- Preferences among the different positions in the platoon (and reasons for that preference)
- What information they would like to have from the lead truck when they are driving in a follower truck?
- Preferences among visual or audible information display
- Under which conditions they prefer to not use the platoon system (and why)?
- How comfortable were they with the system response to cut-ins?
- How well did they trust the safety of the system in responding to cut-ins?
- How comfortable and confident were they with the responses on upgrades and downgrades?
- How inconvenient did they find the need to coordinate departures with the other trucks?
- How inconvenient was it to stay together with the other trucks in maintaining the same speed and stopping at the same time and place?
- What was their overall satisfaction with platoon driving?
- How much did they depend on trusting the other drivers in the platoon?
- Does the platoon driving make their job more or less attractive?
- Did they find they were paying more or less attention to the driving task compared with normal individual truck driving?

- How has the experience of driving the platoon trucks changed how they drive when they are not part of the platoon?
- Did they have any concerns about the performance of the system?
- What aspects of the platoon system would they have liked to change?
- Overall, do they prefer driving individually or as part of a platoon? (and why?)

The drivers would also be instructed to log information about certain circumstances that they may encounter during their trips. If the logs are written and spoken in Spanish, they would need to be translated by the PATH team later. As many as possible of the following items should be logged in real time using the voice recording feature on the trucks, and some should also be documented in written logs at their next rest stop:

- Any failure of the CACC control system performance or unexpected behavior (such as false positive braking)
- Other potentially dangerous situations that they encounter, such as a close cut-in or other bad driving behavior by another driver
- Reason for disengaging the CACC system
- Adverse weather condition in which they were not comfortable using the CACC system
- Report on reason for any emergency braking intervention
- Report on any crash
- Report on any traffic stop by law enforcement officer

Report on any stop for inspection fleet operator's opinions about use of the platooning system:

The following questions for the Roly's Trucking fleet operations staff are aimed at how the platoon operations affect their ability to do their jobs and the practical implications for the integration of platooning into their normal operations:

- How much additional effort was required to coordinate the simultaneous departures of the platoon trucks?
- How much additional training was needed for fleet operations staff to coordinate the platoon truck departures?
- How much change to the departure times did the departure coordination typically require? To what extent did this require earlier or later departures than they would have been otherwise?
- Did they notice any differences in maintenance needs for the platooning trucks compared to other new trucks?
- How confident are they in the reliability of the truck platooning technology?
- How confident are they in the safety of the truck platooning technology?
- Do they perceive positive or negative attitudes about the platoon driving from their drivers? Based on what primary factors?

- What effects do they believe it has now and will have in the future on the efficiency of their fleet operations? If the effect is not favorable, how would it need to be changed to produce a favorable impact on their efficiency?
- Would they recommend for or against truck platooning to their peers in the industry? Based on what primary favorable or unfavorable factors?

State Partners' Opinions about the Platooning System

During the course of the project, the key state DOT and law enforcement partners from California, Arizona, New Mexico, and Texas would be engaged as described in the Partnership Plan (see Reference 9) to capture their perspectives and opinions on truck platooning. Finally, after the testing period ends, PATH would conduct a post-test workshop with all of the state partners to capture lessons learned and their final opinions regarding the truck platooning field test. This information may help supplement the information collected during the FOT for performance measures SL-001 and SL-0003 in Appendix A.

Chapter 4. Data Acquisition and Management Plan

This chapter presents a data management plan (DMP) that is consistent with USDOT guidance for DMPs. The purpose of this DMP is to describe how PATH will handle project data both during and after the truck platooning project, and to ensure that this project conforms to USDOT policy on the dissemination and sharing of research results. Accordingly, this section identifies the data to be collected, how the data will be collected, how the data will be managed, how the data will be made accessible, how the data will be stored, and what data standard(s) will be used.

4.1 Performance Measures

Establishing good performance measures is critical to answering the key research questions of the Truck Platooning FOT. In Phase 1 of the project, the PATH team introduced a set of performance measures to meet the USDOT's performance measure requirements. In developing these performance measures, the PATH team participated in a series of meetings with the IE to discuss each of the requirements and the related performance measures in more detail. The result of those meetings was a complete list and description of specific performance measures to be addressed during the FOT. The PATH team has refined the list from Phase 1 and included an updated list of performance measures in Appendix A.

4.2 Data Overview

The purpose of this section is to specify the data that must be collected during the truck platooning FOT in order to inform the performance measures described in Appendix A and conduct the reporting and analysis described in Section 4. Table 3 lists the broad categories of data to be collected during the Phase 2 field test including data collected at specific project milestones, abnormal event data, fleet operator data, voice recorded data, engineering data and driver monitoring data. For each of those categories, the table lists the data sets to be collected and additional details including description, type, collection method and file format. Note that an asterisk is shown next to the data sets that might have privacy or ethical concerns.

Table 3. Data Set Descriptions

Category	Data Set	Description	Type	Collection Method	File Format
Data collected at specific project milestones	Driver Surveys	Questionnaires to cover drivers' opinions about ease of use of the system, preferences for platooning roles, etc. Drivers complete these at the beginning	Text	Drivers fill out bilingual questionnaires (paper forms) to be converted into Excel files	.xls

Category	Data Set	Description	Type	Collection Method	File Format
		and end of their assigned driving assignments.			
	Fleet Surveys	Questionnaires cover fleet dispatcher and manager challenges, attitudes, preferences, and value assessments of platooning logistics. Staff will complete these at the beginning of the FOT and at the end of each cohort period.	Text	Fleet operators fill out questionnaires (paper or online forms) which are converted into Excel files	.xls
	Truck Characteristics	Weight, trailer weight, length, maximum torque	Numerical data	Truck documentation	.csv
	Driver Training Data	Number of hours spent training (or retraining) drivers	Text	Recorded by PATH team	.txt, .xls
Abnormal Events	Crash Events*	Crashes in which project vehicle was involved	Numerical data, Text	GPS Diagnostics (fleet operator tool), engineering data, dispatcher and driver reports	.csv, .txt, .pdf
	Failure Events or Driver Concerns	These are system failures, near-crashes or any other serious concerns reported by drivers	Text	Driver reports and remote monitoring of diagnostics and engineering data	.txt, .pdf
Fleet Operator Data	Fuel/Maintenance Data	Fuel portal (loves) to export fuel purchases, daily maintenance report	Numerical data, text	GPS Diagnostics, Fuel transaction report	.csv, .txt, .pdf
	Inspections	Basic Inspection of Terminal (BIT) required of trucks every 90 days in CA	Inspection report and tag given to driver; kept with driver	Enforcement activities DVIR GPS Diagnostics	.csv, .xls, .pdf

Category	Data Set	Description	Type	Collection Method	File Format
		Driver Vehicle Inspection Report (DVIR) before and after every trip Random pull-overs during trips	logs, numerical data		
	Dispatch Data	Dispatch schedules, departure and arrival times, delays, loads	Numerical data, text	Fleet Operator Software Reports Trip history export from Dispatcher report	.txt, .csv
	Driver Logs*	Hours of Service; time spent on/off duty	Numerical data, automatic ally recorded	GPS Diagnostics	.xls, .csv
Voice Recorded Data	Voice recordings* of driver concerns, incidents, disengagements, and other observations	Subjective recordings by drivers including observations of what s/he considers important information	Audio data	Audio input to front-facing video camera, triggered and timestamped when driver presses audio record button on DVI	.mp4
	Transcripts of voice recordings*	Written transcripts of drivers' voice recordings (translated from Spanish to English if necessary).	Text	Transcripts created using speech-to-text and language translation tools. Edited by PATH team.	.txt
Engineerin g Data	CAN Bus Data	Raw CAN bus data, saved in text log files	Numerical data	PATH database CAN client logs	.txt
	CACC Control Data	Control algorithm inputs and outputs, saved to text log files	Numerical data	PATH logs for control algorithm & general logs for system	.txt

Category	Data Set	Description	Type	Collection Method	File Format
	Lidar Sensor Data	Data from Lidar sensors added to capture surrounding traffic	Numerical data	Lidar Sensors	.txt
	Look Ahead and side Video*	Video continuously recording truck's surroundings	Video data	Video cameras installed by PATH on outside of the truck	.mp4
Driver Behavior Data	Driver and road-ahead video* and associated head pose and trip metadata (all from Jungo system)	30-second video clips of the driver's face and road view centered on the distraction event (15 s before and 15 s after) stored when distraction is detected by Jungo system. These would be reviewed and checked by Westat to confirm that they are valid. A second set of video data includes continuous video of the driver's face and road view recorded at low temporal resolution (3 frames per second).	Video data with text list	Jungo System (including two cameras inside the cab)	MP4 video (3Hz for full trips or 15-20Hz for events), JPEG stills at events, and CSV data for head pose and trip metadata
	Driver Fatigue Monitoring Data* from SmartCap	EEG – based data on driver's level of drowsiness/alertness summarized with a single alertness level for each 30 second epoch of driving Periodic updates to driver state logged in CSV files.	Numerical data and classification of driver state	Smart Cap System	CSV data

* Data with possible privacy, ethical, or confidentiality concerns

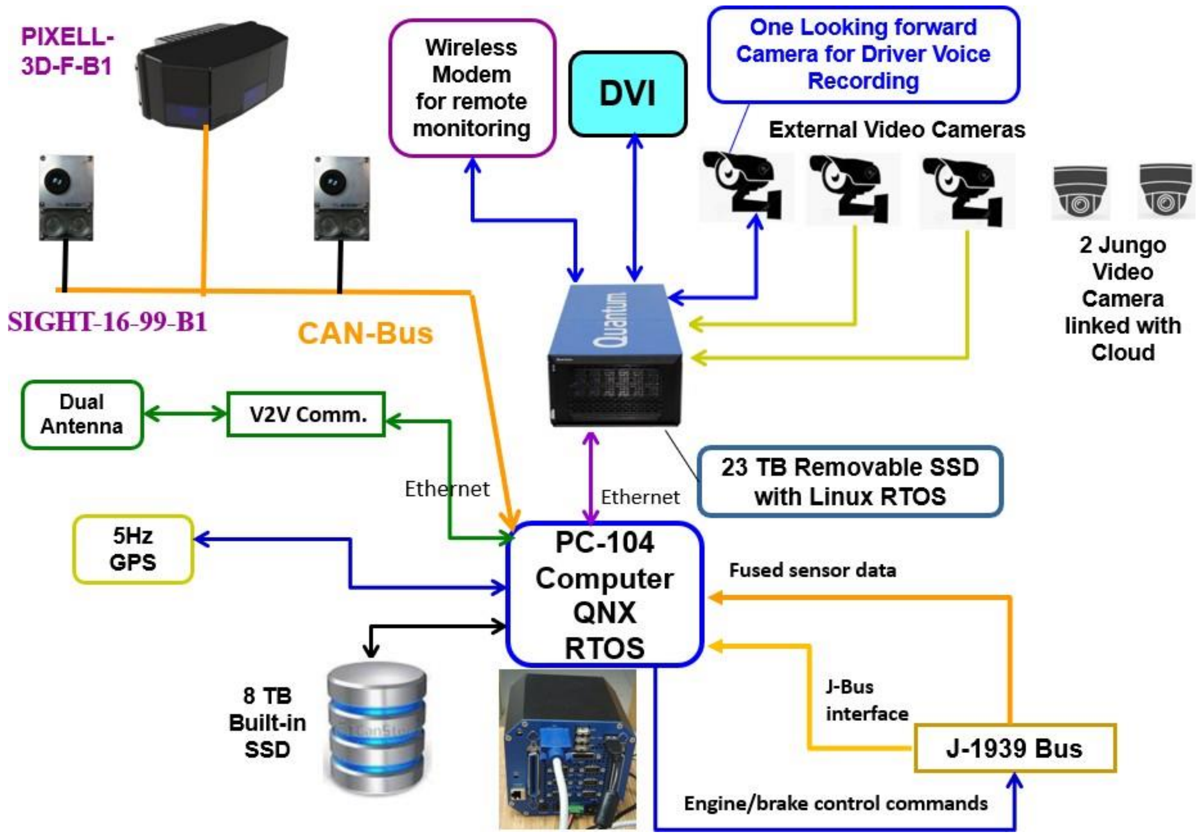
4.3 Data Acquisition System

The previous section described the different data sets to be collected during the FOT. This section expands on the information above by providing an overview of the specific data acquisition systems that continuously capture engineering and driver monitoring data onboard the trucks. This section also covers PATH's planned remote monitoring and data verification processes.

The PATH truck platooning system utilizes a data acquisition system (DAS) that is comprised of several subsystems as shown in Figure 7.

The DAS for the FOT includes one industrial PC-104 computer and the Quantum Data Collection System which has an internal PC with Linux as the real-time operating system installed on each truck. The first PC is a control computer that collects the engineering data from the truck's data bus and the CACC system and saves it continuously to a large data drive. The second is an engineering computer that collects other sensor data from video cameras, lidar units, and driver monitoring system and saves it on the second large data drive. For data monitoring, the PATH team installed a cellular modem link to communicate with each truck, with functions to automatically report data health through the modem link to the PATH data server.

See Figure 7, below. This figure depicts the overall hardware structure of the control system and the data collection system. It includes the main control computer which runs QNX as the Real-Time Operating System which receives engineering data from the J-1939 Bus, three fixed beam lidar, 5 Hz GPS unit, three video cameras, and the V2V communication. It also linked with the Quantum data collection system with an internal processor running Linux as the Real-Time Operating System. The latter collects video data and runs DVI and real-time monitoring program through a wireless modem. It also receives and saves all the engineering data from the control computer.



Source: Lu, 2022

Figure 7. Data acquisition system installed on each truck: two large data drives are installed; one for CACC engineering data and one for extra sensor data

4.3.1 Data Upload from Trucks to PATH Server

The PATH project team developed an approach to capture data from the four CACC trucks and upload the data to the PATH data server at the Roly's facility in Rancho Cucamonga. This approach allows the project team to capture continuous video data to record interactions with surrounding traffic and to determine driver fatigue and attentiveness. The data capture approach (for continuous video data capture) is described below.

In this approach, all the video data (three PATH video cameras covering the external driving scene and two Jungo cameras covering driver face and look ahead scene) are recorded continuously. With this approach, the three PATH video cameras capture the traffic scene in front of the truck and the left lane and right lane traffic. Such video can support later analyses to understand the interactions of the CACC trucks and other traffic in all maneuvers: acceleration and deceleration, joining and splitting, lane changing, other vehicle cut-in and cut-out, and other vehicle merges from on-ramps and passing traffic. This also captures the other drivers' continuous behavior around the platooned trucks for safety and mobility related modeling and analysis. Furthermore, by capturing continuous truck driver facial video data (coupled with look ahead video), future research projects would be able to conduct more detailed analysis on how driver attentiveness and fatigue is associated with long-haul trucking.

Table 4 shows the estimates of total data size in this enhanced strategy for data collection. The data include continuously recorded external video camera data (x3), the engineering data and continuously recorded Jungo driver face and look ahead video data. Based on field testing, the size of the Jungo camera data is estimated to be 0.575 GB per hour total. This includes continuous Jungo video data at 3 frames per second and event-based Jungo video at 15 frames per second. The total data size combining all data sources is about 2.6 TB for the four trucks (0.65 TB per truck) for one full, 56-hour round trip. PATH purchased a Quantum Data Collection System which has an internal industrial computer and a removable 23 TB solid state drives (SSD) to be able to store and transfer this amount of data from the trucks after each trip as explained below.

Table 4. Total data size estimates for data collection for each FOT round trip

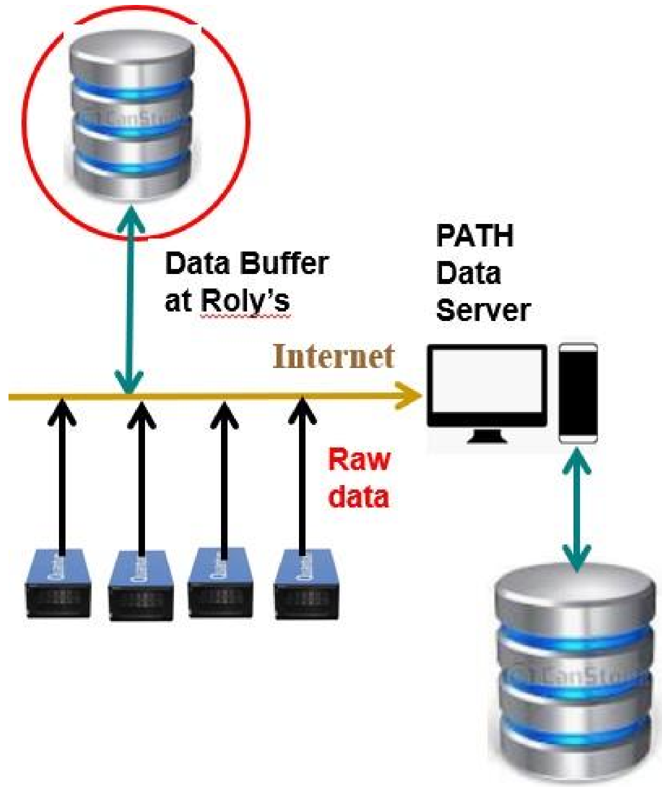
Sensor	Data size per hour in [GB]	Number of units on each truck	Hours per round trip	Number of trucks	Subtotal data size in [GB]
Video camera data	3.30	3	56	4	2217.60
Engineering data	1.00	1	56	4	224.00
Jungo camera data	0.57	1	56	4	127.23
Total data size					2,568.83

To transfer the 2.6 TB of data from the trucks to the PATH server, the chosen approach was removable SSDs and a cable connection to the PATH server. Table 5 shows the estimate of time necessary for transferring the enhanced set of data that includes continuous video.

Table 5. Number of hours to transfer data from trucks

Connection Type	MB/s	MB/hr	GB/hr	Hrs needed for data uploading
SSD with cable connection	120	432,000	432	5.9

Table 5 indicates that using removable SSDs with a cable connection takes less than six hours to upload the data, which is reasonable for transferring the large amount of data captured. PATH planned to install a PATH data transfer computer and Redundant Array of Independent Disks (RAID) storage device at Roly's Trucking (capable of accepting removable SSDs from each truck), and subsequently upload the data to the PATH server over Roly's Internet service as shown in Figure 8. This figure shows a schematic view of the flow of the test data from the Quantum removable SSD drive at Roly's, where it is connected to a RAID data storage device and the internet. At the other end of the Internet connection is a PATH data server connected to a massive backup storage device.



Source: Lu, 2022

Figure 8. Data uploading using removable SSDs cable-linked with PATH computer at Roly's

After each trip, the data can be transferred in the following sequence:

1. Remove the high-capacity solid-state drive (SSD) from each truck and connect it directly with the PATH data computer at Roly's. Replace it with a second SSD that can be installed immediately on the truck to record the data for the next trip.
2. Copy all the data to the local RAID data storage of the PATH data computer at Roly's.
3. Transfer the data from the RAID data storage to PATH data server via the Internet.
4. Prepare the SSD for use on a subsequent trip after verifying that data was successfully copied to RAID and the PATH data server. Once successful data transfer has been verified, the old data on the SSD will be deleted to increase storage capacity for the next trip.

The advantages of using a RAID or RAID-like data storage at Roly's trucking are:

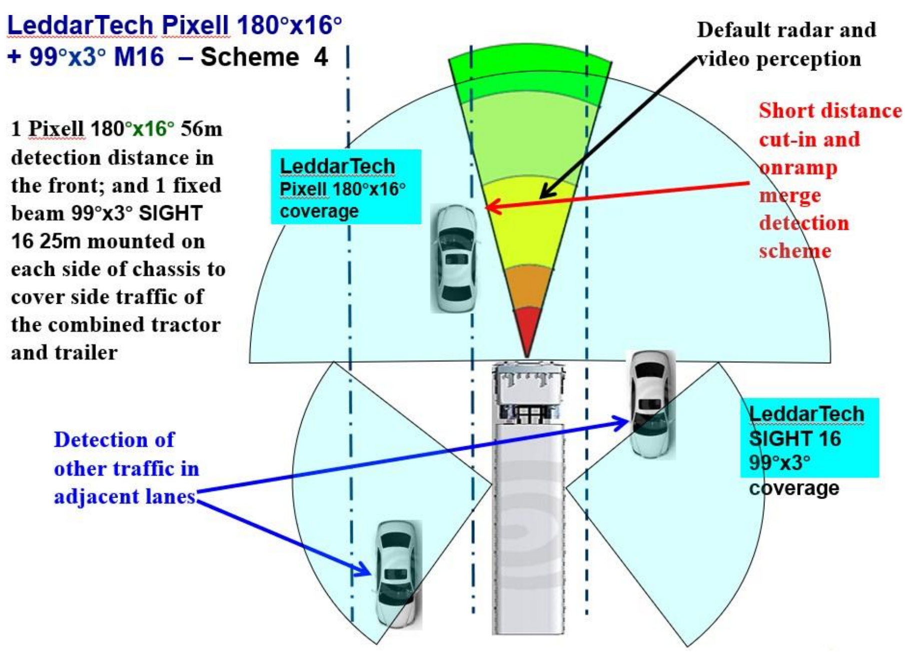
- It uses local data copying for quickly transferring data from removable SSD to RAID Data Storage, which does not rely on the internet; this avoids problems associated with a bad internet connection or speed drops.
- PATH team has more time and flexibility to verify the data saved on the RAID system remotely before transferring it to PATH, which can be done through the observation of some sample data.

For this approach, an IT engineer of Roly's Trucking would swap out SSDs on the trucks and insert them in the SSD cage linked via a cable connection with the data storage computer at Roly's Trucking as shown in Figure 8. This approach produces the fastest turnaround at Roly's. The data transfer to PATH could start immediately after each completed trip or sometime late at night. Two SSD units were acquired for each truck to ensure that the next departure of the trucks will not be delayed if any problems arise in transferring the data from the SSD to the local RAID storage device. In summary, a total of nine removable SSDs (two per truck and one spare) and one data computer with a RAID 32 TB Data Storage component would be installed at the Roly's facility.

4.3.2 Truck Mounted Sensors for Traffic Detection

Figure 9 and Figure 10 show how the traffic detection sensors were installed on each truck. These include fixed beam Lidar sensors and wide-angle video cameras to detect surrounding traffic. The areas of coverage are shown in each figure. Since Roly's Trucking changes out trailers, it is impractical to mount those sensors directly on the trailers. Therefore, all sensors were mounted on the tractor chassis.

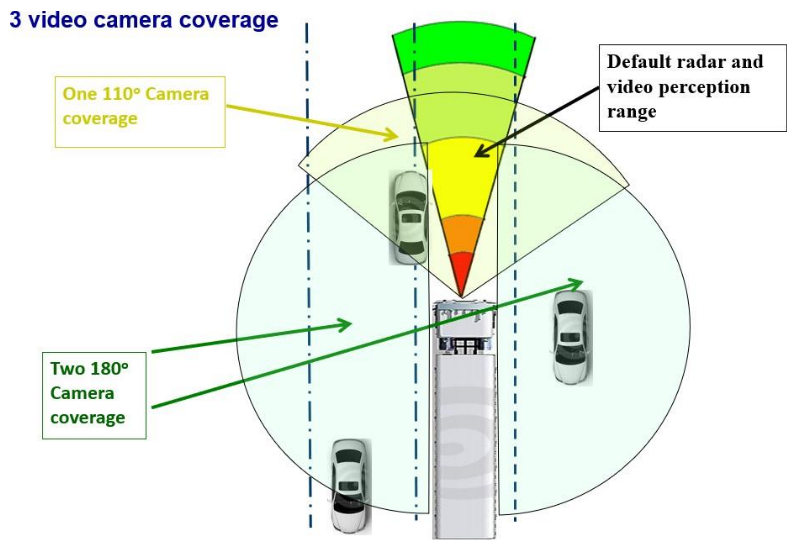
See Figure 9, below, which provides an aerial view of a truck surrounded by other vehicles, with depictions of the narrow field of view of the forward radar and video camera systems used for CACC control, the 180-degree forward field of view of the Pixell lidar, and the 99-degree fields of view of the LeddarTech SIGNT units located on both sides of the truck.



Source: Lu, 2022

Figure 9. Three fixed beam lidar coverage scheme, mounted on the tractor only

Figure 10 provides an aerial view of a truck surrounded by other vehicles, with depictions of the narrow field of view of the forward radar and video systems used for CACC control, the 110 degrees field of view of the forward video camera and the 180-degree fields of view of the video cameras mounted on both sides of the truck.



Source: Lu, 2022

Figure 10. Three wide angle video camera coverage areas, mounted on the tractor only

4.3.3 On-board Driver Monitoring Systems

For purposes of assessing driver attention and fatigue/drowsiness, PATH selected a pair of systems; the SmartCap LifeBand system and the Jungo VuDrive system.

The SmartCap LifeBand system uses dry EEG monitoring and AI to determine the fatigue level of the wearer. This device was developed and first used over a decade ago in Australian mining operations. However, it has been expanded to over the road (OTR) trucking and other operations where fatigue is a problem. The system uses levels of 1 (hyper alertness) to 5 (involuntary sleep) but provides reporting of levels 2 through 4 as described in Figure 11, below. The system works in conjunction with a smartphone/tablet app that records fatigue levels continuously and provides alerting to the app/user (if desired) to allow self-correction of fatigue situations. For this application, PATH anticipated using the LifeBand in a mode that allows all but the most serious fatigue levels to be monitored continuously and quietly. However, if drivers become dangerously close to an involuntary sleep condition, they would be alerted. Otherwise, the system would silently report fatigue levels for this study's reporting purposes. Levels along with date/time information are recorded in the app until a communication signal that allows data to be pushed to a cloud server can be acquired.

See Figure 11. This figure provides a graphical depiction of the levels of fatigue detected by the SmartCap system, ranging from Level 2 (typical) to Level 3 (early indicators of fatigue), Level 3 (transitioning phase for early warning of fatigue and Level 4 (heightened risk of microsleep).

2	TYPICAL LEVEL OF ALERTNESS	No immediate action required
3	ALERT WITH SOME EARLY INDICATORS	No immediate action required
3^{+}	TRANSITIONING PHASE FROM 3-4 (EARLY WARNING)	Your risk of a microsleep is increasing, take action to help manage your fatigue.
4	HEIGHTENED RISK OF MICROSLEEP	You are at heightened risk of microsleep and need to take IMMEDIATE action.

Source: Lu, 2022

Figure 11. SmartCap Fatigue Levels

No actual EEG data, with its inherent confidentiality implications, is recorded, but the fatigue level data is recorded continuously and can be reported at any desired frequency. For purposes of this project, the time in each level would be reported at an update interval of 15 minutes.

The SmartCap LifeBand system is small and lightweight, fitting easily in the band of various styles of hats or to be worn without a hat. It is rechargeable, with a battery life that should allow up to a week of driving without the need to recharge. Notifications of the need for charging are provided to the drivers, who are responsible for ensuring that the bands are adequately charged and ready for operation. Since a charge should easily last the duration of a given trip, PATH planned a reminder to drivers of the need for charging at the depot should drivers choose to forego charging after each driving period is completed. Westat would receive notifications about the need for charging and failures to use the band during drives in addition to metrics of fatigue on a regular and event-based basis. The LifeBand calibrates automatically and having one for each driver in the study allows unique identification of which driver is in a given truck with no need for manual identification for the system after an initial assignment. Because data elements are posted to a SmartCap cloud server when communication becomes available, this imposes minimal burden on the overall data management for the project. Instead, data can be pushed from the SmartCap server to the team's data management hub and then on to the data repository for sharing with FHWA and the IE.

Although the SmartEye eye tracking system was considered for this effort as a means of determining driver attention and/or fatigue, the team settled on the Jungo VuDrive system as a more practical solution to collect data on attention and distraction. The Jungo system, like the SmartCap, uses AI-based software to manage the video information being collected and to turn that voluminous data into more manageable indications of key behaviors. This system has been developed as a means for activity inside a vehicle's cabin to be monitored and reported. Among the software's potential monitored behaviors are eye closures, yawning, gaze direction, head pose, and emotions. It can actually do this detection and monitoring for a number of occupants within the vehicle, though our application will be simpler than that due to constraints on the processing power of the hardware.

Jungo system hardware includes a forward looking (i.e., road) camera as well as one trained on the driver's face (and the surrounding cabin). The face camera includes IR illumination, so it is able to monitor and report in both daytime and dark conditions. The cameras are capable of recording dual video on a micro-SD card as well as logging the AI-enabled parameters. The system includes wireless connectivity to allow transmission of the AI reporting data to a cloud server and/or alerts or prescribed email address at regular intervals, if service is available. Otherwise, data is stored on an SD card until service is available, the SD card is removed, or data is pulled onto one of the on-board PATH data collection platforms for retrieval. Among the benefits of the Jungo system are its ability to operate without calibration requirements after the initial installation. GPS data is collected in the Jungo data stream as well. Based on hands-on testing, PATH anticipates being able to collect over 9 full days of dual-camera data on a single 128GB micro-SD card, assuming 24-hour driving operations, making data retrieval and maintenance very manageable within the constraints of the study. Additionally, the plan is to offload the SD card data to the PATH SSDs as it is collected. This should generally keep the SD card from filling up and means that touchless collection should be possible with the Jungo system for the duration of the study.

PATH anticipates that the combination of the LifeBand and VuDrive systems would provide a reliable and cost-effective means of collecting what would otherwise be very expensive and labor-intensive, both during and after collection.

Measures of distraction and fatigue/drowsiness would be tied to independent variables associated with drivers, trip characteristics, platoon characteristics, rather, road characteristics, etc. collected through the rest of the instrumentation systems for inclusion and comparison to answer the requirements of performance measurement items. This integration facilitates the detection of patterns and relationships among these situations and the dependent measures of distraction and fatigue. They can also be compared to other measures of performance to recognize correlations and relationships that may be indicative of positive or negative behavior.

4.3.4 Remote Monitoring and Data Verification

The PATH team implemented the wireless modem link with the four trucks for periodic monitoring of the CACC system. A minimum data set which includes some critical parameter(s) of each component was identified to be passed to PATH in near real-time through the modem. The fault mode parameter can be used to identify if the component works correctly and if the data is saved properly. The following parameters would be checked for remote monitoring at a minimum: outputs of all the major components of the CACC system, GPS UTC synchronized timestamp, DSRC time ticking, radar health parameter and target distance, brake pedal deflection, PC-104 special process checking, and others. In addition to the remote monitoring of the PATH systems, the Jungo and SmartCap systems would be reporting back periodically and on an event-based timing regimen through a cell phone modem provided with the Jungo system.

PATH assigned a data analyst to be responsible for performing the remote monitoring checks on a daily basis during the trips. If they uncover any issues during the checks, they should notify the PATH PI immediately so that PATH can investigate the issue and find a resolution as soon as possible. Depending on the situation, it may be a temporary error or permanent fault such as a hardware issue. If it is the former, it may be possible to fix it overnight remotely. But if it is the latter, it would require waiting for the truck to return to Roly’s before taking any action. If it is a hardware issue on one of the platooning trucks, the reference truck could be swapped with the faulty platooning truck to use the defective truck as the reference truck, if feasible.

In addition to remote monitoring, PATH's data analyst would be responsible for verification of the saved data after the data uploading from the trucks to the PATH data computer at Roly's and to the PATH data server. The same minimum data list that PATH uses for the remote monitoring system to check the data health in near real-time would be used for data verification of the saved and uploaded data to make sure that the data transfers are completed successfully without corruption. PATH will also check that the data streams are synchronized properly by timestamps. The saved Jingo and SmartCap data would also be checked. If PATH discovers any issues with the saved data, the issue will be investigated immediately and a resolution will be found as soon as possible.

4.4 Data Stewardship

4.4.1 Data Owner and Steward

University of California is the owner of all of the data that are collected during Phase 2 of the Truck Platooning Early Deployment Assessment project. However, in accordance with the Federal Acquisition Regulation (FAR) contract terms (https://www.acquisition.gov/far/52.227-14) USDOT has unlimited rights to the project data including the right to use, disclose, reproduce, prepare derivative works, distribute copies to the public, and perform publicly and display publicly, in any manner and for any purpose, and to have or permit others to do so. As data owner, University of California has the authority, ability, and responsibility to access, create, modify, store, use, share, and protect the data. For this project, PATH would act as the data steward for all of the data. The data steward is the organization that is delegated the privileges and responsibilities to manage, control, and maintain the quality of a data asset throughout the data lifecycle.

4.4.2 Data Access

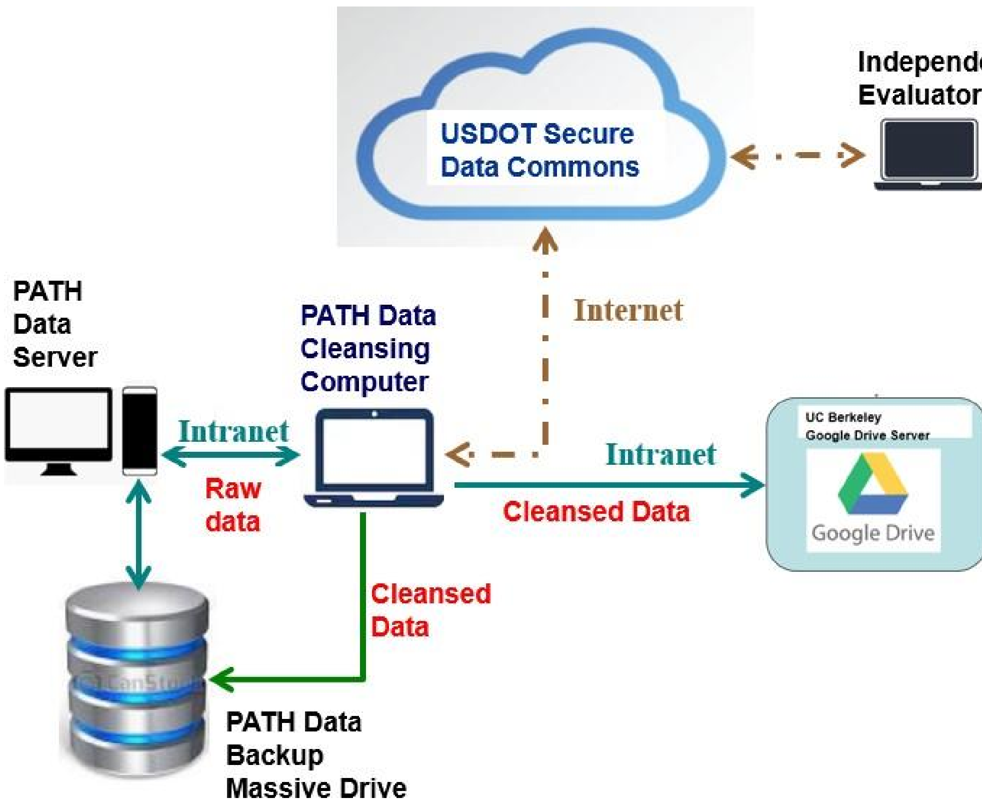
All project data would comply with all USDOT data security requirements. The PATH team expected all data described above to be made accessible to USDOT and the IE after working with them to identify any sensitive data. Certain elements of raw data may contain confidential business information (CBI) or personally identifiable information (PII). The data sets that may contain CBI or PII are noted with an asterisk in Figure 12. These data would be identified as sensitive before sharing with USDOT or the IE. Only those who are included as qualified participants during the Institutional Review Board (IRB) process would have access to the sensitive raw data.

To safeguard the security of collected data PATH developed a stringent protection policy to deny unauthorized access. The collected raw engineering and other sensor data would be downloaded and stored at the PATH Data Server in a well-organized chronological order. Local storage would run a Debian-based system, Open Media Vault. Security measures include mandatory two-factor authentication, limited connectivity to local subnets, dedicated ports, and VPN access. User activity monitoring would be in place for dedicated users with data access. PATH does not expect to have a database structure. Instead, all the data would be deposited and classified into three data types: engineering data, identifiable non-IRB sensitive video data (e.g., video of surrounding traffic showing license plates), and IRB sensitive data (e.g., video of driver's face, driver voice recordings and SmartCap data). The data would be saved under those three categories in a chronological order.

From the PATH Data Server, all of the raw data except for the names and contact information of the test subjects would be sent to the UC Berkeley Google Drive Server as shown in Figure 12. The Google

Server separates this data into the three data types described above. The Google Server would be linked to the Secure Data Commons (SDC) via a secure internet connection and project data sent to SDC on a periodic basis. If the SDC is not available for this project, PATH would provide USDOT and the IE direct access to the UCB Google Drive using the IRB rules for data access. Access to Google Drive is limited by login permit. PATH would not have a dynamic interactive module beten the data and the user, which is out of the scope of the project. The data storage on Google Drive is expected to be limited to the project execution period. Thus, it is recommended that the SDC be used for data sharing since it will have long term storage capabilities.

See Figure 12, below. This figure provides a schematic depiction of the data storage, processing and sharing flows of data. It begins with the PATH data server connected to the PATH data cleansing computer, which is connected via Intranet to the UC Berkeley Google Drive, where the cleansed data are stored. It is also connected via Internet to the USDOT Secure Data Commons, where it can be accessed by the Independent Evaluator.



Source: Lu, 2022

Figure 12. Scheme for Data Storage, Processing and Sharing with FHWA and IE

For in-house data processing and analysis, the PATH team proposes to use software such as Matlab which has flexible programming capabilities. The reasoning is that the relationship between the raw data collected and the performance measures is complex, and quantifying those relationships requires complicated programming; using already-programmed functions in Matlab is convenient. The Test and Evaluation Plan lists the project data that PATH expects to collect. Different approaches to calculating performance measures may use slightly different sets of raw data for analysis depending on the algorithm and data health/accuracy. PATH plans to document these approaches at a high level in the final version of the Test and Evaluation Plan and in more detail in the Evaluation Report.

For sharing data with USDOT and the IE, all of the data, including IRB sensitive data, would be stored on the UCB Google Drive. From there, it could be shared through the SDC, which has mechanisms in place to restrict access to IRB sensitive data, or directly with USDOT and the IE if the SDC is not available. IRB sensitive raw data could only be accessible to the project team, which includes whoever has IRB approval and has been deemed by USDOT to have a legitimate interest in the project data. If data needed to be shared directly from the UCB Google Drive, a login process would be created, and a user account log generated to keep records of entries into the data storage system.

4.4.3 Data Re-Use, Redistribution, and Derivative Products Policies

Since this project is USDOT-funded, an open license would be used for all of the datasets generated and shared during the project. The PATH team proposed using the following Creative Commons license for all project data:

- CC BY-NC-SA

This license allows users to distribute, remix, adapt, and build upon the material in any medium or format for noncommercial purposes only, and only so long as attribution is given to the creator. If users' remix, adapt, or build upon the material, they must license the modified material under identical terms. More information about this license is available at the following URL: https://creativecommons.org/licenses/by-nc-sa/4.0/.

In addition to the Creative Commons license restrictions, there are also restrictions associated with the IRB-sensitive data. Namely, any third party who desires to access data deemed to be confidential or sensitive by the IRB will also have to pass IRB-approved training for human subject related research.

4.4.4 Data Storage and Retention

Storing and retaining the data is a key part of the data steward's responsibilities to manage, control, and maintain the quality of a data asset throughout the project lifecycle. The storage systems for this project were described above. To summarize, data storage on the trucks is accomplished using two industrial PCs installed on each truck. The first PC is a control computer that collects the engineering data from the truck's data bus and the CACC system and saves it continuously to a large data drive. The second is the Quantum Data Collection System with an engineering computer that collects other sensor data from video cameras and lidar units and saves it on the second large data drive.

As discussed in Section 4.3.1, the amount of data uploaded from the trucks to the PATH server would be sizable. PATH estimates that 2.6 TB of data from each FOT round trip. The uploaded raw data from each truck (0.65 TB) would be stored at Roly's and sent via the internet to the PATH Data Server at the Richmond Field Station. The PATH Data Server has two Massive Drives with 32 TB storage capacity as shown in Fiure 12. As discussed before, the raw data would have very limited access by the team members and restricted to those with qualified IRB training and a direct need for use of the data. Raw data would be processed by the PATH team and made available for analysis purposes. The raw data and the processed data would be stored in a Google Drive. The PATH team controls access to the Google Drive folder. Based on the information from Google Inc., there is no limit on total data size in using the Google Drive for data storage.

All project data would be shared with USDOT and the IE through the SDC as shown in Figure 12. With respect to data backups, the PATH team would use massive storage to compress and back up the engineering data. The backup data would not include the video data due to its large size.

4.5 Data Standards

Much of the data being collected in this project does not have relevant data standards to follow since this is still a research project. Some of the data may follow certain standards and others may not. The following is a description of how the project data would follow data standards as best as possible:

- J-1939 Bus data follow the SAE J-1939 Data Standard
- Some CAN bus data may not follow a data standard. For example, some numerical information can be passed through the CAN for control purposes, which would not follow a standard. However, PATH mainly saves the engineering and lidar data in text files which can be converted to a format suitable for the SDC system.
- V2V (DSRC) data follow an extended list of V2V data for the V2V (DSRC) information passing packet. The list extends the basic safety message (BSM) I and BSM II. The reason for the extension is that BSM I and BSM II are not adequate for CACC/platooning control and related maneuvers.
- GPS data follow the GPS data standard with adequate decimal places to guarantee the accuracy of vehicle position in the earth/ground coordinate system.
- Control data and driver behavior data are new and have only been used for research purposes. There is currently no standard for these types of data until the technology becomes mature and converges to an approach that can be standardized.

4.6 Data Lists and Metadata

A listing of the digital data sets (and associated metadata) to be captured during the FOT is provided in the Test and Evaluation Plan (see Reference 11).

Chapter 5. Human Use Approval Plan

The purpose of the Human Use Approval Plan is to describe the plan and process that PATH followed to obtain human use approval to conduct the Phase 2 field test. Any University of California, Berkeley (UCB) research that uses humans, human tissue, surveys of human subjects, or human subjects' records requires review from its Institutional Review Board (IRB), the Committee for Protection of Human Subjects (CPHS) regardless of sponsorship. Since the FOT will involve professional truck drivers, those relevant activities need IRB approval.

To help protect study participants' privacy and to prevent any court-ordered release of study participants' interview/questionnaire data or DAS data in the event of a crash or other incident, PATH had successfully applied for a Certificate of Confidentiality (CoC) from the National Institute of Health (NIH).

Human use approval is needed for all three stages of testing during the project including the SAT (DAT portion only), the ORT, and the FOT. The Human Use Approval Plan covers all the elements of the study protocol as required by the CPHS, as well as the requirement of applying for the CoC.

5.1 Human Subjects Testing Protocol

All activities that involve the use of human subjects must be reviewed and approved by UCB's CPHS, which is comprised of two groups that serve as the IRB. The primary mission of the IRB is to ensure the protection of the rights and welfare of all human participants in research conducted by UCB's faculty, staff, and students (https://cphs.berkeley.edu/). The CPHS review and approval process are applied not only to the activities conducted by UCB staff but also by subcontractors supporting the project led by UC Berkeley, as well as any usage of the human subject research data (i.e., for the independent evaluation).

The human subject research protocol requires various elements, such as background and purpose of the study, qualifications of research personnel, details about subject recruitment, detailed plan of data collection, as well as an informed consent form. In order to receive approval for the protocol, the PATH team is required to document each element of the protocol and provide information such as how, where, when, and by whom subjects will be selected and approached for study participation, as well as actions the project team have taken or will take in order to complete the protocol. More details on the testing protocol contents are provided in the Human Use Approval Plan deliverable (See Reference 9).

5.2 Certificate of Confidentiality (CoC)

The application for CoC would occur after the protocol is finalized and the CPHS has provided at least conditional approval. With the CoC, other collected data (e.g., driver awareness, speed) should be protected from compelled disclosure. However, there are still some limitations under a CoC. For example, voluntary disclosure of information by study participants themselves, as well as voluntary disclosure/compliance by the researcher of information on such things as child abuse, reportable communicable diseases, possible threat, to self or others. More detailed information can be found in the UCB's guidelines (https://cphs.berkeley.edu/coc.pdf).

5.3 Timeline for Obtaining Human Use Approval

The UCB CPHS requires a minimum of eight weeks for the initial review of the protocol. Based on the past experience, an additional 4-8 weeks are typically required after the initial review to address questions or concerns that are brought up by the CPHS members during the initial review. This occurs after the details of the subject requirements have been disclosed, and after the driver recruitment and training materials have been developed. Once the human subject protocol is approved and is in place for the project, the UCB CPHS has a process for making changes and amendments, and this process normally takes an additional 8-12 weeks for review and approval. Given that the entire human use approval process may take up to six months to complete, the PATH team submitted the initial testing protocol into the UCB e-protocol system and in the summer of 2021, CPHS approved the human subject recruitment and data collection.

Chapter 6. Partnering and Outreach Approach

Building partnerships and conducting outreach are critical to the success of the truck platooning FOT. To ensure success in this area, the PATH team developed a Partnership Plan (see Reference 9) to document both current and planned activities that describe how the PATH team engaged key public and private stakeholders and established all necessary commitments across the test corridor to support the field operational testing of the platooning system. Below is a summary of PATH's approach to partnering and outreach.

6.1 Project Partners and their Roles

6.1.1 Core Team

California PATH served as the Prime Contractor for this effort, with Westat and Cambridge Systematics as subcontractors for their activities. Roly's Trucking was the trucking industry operator of the truck platooning system as a subcontractor in support of California PATH. Volvo Group North America supported the phase 2 project at no cost to the project. Bendix Commercial Vehicle Systems also provided technical support to PATH on their systems on the trucks through a non-disclosure agreement. These partners comprised the core team and their roles and responsibilities are defined below.

University of California PATH

California PATH is a university research program focusing on intelligent transportation systems that is managed by the Institute of Transportation Studies, University of California, Berkeley. PATH has managed the overall program, developed and implemented truck platooning technology, and planned to evaluate its performance and impacts. PATH's specific responsibilities include:

- Being Prime Contractor and managing all aspects of the program, including subcontractors and partners, and implementing project management best practices.
- Maintaining a consistent line of communication with FHWA's assigned Project Manager for this effort.
- Providing the technical and scientific leadership to plan, engineer, and deploy the truck platooning system.
- Providing training for the fleet operator driver pool and dispatching/operations management.
- Collecting and analyzing all test data during the testing phase; coordinating with Roly's Trucking staff to ensure that all data is properly downloaded off the trucks after each trip and uploaded to the PATH server.
- Providing all required project data and reports to FHWA and its Independent Evaluator.
- Providing monitoring and oversight of all system operations and maintenance during the field operational test including CACC system and data acquisition system.

Roly’s Trucking, Inc.

Roly’s Trucking is a medium sized minority-owned trucking company which deploys dozens of long-haul trucks daily on the I-10 Corridor between the Los Angeles Basin and Texas. Roly’s is the trucking industry participant that will operate the platooning system on equipped Volvo trucks (in coordination with California PATH) for the duration of the field operational test. Their specific responsibilities include:

- Acquiring trucks and leasing them to PATH for the duration of the project in consultation with PATH and Volvo.
- Operating the four Volvo trucks leased for the duration of the operational test and covering the cost of driver labor and fuel during the field test as cost share.
- Providing insurance for operation of the trucks during the field operational test to cover both the trucks and Roly’s drivers.
- Managing the over-the-road operations of the four trucks to be implemented with the platooning system technology, including planning the logistics of freight dispatching to ensure ongoing use of the three trucks in “platooning configuration” (as freight demand allows) for trips between the Los Angeles Basin and Texas.
- Coordinating with California PATH to train drivers and operations staff to use the platooning system, and to implement the human factors equipment and testing procedures to measure driver behavior.
- Coordinating with California PATH to support data collection throughout the course of the test.

Volvo Group North America

Volvo Group is a truck original equipment manufacturer (OEM) and one of the world’s leading manufacturers of trucks, buses, construction equipment, and marine and industrial engines. Volvo provided technical assistance with installation and calibration of an Adaptive Cruise Control (ACC) system on four Volvo trucks, technical assistance with development and implementation of data transfers/download from the data buses, and general operations and maintenance support advice for the duration of the FOT. Specific responsibilities included:

- Providing help with installation and calibration of a Bendix ACC system on four Volvo model VNL-64T760 trucks.
- Providing information needed to allow PATH to access the real-time data from the ACC system and from the vehicle data bus needed to implement CACC control.
- Providing interface and control override capabilities for proper direct engine torque, engine retarder, and service brake control.
- Providing ongoing technical support during the development and testing period to keep the Volvo-provided systems working correctly.
- Providing technical information about the configuration details that need to be specified for the new trucks when they are purchased and leased so that they will be as close as possible to the trucks on which PATH previously implemented CACC.
- Providing technical support for repairs as needed in case any of the non-standard Volvo systems on the test trucks are not working correctly.

Bendix

Bendix Commercial Vehicle Systems designs, develops, and supplies leading-edge active safety technologies, energy management solutions, air brake charging, and control systems and components under the Bendix® brand name for medium- and heavy-duty trucks, tractors, trailers, buses, and other commercial vehicles throughout North America. PATH signed a non-disclosure agreement with Bendix for technical support from Bendix on their systems on the Volvo trucks to be used in the project. Technical support was provided by Bendix on the following truck components:

- Disk brake control
- Fused radar and video camera for target detection and tracking
- Sensor-based collision mitigation system.

Westat, Inc.

Westat is a research firm known for the quality of their statistical design, technical research, large- and small-scale data collection, survey research, and program evaluation work. They led the human factors aspects of testing and data collection for the project effort as defined in the Test and Evaluation Plan. Specific responsibilities included:

- Designing all human factors aspects of the Test and Evaluation Plan including the approach to monitor driver fatigue and attentiveness during the platooning tests.
- Assisting with the human factors related data collection and processing during the tests to ensure the data is adequate to inform the relevant performance measures and answer the key human factors research questions.

Cambridge Systematics

Cambridge Systematics is a transportation engineering firm with over 45 years of experience leveraging technology and ingenuity to advance transportation solutions. They provided continuous coordination of the involvement of Roly's management and operations staff for the duration of phase 2 and coordination of all stakeholder activities for the team, including agency and trucking association relationships across the four I-10 corridor states. Specific responsibilities included:

- Implementation of the Partnership Plan – work with all partners to facilitate partner and external stakeholder engagement.
- Managing team relationship with the trucking fleet participant (Roly's Trucking, Inc.) to ensure regular communication of Roly's needs from California PATH and the other partners, and vice-versa.
- Assisting PATH in developing and implementing a Demonstration Kickoff Meeting/Event at Roly's Trucking in Rancho Cucamonga, CA, with FHWA, the Independent Evaluator, and certain project stakeholders that were invited to attend.

6.1.2 Additional Key Partners

The following additional partners played key public and private support and coordination roles and help with operations of the truck platooning across the four states of the I-10 corridor (California, Arizona, New Mexico, and Texas):

Caltrans and the California Highway Patrol (CHP)

Continuing their involvement from Phase 1 and going back to their original involvement with California PATH in the FHWA Exploratory Advanced Research (EAR) Program truck platooning project, Caltrans led coordination with infrastructure operations on California freeways, and provided insights into impacts assessment as it relates to the transportation infrastructure. Additionally, Caltrans funded a related PATH project to enhance technology in the CACC system, which provides an important cost match. CHP, in coordination with Caltrans, worked with the California PATH team to ensure that enforcement operations are properly coordinated with the truck platooning tests. PATH held a coordination meeting with Caltrans and CHP on September 10, 2020. This meeting provided PATH an opportunity to brief CHP on their field test approach and to hear CHP’s concerns and suggestions for a successful project.

I-10 Corridor Coalition and member states

This coalition comprises the departments of transportation (DOT) of California, Arizona, New Mexico, and Texas and is supported by the trucking associations of each state. The coalition includes defined leaders at the DOT technology/operations levels in each state who assisted the California PATH team in conducting multi-state operations, and in particular, facilitating agreements and outreach efforts necessary to support operations in each state along I-10. Successful engagement in this regard was conducted with the DOT’s of Arizona, New Mexico and Texas.

State Trucking Associations

Beginning in spring 2021, outreach would be continued with the trucking associations of each state to ensure that the trucking industry was engaged and aware of the platooning field operational test. In Phase 1, the California PATH team engaged the California Trucking Association and the Arizona Trucking Association to discuss this project. These associations would be re-engaged, and initial engagements would be made with the New Mexico Trucking Association and the Texas Truck Association.

European Commission's Directorate General for Research and Innovation (DG-RTD)

During Phase 1, the European Commission expressed their interest in opportunities for "twinning" their truck platooning research projects with similar projects sponsored by USDOT to gain synergies between the efforts of the researchers on both sides of the Atlantic. PATH discussed “twinning” of the FHWA field testing project with related European truck platooning projects with the European Commission Directorate-General for Research and Innovation (DG-RTD) and they supported this in concept. However, the timing of this project did not match well with European project activities. PATH representatives participated in the September 2021 demonstration by the European truck platooning project ENSEMBLE, where the two project teams exchanged technical briefings and learnings from the respective project work.

6.2 Fleet Partner Coordination

A key element of the truck platooning FOT is the ongoing participation of PATH team fleet partner Roly's Trucking. In Phase 1 of the project, the PATH team recruited a trucking company partner, Roly's Trucking, to operate the trucks for this FOT. Roly's Trucking was selected for this operational test by PATH due to the following aspects of their operations which create a solid operational baseline to conduct long-haul truck platooning operational testing:

- Most of Roly's freight movements are long-haul truck moves of freight on the I-10 Corridor between the Los Angeles basin and the Texas Triangle (Dallas/Fort Worth, Houston, and San Antonio) – this fits exactly in the desired geography that California PATH and the I-10 Corridor Coalition intended for the focus of operational testing.
- Roly's deploys dozens of long-haul trucks daily on the I-10 Corridor between the Los Angeles basin and the Texas Triangle – this provides the opportunity to schedule truck platoons of three vehicles to meet the needs of the operational test.
- Roly's is willing to support video and other equipment monitoring of driver reactions to the truck platooning system, as well as to support data collection requirements.
- Roly's management has experience in meeting the requirements of USDOT technology field testing due to their Operations Manager's (Mike Johnson) previous experience in supporting USDOT's Phase 1 Freight Advanced Traveler Information System (FRATIS) testing in Los Angeles in 2012-2014.

California PATH Team members conducted a site visit in November 2019 to Roly's Trucking facility in Rancho Cucamonga, California to view Roly's operations firsthand and to sit down with Roly's staff to examine detailed questions that the team had in terms of Roly's roles, and in regard to key technical details of the experimental plan and data collection needs. Throughout the project, PATH had multiple interactions with Roly's regarding their ability to support all aspects of the field operational test including acquiring and then leasing the trucks to PATH for the duration of the project, supporting PATH in recruiting and training drivers for the test, dispatching and operating the trucks in platoons during the test, and supporting project data collection (including participating in driver and fleet operator survey administration).

See Figure 13, below. This figure combines four photographs that depict the facility of Roly's Trucking at Rancho Cucamonga, CA, including: trucks, trailers, the storage house, and loading docks.

Source: Roly's Trucking Facility, November 4, 2019

Figure 13. Team Site Visit Photos at Roly's Facility

To formalize the partnership between PATH and Roly's, Roly's signed a purchase order agreement that defines in detail their roles and responsibilities as a vendor to PATH for this project. The key features of this agreement are organized by the relevant tasks described in Section 6.1.1 above. This agreement includes providing four dedicated Volvo trucks for the duration of this project, which effectively serves as a lease of the trucks to PATH for use on this project. The trucks were instrumented and tested by PATH at the Richmond Field Station. If the project had proceeded as planned, they would then have been used by PATH and Roly's drivers for the SAT and ORT. After testing, if a "go" decision had been made by FHWA, the trucks would have been delivered to Roly's to operate them for the duration of the FOT. Roly's will take possession of the trucks at the end of the project, after removal of the experimental equipment.

The PATH team has relied on its project partner and subcontractor, Cambridge Systematics, to implement the continuous partner communication with Roly's during this project. This includes:

- Acting as a communications bridge between Roly's and the rest of the PATH Team

- Ensuring that Roly's needs are met and being continually available to assist Roly's to answer questions and resolve problems that are expected to periodically arise during a major field operational test.
- Ensuring that Roly's responsibilities to the team are also implemented, especially during the FOT phase of the project.
- Assisting Roly's in planning and preparing for a potential demonstration meeting/USDOT visit at Roly's facility.

6.3 Stakeholder Engagement Strategy

Another key element of this project is the PATH team's approach to working with public and private stakeholders in the other three states (excluding California, in which Caltrans and CHP are considered existing partners): Arizona, New Mexico, and Texas. The primary goals of this engagement are to facilitate safe and legal operations for platooning on I-10 through each state, and to promote acceptance of platooning technology for long-haul trucking fleet operators who transport freight on the corridor.

To ensure consistent operations across the four states – and obtain assistance from the states in harmonizing legal operations for the Phase 2 operations and testing – the project team has engaged the I-10 Corridor Coalition which consists of Caltrans, the Arizona Department of Transportation (ADOT), the New Mexico Department of Transportation (NMDOT), and the Texas Department of Transportation (TXDOT). Collectively, these DOTs have been examining long-haul truck Vehicle-to-anything (V2X) applications, truck CAV infrastructure support, and truck CAV operations and regulatory needs on the I-10 corridor.

The I-10 Corridor Coalition includes senior-level transportation officials in each of the four states. These individuals included both state DOT personnel and state enforcement operations personnel and were leveraged by the California PATH team to set the stage for safe and legal operation of the platooning system for the operational testing. PATH held a series of meetings and engagement activities with each of the states. All three meetings were successful in obtaining initial information on the regulations and processes for exceptions to "following too closely" codes in each of the three states. Additionally, information on other specific rules and requirements in each state was gathered. A major focus of these efforts involves working with each state to develop the necessary agreements/commitments to support operational testing of the platooning system that is either consistent with current laws, or which provides documented exceptions to current laws to support the testing.

The PATH team relied on its project partner/subcontractor, Cambridge Systematics, to implement the continuous stakeholder engagement with the I-10 Corridor Coalition and the corresponding state trucking associations for this project, including:

- Maintaining regular communications with the I-10 Corridor Coalition member states, providing updates on Coalition webinars at applicable times during the project, and accessing Coalition assistance to facilitate cooperation with enforcement agencies in each state to support safe and legal platooning testing.

- Providing periodic updates to the representatives at the four state trucking associations (CA, AZ, NM, TX), and working with those associations as needed to create outreach opportunities to the trucking industry about this program.

In addition to coordinating with the stakeholders identified above, more broad-based outreach was planned for select freight industry events and relevant public sector events and venues. For example, during Phase 1, a brief overview of the platooning FOT concept was provided by Cambridge Systematics staff to an audience of over 500 attendees at the ITS California Annual Meeting in September 2019. During Phase 2, an example of this type of outreach could be a technical presentation at the American Trucking Associations (ATA) Management Conference & Exhibition (MCE) - this annual conference brings together about 3000 trucking leaders from across the country, and highlights economic, regulatory, and business trends focused on trucking fleet operations. PATH also plans to leverage the state trucking associations during Phase 2 to conduct outreach to the freight industry.

Finally, the PATH team has developed a Project Fact Sheet to support ongoing outreach activities. This Fact Sheet was first used to support the I-10 state stakeholder meetings described above. The state DOTs have said they will share the Fact Sheet with their agency leadership and other relevant agencies such as law enforcement

Appendix A. Truck Platooning Performance Measures

The following abbreviations, CACC system parameters and key platooning terms are used in Table A.1, which describes the Truck Platooning FOT performance measures:

Key Area IDs

OP: Platoon Operational Characteristics

S: Safety

M: Mobility

EE: Energy and Emissions

FLT: Fleet Operator and Driver Impacts

II: Infrastructure Impacts

SL: State and Local Government Impacts

VED: Vehicle Equipment Design Impacts

Priority Levels

MI: Most Important

I: Important

D: Desirable

CACC System Parameters

Driving mode: manual, CC (Cruise Control), ACC (Adaptive Cruise Control), CACC

CACC switch status: OFF, ON, resume

Brake pedal status: OFF, ON, percentage deflection

Acceleration pedal status: OFF, ON, percentage deflection

RMSE: Root Mean Square Error

T-Gap setting levels for ACC and CACC: e.g., 1 to 5

System fault mode: DSRC (Dedicated Short-Range Communications), radar/lidar/camera target tracking, control system, brake system control, torque/acceleration/speed control

Platooning mode: For a three-truck platoon, when truck 1 is in manual or ACC mode and trucks 2 and 3 are in CACC. For a two-truck platoon, when truck 1 is in manual or ACC mode and truck 2 is in CACC.

Disengagement: when an equipped truck operating in platooning mode transitions to manual driving, either automatically or by driver intervention.

Cut-in: when an unequipped vehicle drives in between two equipped trucks that are operating in platooning mode.

Table A.1 – PATH Team Performance Measures

ID	Requirement	Priority	Performance Measures	Definition	Data Needed	Sorting Criteria
OP-001	Performance measure(s) should capture how long it takes for truck platoon to be formed.	I	Truck departure delay associated with need to coordinate departures of the platooned trucks.	Difference between actual truck platoon departure time with times when the individual trucks would have been dispatched if they had not been platooned.	Actual truck platoon departure time; times when each truck could have been ready to depart; data provided by fleet operator	Two-truck vs. three-truck platoon dispatches
OP-002	Performance measure(s) should capture general behavior of trucks/drivers (e.g., speeding behavior, lane changing, etc.) as they seek to form or stay in a platoon.	MI	Frequency of lane changing Percentage of manual driving above speed limit (compare platooning trucks to reference trucks)	Number of lane changes made per 1000 miles Percentage of time in manual driving mode that truck speed is at least 5 mph over speed limit for both platooning trucks and the reference truck.	Driving mode (manual, CC, ACC, CACC); longitudinal speed/acceleration, during manual mode. Lane change event flags	Values for trucks in platoon are compared with values for reference trucks- Sort by geographic location (to identify how these are concentrated)
OP-003	Performance measure(s) should capture the usage rate of truck platoon system.	MI	Percentage of highway driving time/distance spent in platooning mode	For three-truck platoon, total time/distance when truck 1 is in manual or ACC and trucks 2 and 3 are in CACC divided by total time/distance. For two-truck platoon, total time/distance when truck 1 in in	Driving mode; location, front target relative speed/distance/accel; Gap setting level; road geometry (grade); load, vehicle position in platoon, lighting and weather conditions, and traffic density	Sort by gap setting, grade, load, lighting and weather conditions, location (highway section) and traffic density

				manual or ACC and truck 2 is in CACC divided by total time/distance.		
OP-004	Performance measure(s) should capture the frequency of splits and re-joins that occur due to unequipped cut-in vehicles	MI	Frequency of “cut-in” events and of cut-in events that required disengagements, and durations of each class of cut-in.	# of times a cut-in occurs and # of times a cut-in leads to CACC disengagement per 1000 miles. For all cut-ins, tabulate distribution of duration of cut-in and additional time needed to complete recovery (re-joining). Also sort by 2 vs 3 truck platoon.	For each cut-in event flag, capture: Driving mode, T-Gap setting of each vehicle; front target relative speed/distance/accel; cut-in vehicle location with respect to the platoon; time from arrival of cut-in vehicle to its departure; additional time for following truck to resume target gap behind preceding truck, GPS locations of each vehicle; weather and lighting condition records.	Sort by actual time gap, size of platoon, location of cut-in within platoon (trucks 1-2 or 2-3), grade, load, lighting and weather conditions, and traffic density, and severity of cut in (with or without disengagement
S-001	Performance measure(s) should capture how often platoon system notifies (or fails to notify) truck platoon drivers it is no longer controlling longitudinal gap	I	Frequency of CACC system failures that cause automatic disengagements	# of times the CACC system reports a fault serious enough to require automatic disengagement, and number of these faults that produce alerts to drivers per 1000 miles.	For each CACC failure serious enough to cause automatic disengagement, record: Driving mode; system fault mode; CACC switch status (on, off, resume), brake pedal status (0,1), T-Gap setting, front target relative distance/speed/accel; vehicle speed, whether driver was notified, etc.	Sort by system fault mode and whether driver was notified.

S-002	Performance measure(s) should capture how often platoon drivers disengage platoon system control	MI	Frequency of driver-initiated disengagements	# of times a driver manually disengages the system per 1000 miles	Manual disengagement flag, time gap setting, position of disengaging truck within platoon, speed, weather and lighting conditions, traffic conditions, geographic location. Reasons for disengagement will be manually coded by researchers into categories based on audio notes recorded by drivers.	Sort by the reasons for disengagement, position in the platoon, special weather or lighting conditions, location, traffic conditions.
S-003	Performance measure(s) should capture the number and types of platoon system failures	MI	Frequency of CACC system failures of each primary type (V2V communication, range sensing, vehicle response)	# of times the CACC system reports a fault of each type per 1000 miles.	For each failure, record the: Driving mode; system fault mode flag; T-Gap setting, max speed setting; info from driver voice recorded; explanation of reason for failure; front target relative distance/speed/accel; vehicle speed etc.	Sort by system fault mode, lighting and weather conditions, traffic density, and causes cited in driver voice recordings
S-004	Performance measure(s) should capture the overall reliability of the truck platoon system	MI	CACC system reliability (fraction of time that the system can be used during a trip when desired) and availability (fraction of	Reliability: 1 – (total amount of time system has a fault reported divided by total trip time). This is expressed as a percentage. Availability: # of truck trips dispatched with properly working	CACC system fault mode; duration of fault; any notable pre-failure events (cut-ins, hard braking events, etc.). Logs of truck CACC condition at time of dispatch of each trip.	Sort by grade, load, lighting and weather conditions, any notable pre-failure events (cut-ins, hard braking events, etc.)

			vehicle trips that can be dispatched with properly working CACC system)	CACC system divided by total # of truck trips dispatched, expressed in percent.		
S-005	Performance measure(s) should capture truck driver fatigue (i.e., levels of drowsiness) under platoon and non-platoon modes	MI	SmartCap Fatigue Level (1-5) average within 15-minute epochs as well as total durations at each level.	Fatigue level is reported by the SmartCap system (see Section 3.3.3) as a number from 1 to 5, with 1 being hyper-alert and 5 being asleep. Only levels 2-4 are reported, with 4 for some period of time triggering an alert to the driver.	Driving mode; elapsed time and/or distance in the trip and in hours of service; vehicle position in platoon; lighting and weather conditions, among other factors. Fatigue levels will be reported every 15 minutes although the system detects it continuously.	Sort by driving mode, elapsed time and/or distance in the trip and in hours of service, time of day, vehicle position in platoon, lighting, and weather conditions, among other factors.
S-006	Performance measure(s) should capture truck platoon driver attentiveness / vigilance (e.g., influence on distraction)	MI	Number of distraction events flagged within 15-minute epochs, types of distraction events (e.g., device, outside attractions, conversation,	While forward and face video are being recorded, the Jungo AI system (see Section 3.3.3) determines glance direction, head pose, eye closures, etc. The glance direction and head pose elements will provide information on the driver's attention.	Driving mode; elapsed time and/or distance in the trip and in hours of service; vehicle position in platoon; lighting and weather conditions, among other factors. Video will be recorded continuously, but the Jungo AI system will provide measures of distraction and attention to elements	Sort by driving mode, elapsed time and/or distance in the trip and in hours of service, time of day, vehicle position in platoon, lighting, and weather conditions, among other factors.

			etc.) and average length of time that the driver's attention is directed away from forward roadway. (Need to compare drivers of platooning trucks to drivers of reference truck to understand impact of platooning.)		other than the road on a periodic basis. The AI engine will report on counts and durations of sustained attention away from the forward roadway within periods of 15 minutes. No manual coding or analysis of the video records are envisioned, but spot checks of agreement between video and AI output will be performed on epochs identified as distraction events.	
S-007	Performance measure(s) should capture rates of crashes, near-crashes, and crash-relevant conflicts (including safety-critical events) between the trucks in the platoon.	MI	Frequency of crashes between equipped trucks Frequency of near- crashes between equipped trucks	Total # of crashes between equipped trucks per 1000 miles Total # of near crashes (as defined by a couple of time-to-collision threshold values) between equipped trucks per 1000 miles	Driving mode; target relative speed/distance/accel; Time-to-Collision; cut-in flag; timestamp synchronized video scene and driver voice recording data; driver behavior data (fatigue and attentiveness); traffic data from sensor for the surrounding traffic; road geometry	Sort by gap setting, grade, load, lighting and weather conditions, traffic density, and driver voice recording causes.

S-008	Performance measure(s) should capture rates of crashes, near-crashes, and crash-relevant conflicts (including safety-critical events) between platoon trucks and unequipped cut-in vehicles	MI	Frequency of crashes between equipped trucks and unequipped cut-in vehicles Frequency of near- crashes between equipped trucks and unequipped cut-in vehicles	Total # of crashes between equipped trucks and unequipped cut-in vehicles per 1000 miles Total # of near crashes (as defined by a couple of time-to-collision threshold values) between equipped trucks and unequipped cut-in vehicles per 1000 miles	Driving mode; target relative speed/distance/accel; Time-to-Collision; cut-in flag; time-stamp synchronized video scene and driver voice recording data; driver behavior data (fatigue and attentiveness); traffic data from sensor for the surrounding traffic; road geometry	Sort by gap setting, grade, load, lighting and weather conditions, and traffic density and driver voice recording causes
S-009	Performance measure(s) should capture rates of crashes, near-crashes, and crash-relevant conflicts (including safety-critical events) between platoon trucks and surrounding traffic (excluding cut-in unequipped vehicles)	MI	Frequency of crashes between equipped trucks and unequipped, non-cut-in vehicles Frequency of near- crashes between equipped trucks and unequipped non-cut-in vehicles	Total # of crashes between equipped trucks and unequipped non-cut-in vehicles per 1000 miles Total # of near crashes (as defined by a couple of time-to-collision threshold values) between equipped trucks and unequipped non-cut-in vehicles per 1000 miles	Driving mode; target relative speed/distance/accel; Time-to-Collision; cut-in flag; time-stamp synchronized video scene and driver voice recording data; driver behavior data (fatigue and attentiveness); traffic data from sensor for the surrounding traffic; road geometry	Sort by gap setting, grade, load, lighting and weather conditions, and traffic density and driver voice recording causes.

S-010	Performance measure(s) should capture the following truck's compliance with the system-defined minimum safe following gap	MI	Frequency with which a following truck in CACC mode falls below system-defined min gap Percent of time following truck in CACC mode falls below system-defined min gap	Number of times a following truck in CACC mode falls below system-defined min gap per 1000 miles Duration of time following truck in CACC mode falls below system-defined min gap divided by total time in CACC mode.	During operations in CACC mode, record all instances in which the time gap between a truck and its predecessor falls below the minimum allowable time gap, and record the relevant conditions at the time: target relative distance/speed/accel; vehicle total mass [kg]; road grade [%], V2V communication status, any fault condition flags	Sort by gap setting, grade, load, lighting, and weather conditions
S-011	Performance measure(s) should capture instances where platoon system initiates unnecessary collision avoidance (i.e., false positives).	I	Frequency of inappropriate braking actions by the CACC system (false positives) as reported by drivers.	Specific instances when drivers make a voice or written report of an inappropriate braking action per 1000 miles. (Note this is not collision avoidance, which is not part of CACC functionality)	Driver voice reports or post-trip written logs of inappropriate braking actions. For each event, record the time of occurrence, truck speed, Driving mode, position in platoon, all fault flags, braking profile, forward target distance/speed/accel, and TTC.	Report on individual event basis.

S-012	Performance measure(s) should capture the accuracy with which the platoon trucks maintain the system's current set/target following gap(s)	MI	Root Mean Square Error (RMSE) of distance tracking Max Error of distance tracking	Difference between actual distance to forward truck and desired following distance based on time gap setting. Maximum and RMSE values calculated for each period of continuous CACC usage.	Target relative distance; reference distance; vehicle total mass [kg]; road grade [%]	Sort by gap setting, grade, load, lighting, and weather conditions
M-001	Performance measure(s) should capture differences in travel time/travel time reliability of truck trips under platooning and non-platooning modes.	D	Difference in Travel Time between platoon trucks and reference trucks per trip.	Total travel time of platoon minus total travel time of reference truck from origin to destination.	Platoon and reference truck will be dispatched at about the same time and the differences in their arrival times at the destination will be recorded to make the comparison.	Sort by trips with two-truck and three-truck platoons.
M-002	Performance measure(s) should capture impacts of truck platoon on tactical behavior of surrounding traffic	I	The PATH team is not planning to report a specific performance measure for this requirement; however, archived data will be available to enable other analysts to	N/A	Side-mounted video cameras and lidars on truck capture information about target objects in adjacent lanes on both sides enabling recording of: truck speed, target lane object speeds and locations. Note that processing of those data will be complicated and not affordable within project budget.	N/A

			estimate this based on the complete speed profiles of the platooned trucks and reference truck and sensor data on the traffic in the adjacent lanes.			
M-003	Performance measure(s) should capture traffic flow impacts of truck platoons on deployment corridor under different conditions.	D	The PATH team is not planning to report a performance measure for this requirement; however, archived data including complete speed profiles of platooned trucks and reference truck will be available for others to try to use to calibrate traffic	N/A	Side-mounted sensors on trucks will capture motions of traffic in adjacent lanes.	N/A

			simulation models			
EE-001	Performance measure(s) should capture changes in fuel use due to truck platoons	MI	Difference in fuel consumption rate between platooning trucks and reference trucks	Difference between the average fuel consumption rate of the 2 or 3 platooning trucks and the average fuel consumption rate of the reference truck for each trip (fuel consumption rate will be converted from grams/sec to gallons/hour)	Fuel injector data from truck CAN bus; gap setting, front vehicle range/relative distance, total mass, road grade, truck position in platoon The reference truck driver will keep within the line of sight (150 ~ 200 m) of platoon so that the traffic will be similar.	Sort by gap setting, front vehicle range/relative distance, total mass, road grade, truck position in platoon.
EE-002	Performance measure(s) should capture changes in emission levels due to truck platoons	D	Difference in total emissions per trip between platooning trucks and reference truck	Difference between the total emissions of the 2 or 3 platooning trucks (averaged) and the total emissions of the reference truck for each trip	From OBD-II connection by polling data; aggregated for each trip; parameters may include CO2, NOx,	Sort by gap setting, front vehicle range/relative distance, total mass, road grade, truck position in platoon.
FLT-001	Performance measure(s) should capture impacts of truck platooning on Fleet Operators daily operations	D	Increased dispatch time due to platooning (per trip) Increased cost due to	Difference between dispatch time of platoon trucks and dispatch time of reference truck per trip Difference between logistics cost of platoon trucks and	Logs of truck dispatching and driver assignments prior to platooning; routing; loads; container/trailer types; driver ID/name, dispatching time; any extra cost in organizing platoon operation	Sort by routing; loads; container/trailer types.

			platooning (per trip)	logistics of reference truck per trip		
FLT - 002	Performance measure(s) should capture cost savings to fleet operators due to fuel efficiency gains	D	Fuel cost savings due to platooning (per 1000 miles)	Difference between average fuel cost of reference truck per 1000 miles and average fuel cost of platooning trucks per 1000 miles	Fuel consumption differences estimated in EE-001 will be used to calculate fuel cost savings by comparing results from platooned trucks with results from reference truck.	Sort by gap setting, front vehicle range/relative distance, total mass, road grade, truck position in platoon.
FLT - 003	Performance measure(s) should capture impacts of training on truck platoon driver's performance as well as fleet operators operations.	D	No quantitative performance measure will be reported. A qualitative assessment will be reported at the end of the test.	Qualitative assessment will be based on results of driver questionnaires.	Drivers and fleet operators will complete questionnaires before and after training. Pre-training questionnaires will address understanding of the platooning technology, expectation of their role and responsibilities, expectations for safety effects, perceived benefits, and perceived desirability of using the platooning technology. Another questionnaire administered immediately after training will address the same topics to determine how training changed comprehension, expectations, etc. Additional questions will	N/A

					assess perceived benefits and limitations of the training itself. Similar questions will be administered as drivers gain on-road experience (see FLT-004 and FLT-005).	
FLT-004	Performance measure(s) should capture how drivers adapt to the truck platoon system over time.	I	mean following distance mean time gap rate of engaging in non-driving	Average following distance per trip by driver: Integrated Distance-Gap over distance divided by the trip distance Average time gap per trip by driver: Integrated Time-Gap over distance divided by the trip distance	Driver ID; following distance; time gap; (over a sample epoch of 1 minute) will be recorded for each driver. Subjective measures will also be collected from interviews with drivers. These include drivers' self-reports about changes in their driving style and use of the platooning system that have happened as they gained experience.	Sort by driving mode; beginning of trip vs end of trip; beginning of test period vs middle of test period

			related activities			
FLT-005	Performance measure(s) should capture driver acceptance/satisfaction of/with truck platoon technology	MI	Subjective rating scale scores (i.e. 0 to 10)	A subjective rating of driver acceptance/satisfaction assigned by the drivers during interviews.	Drivers will be interviewed and will be asked to complete several rating scales (i.e., 0 to 10) to assess their acceptance of and satisfaction with the truck platoon technology. Questions will address drivers' opinions about the platooning system's user interface, usability of the system, comfort with disengagements and re-engagements, preferences for position within the platoon and following distance settings, perception of impact of platooning on workload/stress level, confidence in reliability and trust in the system, perceived impact on fatigue, preferences for aspects of platooning with a team versus driving independently, impact of platooning on job satisfaction/morale, perceived impact of platooning on schedule and pay.	N/A

FLT-006	Performance measure(s) should capture Fleet Operators' acceptance/satisfaction of/with truck platoon technology.	MI	Subjective rating scale scores (i.e., 0 to 10)	A subjective rating of Fleet Operator acceptance/satisfaction assigned by the fleet operator managers during interviews.	Fleet Operations Managers will be interviewed and will be asked to complete several rating scales (i.e., 0 to 10) to assess their acceptance of and satisfaction with the truck platoon technology. Questions will address fleet managers' confidence in the reliability of the system, perceived impact on drivers' fatigue, preferences for platooning versus driving independently, impact of platooning on manager's job satisfaction, perceived impact of platooning on schedules. Perceived costs and benefits of platooning for company, including driver morale.	N/A
FLT-007	Performance measure(s) should capture how truck platoons affects driver behavior (e.g., highway following gap) in non-platoon situations.	MI	mean following distance mean time gap	Average following distance by driver Average time gap by driver	Driver ID; Driving mode; max speed set; actual speed; target relative accel/speed/distance; yaw rate, steering angle, lateral acceleration; truck position in platoon; manual disengagement flag	Sort by Driving mode
II-001	Performance measures should capture the impact	MI	The PATH team is not planning to report a	N/A	Relevant truck characteristics that are static may include axle weights, gross vehicle	N/A

	of truck platoon on bridge structures.		specific performance measure for this requirement; however, truck characteristics and speed profiles can be provided for USDOT analysis		weight, spacing between axles. Dynamic variables that are relevant may include gaps between trucks in the platoon, driving speed of the platoon and acceleration/ deceleration and speed profiles.	
II-002	Performance measure(s) should capture information on infrastructure configuration/characteristics suitable for truck platoons and vice versa, as experienced during trip.	I	Percentage of highway driving time/distance spent in platooning mode (For specific challenging scenarios within the ODD)	Total time/distance when following truck(s) are in CACC mode divided by total time/distance for situations such as: • Positive or negative grades above defined threshold values • Curve radii below defined threshold values • Ambient traffic speeds below defined threshold values • Traffic density above defined threshold values	Identify specific scenarios or locations along the test route(s) with specific road geometry features of concern (curve radii, grades, pavement condition) and capture: drive-mode; actual speed; T-Gap selection; GPS data; front video data; other sensor data; pavement condition data based on recorded driver's voice	Sort by driving scenario (e.g., normal conditions, large downgrade, large upgrade, sharp curve, rough pavement, etc.)
II-003	Performance measure(s) should capture impacts of truck platoon on	D	The PATH team does not plan on having a performance	N/A	N/A	N/A

	roadway pavements.		measure for this requirement since it is impractical.			
SL-001	Performance measure(s) should capture interactions between truck platoon drivers and law enforcement officials	MI	Counts of instances of law enforcement pull-overs Rates of instances of law enforcement pull-overs	Number of times a test truck (control or platoon) is pulled over by law enforcement for inspection or other reason Number of times a test truck (control or platoon) is pulled over by law enforcement per 1000 miles driven	For each instance of a pull-over, information should be collected by way of a voice recorder or call to dispatch that will include elements such as: • Date/time • Location (state, road, travel direction, mile marker) • road type (number of lanes) • Posted speed limit • grade (up, down, or flat) • enforcement agency (state, county, or other) • traffic level (light, heavy, or congested) • weather (clear, rain, snow, ice, fog, windy, or other) • whether or not platooning was engaged at time • number of trucks stopped • duration of the stop • outcome (ticket, warning, info exchange, curiosity)	Sort by platooning vs non-platooning (reference truck)
SL-003	Performance measure(s) should capture impacts/differences (if any) in truck inspection and	D	Measures listed above for SL-001 plus: Delay time due to being	Measures listed above for SL-001 plus: Total amount of time each truck is delayed by pull overs, separately tabulated	Each driver will make a log entry about each inspection or enforcement action that he or she encounters, with specific information about the	Sort by platooning vs non-platooning (reference truck)

	enforcements for truck platooning		pulled over by law enforcement	for platooned trucks and reference truck, and normalized by hours of driving in each mode.	length of the stop. When this involves a truck driving in platoon, the extra delay time will also be logged for the other trucks in the platoon that would not have had to stop otherwise.	
VE D-001	Performance measure(s) should provide information regarding drivers opinions on truck platoon equipment design deficiencies observed	I	No quantitative performance measure will be reported. A qualitative assessment will be reported at the end of the test.	Qualitative assessment will be based on results of driver questionnaires.	Driver survey data: reliability of the system; usefulness of installed equipment related to driver behavior; opinion on driver's distraction such as DVI design; driver's comfort for platoon operation. For specific problems flagged during a trip by driver logging a complaint by voice recording, the relevant vehicle data will be flagged, including T-Gap selection; speed; specific location, road geometry (curvature and grade, number of lanes).	N/A
VE D-002	Performance measure(s) should capture the reliability of V2V communications between trucks in a platoon.	MI	Rate of DSRC failures	Number of DSRC communications failures between each pair of trucks per 1000 miles driven. Note: DSRC failure is a drop out of more than 2 secs.	communication health status data between each pair of trucks in the platoon	Sort by gap setting, front vehicle range/relative distance, road grade, truck position in platoon.

			Count of handshake failures	Number of times when DSRC failed to connect at start of platoon trip		
VED-003	Performance measure(s) should capture the effectiveness of information provided to drivers of following trucks	I	No quantitative performance measure will be reported. A qualitative assessment will be reported at the end of the test.	Qualitative assessment will be based on results of driver questionnaires.	Driver survey data, including questions about differences based on position in platoon.	Sort by position in platoon