Truck Platooning Early Deployment Assessment: Phase 2

Test and Evaluation Plan

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16. Abstract

This report documents the Test and Evaluation Plan of the Federal Highway Administration (FHWA) Truck Platooning Early Deployment Assessment Phase 2 project. The test plan includes four stages: (a) Cooperative Adaptive Cruise Control (CACC) system performance test by PATH team, which combined step-by-step implementation and CACC system tests to make sure each component and the integrated CACC system behaves as expected technically; (b) Driver Acceptance Test (DAT), which would be a round trip drive of three fully loaded CACC trucks driven by professional truck drivers 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; (c) Operational Readiness Test (ORT), which would be the test of the overall system including CACC truck platooning on the test route along Interstates 10 and 20, the data collection system on the trucks, the real-time monitoring system, the data acquisition system (DAS) and uploading from Roly's Trucking to UC Berkeley, and the data logging and storage. This is to find out if the overall system is ready for the fourth stage, the Field Operational Test (FOT). The evaluation plan includes data-health checking, intermediate parameter (metadata) calculation and data analysis with respect to a list of performance measures such as truck-platoon behavior, traffic interactions, safety, fuel-economy benefits, logistics of truck-platoon fleet operations for freight movement, and drivers' behaviors, opinions, and satisfaction with the CACC system, etc.

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Executive Summary

This report documents the Test and Evaluation Plan of the Federal Highway administration (FHWA) Truck Platooning Early Deployment Assessment Phase 2 project. The Test Plan describes how to test the Cooperative Adaptive Cruise Control (CACC) trucks and the overall system in preparation for and including the Field Operational Test (FOT). The Evaluation Plan includes the data list, metadata calculation outline, and performance evaluation procedures for a wide range of aspects of truck platoon performance and operations. Test Plan

The Test Plan includes four stages:

- CACC system performance tests
- Driver acceptance test (DAT)
- System operational readiness test (ORT)
- Field operational test (FOT)

Those four bullet points are briefly described below.

CACC system performance tests

CACC tests were conducted by the PATH project team, combined with 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 as expected technically 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 tests at this stage, the team was able to verify the functionality and reliability of the components and to decide if any components would need to be replaced with better ones.

Driver acceptance test

The driver acceptance test (DAT) would be a round trip drive of three fully loaded CACC trucks by Roly's 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 an especially important step since the drivers would need to accept the CACC system before the FOT. If there are some flaws and deficiencies experienced by the drivers, the project team would need to revise and improve the system to reach the driver's acceptance and satisfaction. The main scenarios to be tested at this stage are:

1. Switch On/Off of the Adaptive Cruise Control (ACC) and 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 including incidents, driver's information input such as ID and platoon position
4. Driver's understanding of the Operational Design Domain (ODD) and driver responsibilities: what the driver must do and must not do, and what the driver can select optionally.

In addition, this test will also check the CACC system functionality and performance under the operation of professional truck drivers in road conditions such as long distance up/down grades.

System operational readiness test

The objective of this test is to check if the overall system is ready for a FOT. The overall system includes:

- CACC truck platooning system driving on the test route along Interstates 10 and 20
- Data collection system on the trucks, which collects driver behavior monitoring data from SmartCap and Jungo system, engineering data from the J-1939 Bus, control computer, GPS (global positioning system), DSRC (dedicated short range communications), DVI, and added sensors such as fixed beam lidar and video data representing the surrounding traffic.
- Real-time monitoring system, which is implemented with a modem link between the CACC trucks in the field and PATH at UC Berkeley. This would allow the project team to:
    - 1.3 Check the CACC system and other components on the trucks in real-time
    - 1.3 Fix some software problems remotely
    - 1.3 Reboot the PC-104 control computer and the Quantum Data Collection System in case necessary.
- Data acquisition system and uploading from Roly's Trucking to UC Berkeley: This process would include:
    1. Insertion of the solid state drives (SSDs) loaded with experimental data from the trucks to the magazines at Roly's Trucking
    2. Automatic activation of data checking and uploading from the SSD to PATH Data Server at Berkeley
    3. Generating a backup copy of the data at RAID data storage at Roly's Trucking.
- Data logging and storage at PATH at UC Berkeley: After data has been uploaded from the SSD at Roly's Trucking to the PATH Data Server, the following actions need to be taken:
    1. initial health checking for completion of the data automatically to find out if there are any significant data errors and determine if any corrective actions are necessary
    2. loading the checked data to Google Drive of UC Berkeley.

Field Operational Test

The FOT will be conducted for 12 months on I-10 and I-20 Corridor between Roly's main terminal in Rancho Cucamonga, California and a Roly's terminal in Fort Worth, west Texas. Professional truck drivers will be recruited on a volunteer basis, trained how to operate the CACC trucks for platooning, and tested for qualification before real operation. The platoon will have three trucks most of the time with the fourth truck driven as a reference truck for performance evaluation. The four trucks may not start from the same origin depending on the demands and their locations in practice. In those cases, on-the-fly platoon forming will be conducted based on predetermined rules such as heavier trucks will be in the front, and the driver may need to input the actual position of the truck after the platoon is formed beside the GPS-based platoon position determination. The truck movements for FOT will be monitored in real-time through modem connections. After each trip, the IT engineer in Roly's trucking will be responsible to swap the SD on the truck with those emptied SDs in the magazines at Roly's Trucking for automatic data uploading to PATH data server. Then those raw data will be checked for health, saved, backed up, shared with FHWA and IE, and aggregated to generate a list of intermediate parameters for performance evaluation and other uses at later stages.

Evaluation Plan

The evaluation plan includes:

1. Data-health checking with bounds and some data correction
2. Calculation of the intermediate parameters (metadata) for later stage data analysis
3. Sharing the data with FHWA and Independent Evaluator (IE) through the USDOT (United States Department of Transportation) Secured Data Commons (SDC)
4. Performance evaluation through data analysis with respect to a list of measures. Those measures are related to:
    - Truck-platoon functionality behavior
    - Interactions of the platoon with the surrounding traffic such as following, lane change, other vehicles cut-in, cut-out, and merging from onramps
    - Safety related scenarios including the relative speed/distance, service brake use, coordinated emergency braking activation, Collision Mitigation System activation, warning system activation (Frontal Collision Warning, Side Collision Warning; Lane Departure Warning, ABS Warning etc.), steering angle, and rate
    - Fuel-economy and emission reduction benefits for truck platooning operation
    - Logistics of truck-platoon fleet operations for freight movement
    - Drivers' behaviors, opinions, acceptance/satisfaction and suggestions with the CACC system, etc.

Chapter 1. Introduction

1.1 Background

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

PATH and its team built upon a previous truck platooning effort funded under the FHWA Exploratory Advanced Research (EAR) Program and subsequently tested under United States 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 CACC technology. The PATH team refined the system to make it suitable for the Phase 2 FOT.

In Phase 2, the PATH team leased four new Volvo trucks and equipped them with CACC technology and a suite of data collection equipment. 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 operate as 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 2-truck platoon might be used in place of the three-truck platoon. The field test was planned to run for 12 consecutive months with data continuously collected and periodically shared with the USDOT and their IE during the test (update intervals for data sharing are identified in Table 5).

1.2 Purpose

The purpose of this Test and Evaluation Plan is to specify how the PATH team planned to capture, monitor, report on, and maintain the data and the calculated key performance measures that have been identified for the field test to ensure that quantitative performance measurement is embedded as a core field test capability. This document builds on the previous Phase 1 deliverables and is an update to the Phase 1 Test and Evaluation Plan.

1.3 Scope

The primary intent of this document is to first summarize the experimental design of the FOT and the performance measures that are critical to the Phase 2 field test and then present a comprehensive data management plan. The data management plan includes several key elements including data description, data acquisition, data storage and access, data reporting, and data analysis.

As part of the process of developing the Phase 1 Test and Evaluation Plan, the PATH team worked closely with the independent evaluator (IE) Noblis to develop the key performance measures and data management plan needed for the Phase 2 field test. The interactions included the PATH team's participation in a two-day workshop, hosted by the IE in Washington DC and follow-up meetings, webinars and phone calls. These interactions continued during Phase 2 of the project as described in the IE Support Plan (see Reference 8). PATH also coordinated with fleet partner Roly's in the development of this plan to get their concurrence on the experimental design (described in Chapter 2) and the data management plan for the Roly's facility (described in Chapter 3).

1.4 References

The following documents are provided as references for this Test and Evaluation Plan deliverable.

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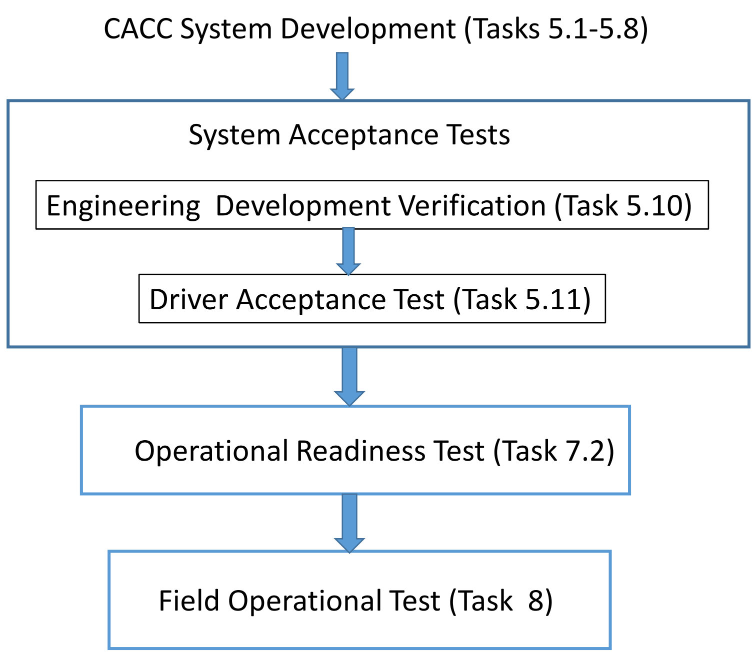
1.5 Document Overview

In the remainder of this document, Chapter 2 provides a summary description of the experimental design for the Phase 2 sequence of tests. Chapter 3 presents the data management plan (DMP). The data management plan follows the USDOT recommended format seen in Reference 11 and covers many important topics including a description of the data to be collected, how that data would be stored and shared, and a discussion of relevant data standards and sample data sets. Finally, Chapter 4 discusses how the data would be reported out to USDOT and the IE and how the data would be analyzed during the evaluation phase of the project.

Chapter 2. Experimental Design

This section presents the experimental design developed for the second phase of the Truck Platooning Early Deployment Assessment Phase 2project. The main purpose of the experimental design is to define how the tests would be structured to capture the data that are needed to inform the performance measures that help answer the key research questions. Another reason for the experimental design is to explain how human subjects (study participants) would be involved in the project in order to obtain human use approval (see Reference 10). PATH planned for three stages of testing involving professional truck drivers (human subjects) in the project: Driver Acceptance Test, Operational Readiness Test, and Field Operational Test (FOT).

Each of these different stages of tests are associated with different tasks in the project work plan (see Reference 7), as shown in Figure 1. 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.



Source: PATH, 2022

Figure 1. Relationship among Planned Testing Stages and Tasks

2.1 Driver Acceptance Test (DAT)

The DAT is an important subset of the System Acceptance Test. The main portion of the System Acceptance Test is a technical verification of the engineering development work, implementing the CACC control system on the four new Volvo trucks, and culminating with public road testing in and near the San Francisco Bay Area. These engineering tests were 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 were done using truck tractors only, the System Acceptance Tests (including the DAT) were done with trailers to provide the most realistic testing conditions. The engineering data acquisition system collects a full set of diagnostic data on the performance of the CACC system, but at this stage testing did not cover the external traffic monitoring video data collection system, which is not needed for purposes of the System Acceptance Test.

The PATH team initially implemented and refined the CACC system developed in the previous FHWA EAR Program project on the Volvo VNL 760 trucks, and also developed the DVI, real-time monitoring system, and data collection system. The lower level control actuation from the previous project was done by direct engine torque control, however for this FOT with regular truck drivers (rather than test drivers), Volvo insisted that the engine control should go through their ACC system instead of bypassing it for safety reasons. However, the default ACC setup on the four VNL 760 trucks purchased by Roly's would not allow us to do so. The main problem is that once the service brake is applied, whether automatically or manually, the engine torque control (ACC) is disabled so the driver would have to reactivate it, which is also true for the manufacturer's production ACC. To resolve this problem, it would be necessary for Volvo and Bendix, the provider of the service brake control ECU (Electronic Control Unit), to work closely to change the ECU hardware and/or software, which the PATH team would not be able to do. This difficulty was not recognized by Volvo and Bendix until after many cycles of low-level Controller Area Network (CAN) data collection and analysis and shipping one truck to Volvo in Greensboro, NC in July 2022 for direct diagnostics. This process took about a year and required a significant number of resources from the PATH team. It also caused a substantial delay of the project so that it could not be accomplished within the proposed timeline and resources. One of the lessons learned from this experience is that the project team should include the manufacturers of the vehicle and its critical subsystems as direct participants so that timely technical support from them can be guaranteed.

After proper technical performance has been verified by means of these local System Acceptance Tests, the next step would be the DAT using drivers from Roly's Trucking.

The DAT is needed to make final refinements on the system to ensure good usability by regular truck drivers based on considerations such as:

- 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 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.

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, we expected to 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 has developed some 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 was designed to 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, and QC and reduction post-processing routines to be used on the data as it comes in from the FOT.

Because this would be the first time that drivers would 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. Furthermore, because the intended users during the FOT would be drivers from Roly's Trucking, it made sense to focus this test on the same population of drivers. This simplifies the driver recruitment process and provides 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 eight and ten 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 would also give 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 are therefore:

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 included 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. This was completed by December 2021.
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 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 drive from PATH in Richmond to Roly's in Rancho Cucamonga, accompanied by four PATH staff in the respective passenger seats, who 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 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 and especially 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 that they observed 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.
7. The lessons learned from this test would be documented in the System Acceptance Test Results Report to FHWA and used to guide modifications to the systems that can be made prior to the FOT.

2.2 Operational Readiness Test (ORT)

The ORT would be conducted as a "dress rehearsal" for the FOT, combining all the elements that would be 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 provides 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 gives USDOT and the IE an opportunity to experience how the trucks operate in mixed traffic while in platooning mode and ask the PATH team questions. If USDOT is comfortable with how the trucks perform in this initial demonstration, then PATH and Roly’s commence the full ORT as outlined below.

The ORT involves 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.

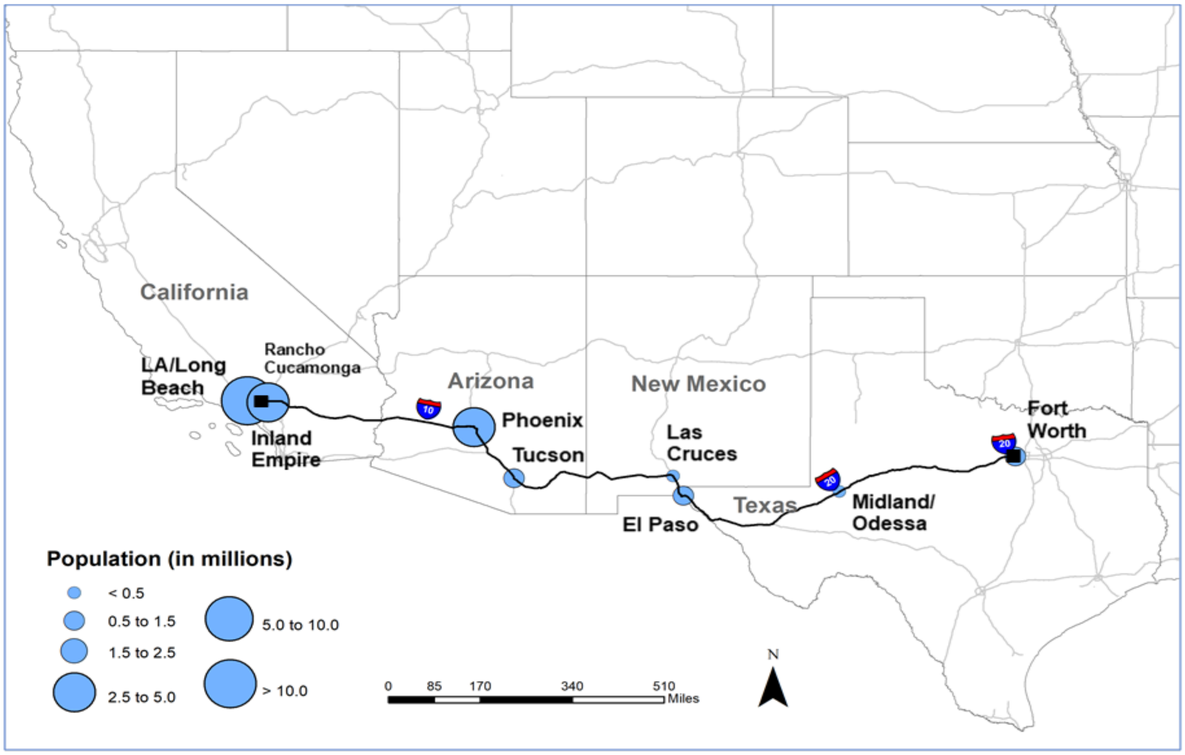
The analysis of the data from the ORT would be focused on ensuring that the CACC control, driver monitoring, and data acquisition systems are working correctly under the full-scale FOT conditions and that the drivers and fleet operations managers are able to conduct the necessary platoon driving and data management operations. This is 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.

2.3 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 a Roly’s terminal in Fort Worth (see Figure 2, below).

Figure 2 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. This route is the busiest shipping route for Roly’s Trucking, which runs dozens of trucks between southern California and Texas daily.



Source: PATH, 2022

Figure 2. 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 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. The reference truck and the platooning truck drivers would be instructed to travel at the same speed and stay within a few miles of each other during the trip. This means that all four trucks would experience the same traffic and weather conditions, and have the same data collection capabilities so that there would be an opportunity for a direct comparison between the platooned and non-platooned truck driving in multiple dimensions (measures of performance for the comparison are discussed in Chapter 4.2):

- Fuel consumption
- Truck driver behavior, including attentiveness and fatigue
- Interactions with surrounding traffic and their safety implications
- Travel time between same origin and destination (accounting for the 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, and 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 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 we 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 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 would 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 could 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"), we were able to calibrate the fuel injector measurements (available during the real-world field test on the trucks) against the gravimetric measurements, so we would be able to use the fuel injector signals that we record from the trucks as the basis for fuel consumption comparisons. These would 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 could then be compared with the fuel injector measurements from the reference truck to determine the savings associated with the platooning. This calibration work was accomplished in collaboration with DOE and Transport Canada, while testing our 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. 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.

2.3.1 Operational Considerations

In order to obtain a comprehensive set of data to reveal the real-world impacts of truck platooning, there are several important operational considerations that 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, but the drivers would be instructed to not use the platooning system in congested traffic in those locations.

The 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 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 would 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 to minimize risks during the FOT the drivers would be instructed to deactivate CACC when the traffic speed decreases below 35 mph. There are some locations (e.g. near interchanges in New Mexico) where the drivers would also be asked to drive manually because of state guidelines so these types of restrictions would be incorporated into the training process. In the end, one of the important learning opportunities from the FOT would be 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).

2.3.2 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 allows us to understand driver and dispatchers' perception and how they may change with growing familiarity of the system.
- Obtaining objective, state of the art measurements of driver drowsiness (fatigue) and attentiveness to their driving related tasks. We 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 are 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 Chapters 2.1 and 2.2, respectively) would not be suitable subjects for this experiment, so additional drivers would 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. Our 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 we intended 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 planned for a dedicated pool of drivers assigned to the test trucks, and in order to obtain a large enough sample of different drivers we planned to rotate this pool 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), we planned for six drivers in each cohort, based on Roly's recommendation. We anticipated that about 20 to 24 drivers would 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 driver cohort was planned to be larger than the number of trucks to provide some scheduling flexibility in the event that not all of the drivers are available when the platoon needs to be dispatched. 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. This is important so that we can 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 make sure 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 Adaptive Cruise Control (ACC) in one of the instrumented trucks (i.e. four reference trucks). This is 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 to enable observation of 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 we would also be examining their car following behavior and their selection of gaps in the ACC mode 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 are expected to use ACC in the reference truck because this enables 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.

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 are 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 the PATH White Paper on Driver Recruitment and Training during their participation in the FOT.

Table 1. Sequence of Events for Test Drivers

Stage/Duration	Description	Round Trips
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

2.3.3 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 3 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, we 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 then checked by Spanish-speaking students who are available for hourly employment, since the software accuracy cannot be trusted completely.

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 we 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 Departments of Transportation (DOTs) 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.

Chapter 3. Data Management Plan (DMP)

This chapter presents a data management plan that is consistent with USDOT guidance for data management plans (DMPs). The purpose of this DMP is to describe how PATH would manage 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 would be collected, how the data would be managed, how the data would be made accessible, how the data would be stored, and what data standard(s) would be used.

3.1 Performance Measures

Establishing good performance measures is critical to answering the key research questions of the Truck Platooning Early Deployment Assessment Phase 2 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.

3.2 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 Chapter 4. Table 2 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 2. 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 and end of their assigned driving assignments.	Text	Drivers fill out bilingual questionnaires (paper forms) to be converted into Excel files	.xls
Data collected at specific project milestones	Fleet Surveys	Questionnaires cover fleet dispatcher and manager challenges, attitudes, preferences, and value assessments of platooning logistics. Staff would 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
Data collected at specific project milestones	Truck Characteristics	Weight, trailer weight, length, maximum torque	Numerical data	Truck documentation	.csv
Data collected at specific project milestones	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
Abnormal Events	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

Category	Data Set	Description	Type	Collection Method	File Format
Fleet Operator Data	Inspections	Basic Inspection of Terminal (BIT) required of trucks every 90 days in CA Driver Vehicle Inspection Report (DVIR) before and after every trip Random pull-overs during trips	Inspection report and tag given to driver; kept with driver logs, numerical data	Enforcement activities DVIR GPS Diagnostics	.csv, .xls, .pdf
Fleet Operator 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
Fleet Operator Data	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, disengagement s 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
Voice Recorded Data	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
Engineering Data	CAN Bus Data	Raw CAN bus data, saved in text log files	Numerical data	PATH database CAN client logs	.txt
Engineering Data	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
Engineering Data	Lidar Sensor Data	Data from Lidar sensors added to capture surrounding traffic	Numerical data	Lidar Sensors	.txt

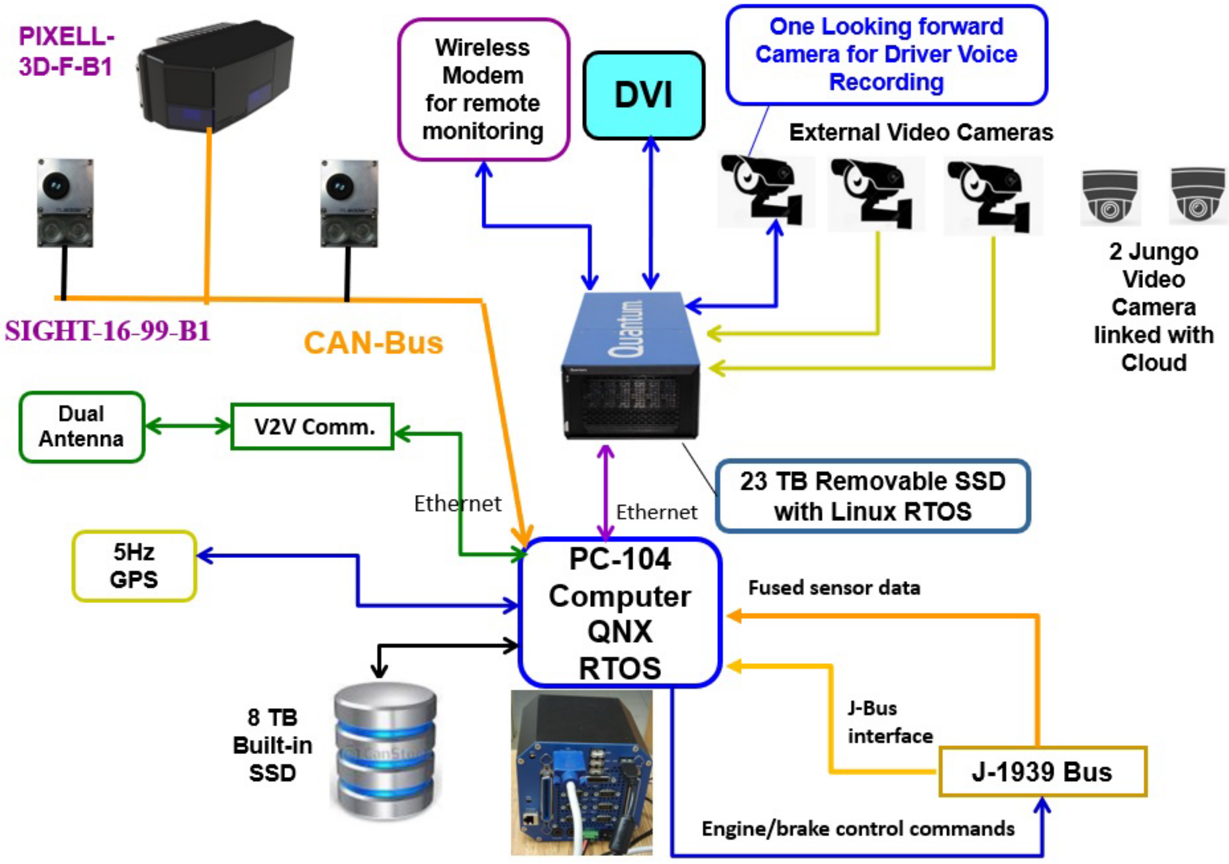
Category	Data Set	Description	Type	Collection Method	File Format
Engineering Data	Look Ahead and side Video*	Video continuously recording truck's surroundings	Video data	Video cameras installed by PATH on outside of the truck	.mp4
Driver Behavior Data	Driver and road-ahead video* and associated head 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 Behavior Data	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

3.3 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 truck. 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 3. 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 would collect the engineering data from the truck's data bus and the CACC system and save it continuously to a large data drive. The second is an engineering computer that would collect other sensor data from video cameras, lidar units and driver monitoring system and save 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 3, 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 camera and the V2V (Vehicle-to-Vehicle) communication. It also linked with the Quantum data collection system with an internal processor running Linux as the Real-Time Operating System. The latter collect video data and runs DVI and real-time monitoring program through wireless modem. It also receives and saves all the engineering data from the control computer.



Source: PATH, 2022

Figure 3. Data acquisition system installed on each truck

3.3.1 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 3 shows the estimates of total data size for 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 Quantum Data Collection System which has an internal industrial computer and a removable 23 TB solid state drive (SSD) to be able to store and transfer this amount of data from the trucks after each trip as explained below.

Table 3. Total data size estimates for data collection for each FOT round trip

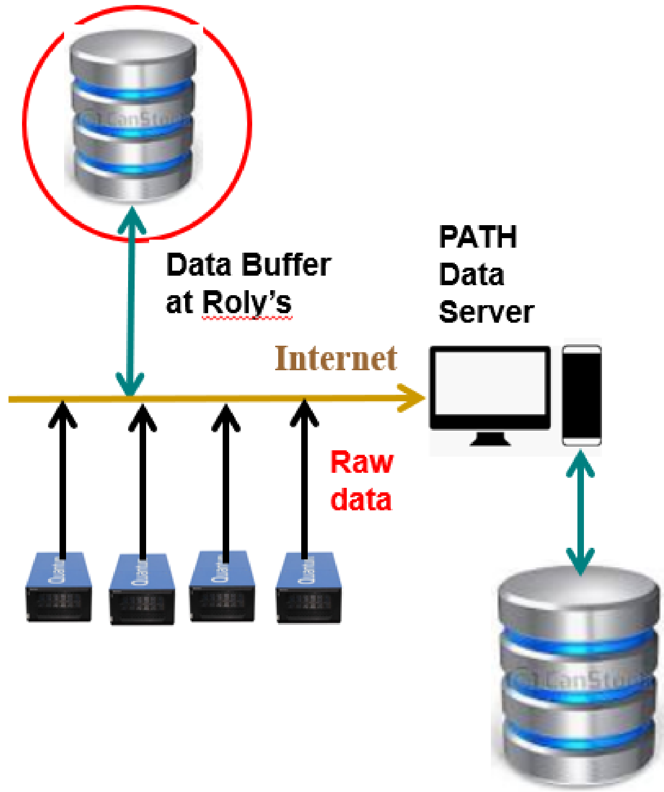
Sensor	Data size per hour in [GB]	Number of units on each truck	Hours per round trip	Number of trucks	Subtotal data size in [GB]
Video camera data	3.30	3	56	4	2217.60
Engineering data	1.00	1	56	4	224.00
Jungo camera data	0.57	1	56	4	127.23
Total data size					2,568.83

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. **Error! Reference source not found.** shows the estimate of time necessary for transferring the enhanced set of data that includes continuous video.

Table 4. 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 4 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. We planned to install a PATH data transfer computer and 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 4, below. 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: PATH, 2022

Figure 4. 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 successful copied to RAID and the PATH data server. Once successful data transfer has been verified, the old data on the SSD would be deleted to increase storage capacity for the next trip.

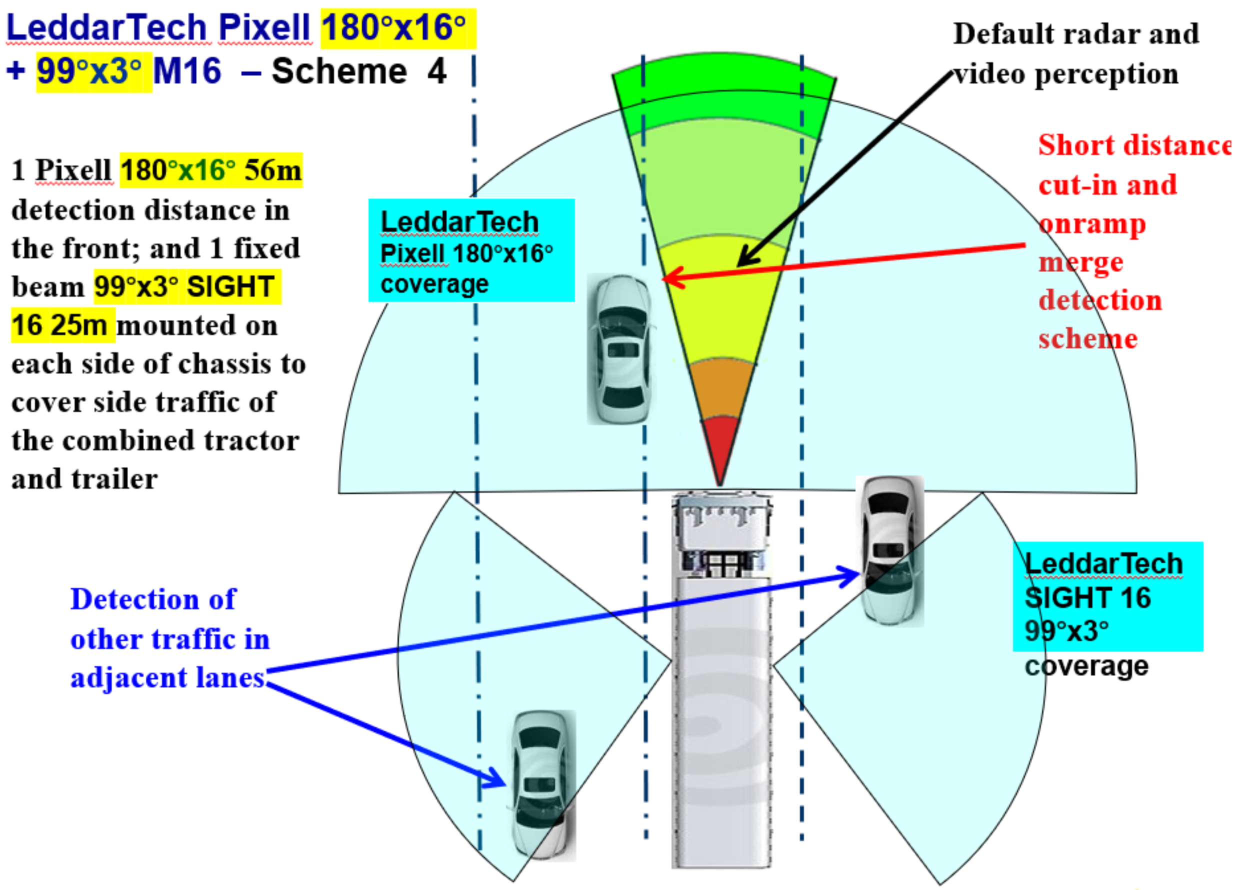
The advantages of using a RAID or RAID-like data storage at Roly's trucking are:

- It uses local data copying for quickly transferring data from removable SSD to RAID Data Storage, which does not rely on the internet; this can avoid 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 4. 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 would 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.

3.3.2 Truck Mounted Sensors for Traffic Detection

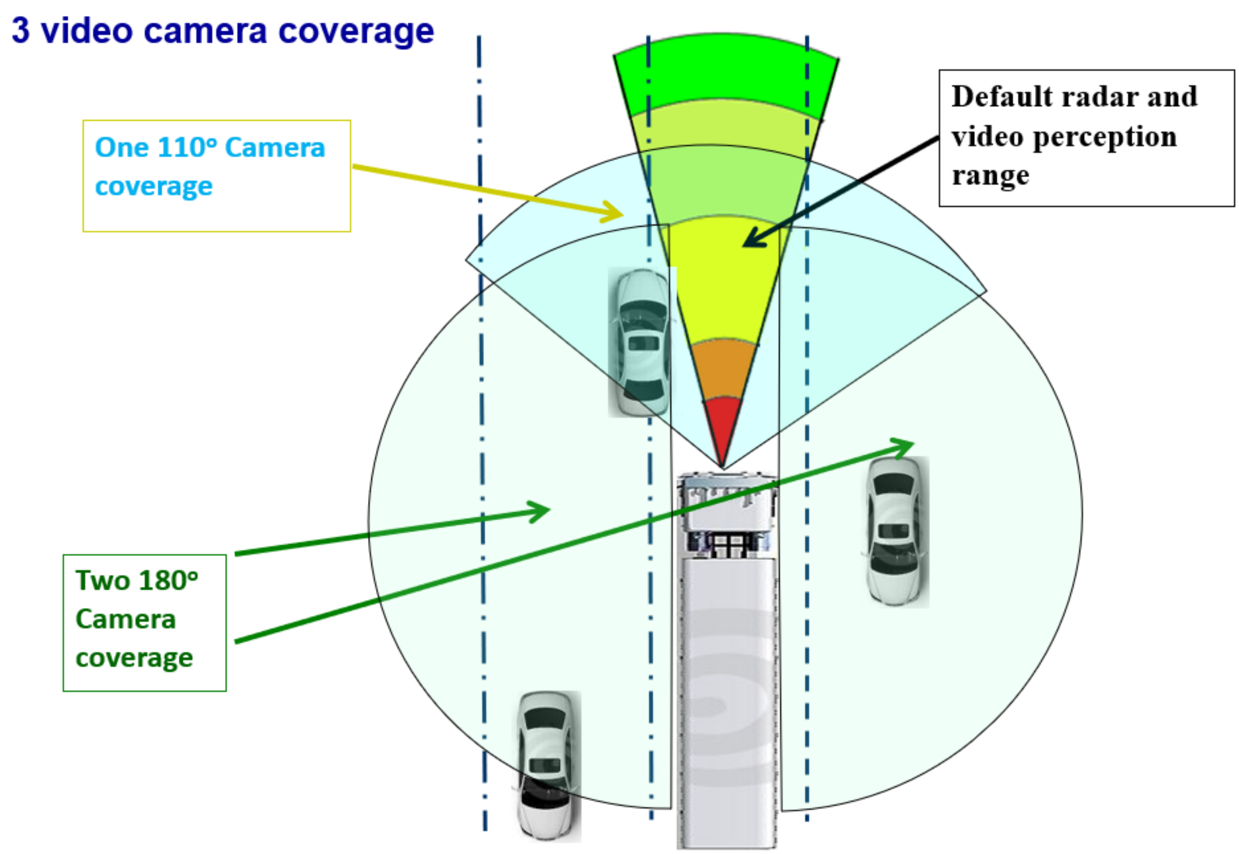
Figure 5 and Figure 6 show how the traffic detection sensors were installed on each truck. These include fixed beam Lidar sensors and wide-angle video cameras to detect surrounding traffic. The areas of coverage are shown in each figure. Since Roly’s Trucking changes out trailers, it is impractical to mount those sensors directly on the trailers. Therefore, all sensors were mounted on the tractor chassis. See Figure 5, below. This figure 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 180-degree forward field of view of the Pixell lidar and the 99-degree fields of view of the Leddar Tech SIGNT units located on both sides of the truck.



Source: PATH, 2022

Figure 5. Three fixed beam lidar coverage scheme, mounted on the tractor only

Figure 6, below, 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 and the 180 degree fields of view of the video cameras mounted on both sides of the truck.



Source: PATH, 2022

Figure 6. Three wide angle video camera coverage areas, mounted on the tractor only

3.3.3 On-board Driver Monitoring Systems

For purposes of assessing driver attention and fatigue/drowsiness, we 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 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 7 below. 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).

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, we 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 be silently reporting 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.

No actual EEG data, with its inherent confidentiality implications, is recorded, but the level data is recorded continuously and can be reported at any desired frequency. For our purposes here, the time in each level would be reported at a frequency of every 15 minutes.

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: PATH, 2022

Figure 7. SmartCap Fatigue Levels

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, we 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 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 would 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 would be 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, we anticipate 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, our 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.

We anticipate 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, weather, 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 would facilitate 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.

3.3.4 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 notify the PATH PI immediately so that PATH could investigate the issue and find a resolution as soon as possible. Depending the situation, it may be a temporary fault 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 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 faulty 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 we use 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. We would 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, they would immediately investigate the issue and find a resolution as soon as possible.

3.4 Data Stewardship

This section provides details concerning data stewardship. Data stewardship involves proper data management throughout the data lifecycle, including, but not limited to, maintaining data quality and safeguarding data.

3.4.1 Data Owner and Steward

University of California is the owner of all of the data that are collected during the second phase of the Truck Platooning Early Deployment Assessment Phase 2 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.

3.4.2 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 Table 5 through Table 8. 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.

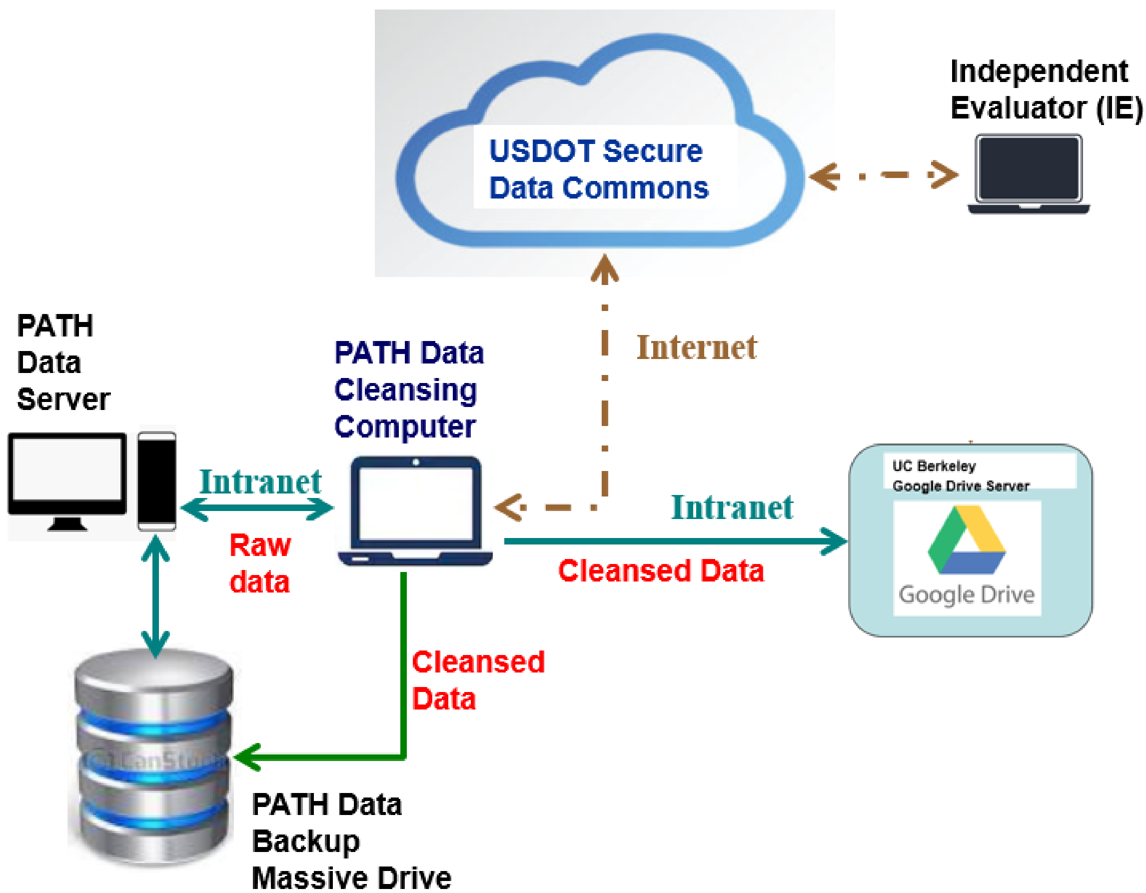
To safeguard the security of collected data, we developed a stringent protection policy, to not allow unauthorized access. The collected raw engineering and other sensor data would be downloaded and stored at the PATH Data Server in a well-organized chronological order. Local storage would run a Debian-based 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. We do 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 8. 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. The IE can access the SDC directly for data checking and analysis. PATH will not have a dynamic interactive module between 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.

For in-house data processing and analysis, the PATH team proposed to use software such as Matlab which has flexible programming capabilities. The reason to do so is that the relationship between the raw data collected and the performance measures is very complicated. Quantifying those relationships requires complicated programming and using ready-programmed functions in Matlab for convenience. This Test and Evaluation Plan lists the project data that we expected 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 planned 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.

Figure 8 provides a schematic depiction of the data storage, processing and sharing flows of data, beginning 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 is accessed by the Independent Evaluator.



Source: PATH, 2022

Figure 8. Scheme for Data Storage, Processing and Sharing with FHWA and IE

For in-house data processing and analysis, the PATH team proposed to use software such as Matlab which has flexible programming capabilities. The reason to do so is that the relationship between the raw data collected and the performance measures is very complicated. Quantifying those relationships requires complicated programming and using ready-programmed functions in Matlab for convenience. This Test and Evaluation Plan lists the project data that we expected 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 planned 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.

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3.4.3 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 reusers 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: 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.

3.4.4 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 but 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 System which has an internal 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 Chapter 4.3.1, the amount of data uploaded from the trucks to the PATH server would be sizable. We estimate 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 Figure 8. 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 8.

With respect to data backups, the PATH team would compress and back up the engineering data on a massive storage. The backed up data would not include the video data due to its large size.

3.5 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 we know:

- 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 decimals 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.

3.6 Data Lists and Metadata

This section provides a tentative list of the digital data sets (and associated metadata) that would be captured during the FOT. Table 5 through Table 8 list the metadata associated with the engineering data sets that would be captured by PATH during the FOT. The remaining tables in this section (Table 9 through Table 14) list driver behavior data from Jungo and SmartCap systems.

Table 5. PATH Engineering Data - J-1939 Bus Data and Control Data

Data Type and Name	Range	Data Type	Unit	Note
UTC Date: YYYY:MM:DD		int:int:int		
UTC Time: HH:MM:SS.sss		int:int:int:int		
Driver request of driving mode through Driver Vehicle Interface	{0,1,2,3,4}	int		0: stopped; 1: manual; 2:CC; 3: ACC; 4: CACC
Actual Driving mode	{0,1,2,3,4}	int		stopped, manual, CC, ACC, CACC
Fault index	0 ~ 100000	int		using prime numbers to represent all individual faults
ACC Time Gap Level	1~5	int		hard coded each time level with a corresponding time gap as int
CACC Time Gap Level	1~5	int		hard coded each time level with a corresponding time gap as int
Driver service brake pedal deflection [%] (measurement)	0.0~100.0	float		
Driver acceleration pedal deflection [%] (measurement)	0.0~100.0	float		
Veh position in platoon	1~3	int		relative position in platoon for a given platoon length
Platoon size	2~3	int		in case of cut-in time over 15 [s], platoon would split
ACC/CACC enable switch status	{0,1}	int		0: OFF; 1: ON
Brake pedal status	{0, 1}	int		0: OFF; 1: ON
Road Max Speed for truck	0 ~ 45	float	[m/s]	
ACC/CACC Set Speed	0 ~ 45	float	[m/s]	
Vehicle measured speed	0 ~ 45	float	[m/s]	
Lateral acceleration	0 ~ 5.0	float	[m/s/s]	
Longitudinal acceleration	0 ~ 5.0	float	[m/s/s]	
Yaw rate	0 ~ 2.0	float	[rad/s]	
Steering angle	0 ~ 2.0	float	[rad]	

Data Type and Name	Range	Data Type	Unit	Note
Road grade estimation	0 ~ 10	float	[%]	
Truck mass estimation	0 ~ 50000	float	[Kg]	
Service Brake command: deceleration	0 ~ 8.0	float	[m/s/s]	
Preceding vehicle speed	0 ~ 45	float	[m/s]	
Preceding vehicle acceleration	0 ~ 8.0	float	[m/s/s]	
Preceding vehicle lateral acceleration	0 ~ 5.0	float	[m/s/s]	
Preceding vehicle yaw rate	0 ~ 2.0	float	[rad/s]	
Preceding vehicle steering angle	0 ~ 2.0	float	[rad]	
Preceding vehicle mass estimation	0 ~ 50000	float	[Kg]	
Lead vehicle speed	0 ~ 45	float	[m/s]	
Lead vehicle acceleration	0 ~ 8.0	float	[m/s/s]	
Lead vehicle lateral acceleration	0 ~ 5.0	float	[m/s/s]	
Lead vehicle yaw rate	0 ~ 2.0	float	[rad/s]	
Lead vehicle steering angle	0 ~ 2.0	float	[rad]	
Lead vehicle mass estimation	0 ~ 50000	float	[Kg]	
Running distance	0.0 ~ 999999.0	float	[m]	integrated from wheel speed as trip distance
Desired following distance	0.0 ~ 150.0	float	[m]	calculated from Time Gap and Measured Speed
Fuel consumption	0.0 ~ 100.0	float	[g/s]	fuel rate from J-1939 Bus
Driver gap request from DVI	1~5	int		
Target acceleration (radar relative acceleration)	0 ~ 2.0	float	[m/ss]	
Target speed (radar relative speed)	0 ~ 45.0	float	[m/s]	
Target distance (radar/lidar measurement)	0.0 ~ 150.0	float	[m]	
Target availability	{0, 1}	int		0: no target; 1: with target; detected in the subject vehicle lane;
Cut-in status	{0, 1}	int		
Windshield wiper status	{0, 1}	int		for local rain indication

Table 6. PATH Engineering Data - GPS Data

Data Type and Name	Range	Data Type	Unit	Note
GPS: veh 1 lat	[-90.0 90.0]	double float	[deg]	
GPS: veh 1 long	[-180.0, 180.0]	double float	[deg]	
GPS: veh 1 Altitude	[-1000.0, 8000.0]	double float	[m]	
GPS: veh 1 heading	[0.0 360.0]	double float	[deg]	
GPS: veh 2 lat	[-90.0 90.0]	double float	[deg]	
GPS: veh 2 long	[-180.0, 180.0]	double float	[deg]	
GPS: veh 2 Altitude	[-1000.0, 8000.0]	double float	[m]	
GPS: veh 2 heading	[0.0 360.0]	double float	[deg]	
GPS: veh 3 lat	[-90.0 90.0]	double float	[deg]	
GPS: veh 3 long	[-180.0, 180.0]	double float	[deg]	
GPS: veh 3 Altitude	[-1000.0, 8000.0]	double float	[m]	
GPS: veh 3 heading	[0.0 360.0]	double float	[deg]	

Table 7. PATH Engineering Data - Emission Data from OBD-II

Data Type and Name	Range	Data Type	Unit	Note
NOx				For emission data, only aggregated data would be shared (relative change of the CACC trucks with respect to manually driven vehicle). This is required by Volvo.

Data Type and Name	Range	Data Type	Unit	Note
CO				For emission data, only aggregated data would be shared (relative change of the CACC trucks with respect to manually driven vehicle). This is required by Volvo.
PMx				For emission data, only aggregated data would be shared (relative change of the CACC trucks with respect to manually driven vehicle). This is required by Volvo.

Table 8. PATH Engineering Data - Additional Sensor Data

Data Type and Name	Range	Data Type	Unit	Note
Adjacent lane target data from lateral lidars (16 beams, fixed angle)				
relative distance	0.1 ~ 30.0	float	[m]	synchronized time stamp
relative speed	0.0 ~ 20.0	float	[m/s]	synchronized time stamp
Forward video camera				synchronized time stamp, for observation of front traffic
Adjacent lane video cameras				synchronized time stamp, for observation of side traffic
Driver voice recordings				synchronized time stamp, for recording driver report of special events

The following table lists the elements associated with the SmartCap system raw fatigue data. The naming Convention is YYMMDD-hhmm-LifeHub_Fatigue_Data.csv - where YYMMDD-hhmm is the date and time that the file was finalized.

Table 9. SmartCap LifeBand Raw Fatigue Data Summary

Item	Data Name	Source	Format	Range	Data Type	Default	Description
1	Fatigue Log ID	SmartCap	[NNNNNNNN]N		Integer		Unique identity of each LifeBand data record from each device. These are not necessarily sequential.
2	Timestamp	SmartCap	DD/MM/YYYY hh:mm:ss	0 to 9999999999	Date/Time		Date and time of the recorded sample. Not clear whether these are TZ-adjust local or GMT times.
3	Plant Name	SmartCap	freeform		Text	None	Indication of the home location of the driver. Entered at LifeBand initiation/assignment.
4	Operator ID	SmartCap	freeform		Text	None	ID of the driver. Entered at LifeBand initiation/assignment.
5	Operator Last Name*	SmartCap	freeform		Text	None	Driver last name. Entered at LifeBand initiation/assignment.
6	Operator First Name*	SmartCap	freeform		Text	None	Driver first name. Entered at LifeBand initiation/assignment.
7	Headwear Label	SmartCap	AAAAAA		Hexadecimal		Unique identity of each LifeBand device.
8	Headwear ID	SmartCap	AAAAAAAA AAAAAAAA		Text		Includes Headware Label plus some other ID.
9	Status	SmartCap	N[.N]	0 to 4	Decimal	0	Decimal value of the fatigue status.
10	Status Name	SmartCap	freeform	LifeBand Removed, Fatigue Level 2, Fatigue Level 3, Fatigue Level 3+, Fatigue Level 4	Text		Readable fatigue status that includes cases where the LifeBand is either not detecting wearing or not being worn.

Item	Data Name	Source	Format	Range	Data Type	Default	Description
11	Shift Start Date/Time	SmartCap	DD/MM/YYYY hh:mm:ss		Date/Time		The date and time of the start of a pre-defined shift. Not clear whether these are TZ-adjust local or GMT times.
12	Shift End Date/Time	SmartCap	DD/MM/YYYY hh:mm:ss		Date/Time		The date and time of the end of a pre-defined shift. Not clear whether these are TZ-adjust local or GMT times.
13	Latitude*	SmartCap	[-N]N[.NNNNNNNNNNN]	-90 to 90	Decimal	0	Latitude measured in decimal degrees above the Equator.
14	Longitude*	SmartCap	[-NN]N[.NNNNNNNNNNN]	-180 to 180	Decimal	degrees	Longitude measured in decimal degrees East of the Greenwich Meridian.
15	Altitude	SmartCap	[NNNNN]N.N		Decimal		Travel direction in degrees measured clockwise from North.

* - Sensitive PII variable.

The following table lists the elements associated with the SmartCap system raw alarm data. The naming convention is YYMMDD-hhmmss-SmartCap_Alarm_Data.csv - where YYMMDD-hhmmss is the date and time that the file was finalized.

Table 10. SmartCap LifeBand Raw Alarm Data Summary

Item	Data Name	Source	Format	Range	Data Type	Units	Default	Description
1	Alarm Log ID	SmartCap	[NNNNNNNN]N		Integer			Unique identity of each LifeBand data record from each device. These are not necessarily sequential.
2	Timestamp	SmartCap	DD/MM/YYYY hh:mm:ss	0 to 9999999999	Date/Time			Date and time of the recorded sample. Not clear whether these are TZ-adjust local or GMT times.
3	Plant Name	SmartCap	freeform		Text		None	Indication of the home location of the driver. Entered at LifeBand initiation/assignment.
4	Operator ID	SmartCap	freeform		Text		None	ID of the driver. Entered at LifeBand initiation/assignment.
5	Operator Last Name*	SmartCap	freeform		Text		None	Driver last name. Entered at LifeBand initiation/assignment.
6	Operator First Name*	SmartCap	freeform		Text		None	Driver first name. Entered at LifeBand initiation/assignment.
7	Headwear Label	SmartCap	AAAAAA		Hexadecimal ?			Unique identity of each LifeBand device.
8	Headwear ID	SmartCap	AAAAAAA AAAAAAAAA		Text			Includes Headware Label plus some other ID.
9	Alarm Rule ID	SmartCap	N[.N]	1 to 2	Integer		0	Indicates the level of fatigue of the driver over some period of time. 1 indicates a high level of fatigue, while 2 indicates a high level of alertness. Taken over time, repeated 1 values indicate a likelihood of a microsleep situation.

Item	Data Name	Source	Format	Range	Data Type	Units	Default	Description
10	Alarm Name	SmartCap	freeform	Level 4 for 0 min, Level 4 for 3 min	Text			Level 4 is the highly fatigued category of the EEG measures. Since it is likely to fluctuate between 2 and 4 over time, having high fatigue for 0 minutes indicates higher alertness, while having it for 3 minutes suggests high fatigue.
11	Comment	SmartCap	freeform				None	
12	Shift Start Date/Time	SmartCap	DD/MM/YYYY hh:mm:ss		Date/Time			The date and time of the start of a pre-defined shift. Not clear whether these are TZ-adjust local or GMT times.
13	Shift End Date/Time	SmartCap	DD/MM/YYYY hh:mm:ss		Date/Time			The date and time of the end of a pre-defined shift. Not clear whether these are TZ-adjust local or GMT times.
14	Latitude*	SmartCap	[-N]N[.NNNN NNNNNNN]	-90 to 90	Decimal	degree s	0	Latitude measured in decimal degrees above the Equator.
15	Longitude*	SmartCap	[-NN]N[.NNNN NNNNNNN]	-180 to 180	Decimal	degree s	0	Longitude measured in decimal degrees East of the Greenwich Meridian.
16	Altitude	SmartCap	[NNNNN]N.N		Decimal	degree s	0	Travel direction in degrees measured clockwise from North.

* - Sensitive PII variable.

The following table lists the elements associated with the Jungo attention event data: Naming Convention: [Trip ID]_In-cabin_events.csv - where Trip ID consists of the start time of the trip in the format YYYYMMDDhhmmss_[unique random UUID]

Table 11. Jungo VuDrive Event Data Summary

Item	FrameNumber	Source	Format	Range	Data Type	Units	Description
1	TimeFromStart	Jungo VuDrive	[NNNNNNN]N	0 to 999999	Integer	frames	Indicates the video frame number of a given event.
2	Date	Jungo VuDrive	[NNNNNNN]N	0 to 999999	Integer	milliseconds	Indicates the time from the beginning of the video of the event. Since the video has a variable frame rate, this is important for being able to reference it in the full trip video
3	EventName	Jungo VuDrive	YYYY-MM-DD hh:mm:ss.000		Date/Time		Date and time of the event to milliseconds. This is currently being reported in the data as Israel time (whose daylight saving time schedule does not sync with ours). Perhaps we can get this to standardize on GMT?
4	EventDetails	Jungo VuDrive	freeform	HELLO, START-RIDE, DISTRACTION, CPU-HIGH, END-RIDE	Text		Provides a description of the type of event. Each trip should have START and END-RIDE events. HIGH-CPU is often seen at the beginning of a trip as well. DISTRACTION, MICRO-SLEEP, and other events are flagged as they occur.
5	EventUUID	Jungo VuDrive	freeform		Text		Currently empty for most cases.
6	VideoFile	Jungo VuDrive	freeform		Text		Unique event identifier that includes the date/time from the trip UUID (but not the rest of that UUID), the EventName, and a random unique identifier.
7	* - Sensitive PII variable.	Jungo VuDrive	freeform		Text	seconds	Unique video file name that includes the EventUUID identifier and an MP4 extension.

The following table (split across 4 pages) lists the elements associated with raw Jungo attention data: The naming convention of the following table is: [Trip ID]_In-cabin_person_results.csv - where Trip ID consists of the start time of the trip in the format YYYYMMDDhhmmss_[unique random UUID]

Table 12. Jungo VuDrive Raw Attention Data Summary

Item	Data Name	Source	Format	Range	Data Type	Units	Default	Description
1	Frame Number	Jungo VuDrive	[NNNNNNN]N	0 to 999999	Integer	frames		Indicates the video frame number of a given event. This file is a frame-by-frame listing of the detection within the full trip video file, so there is one record per frame.
2	Person UUID	Jungo VuDrive			Text		Empty	Unique ID of a given driver.
3	Person UUID Confidence	Jungo VuDrive			Text		9999	Confidence that the system has recognized the correct driver identity with 1 being perfectly confident.
4	Headpose Pitch (deg)	Jungo VuDrive	[-N]N.[NNNNN]	-90 to 90	Decimal	degrees	9999	Forward pitch of the head in degrees from horizontal.
5	Headpose Yaw (deg)	Jungo VuDrive	[-N]N.[NNNNN]	-90 to 90	Decimal	degrees	9999	Lateral yaw of the head in degrees from straight forward.
6	Headpose Roll (deg)	Jungo VuDrive	[-N]N.[NNNNN]	-90 to 90	Decimal	degrees	9999	Tilt of the head in degrees from straight up and down.
7	Headpose (X:Y:Z) (mm)	Jungo VuDrive	[-N]N.[NNNNN]: [-N]N.[NNNNN]: [-N]N.[NNNNN]		Decimal	millimeters		Indication of head pose in millimeters from the angular measures.
8	Headpose Confidence	Jungo VuDrive	decimal	0 to 1	Decimal			Confidence in the Head Pose values provided in the relevant fields above.

Item	Data Name	Source	Format	Range	Data Type	Units	Default	Description
9	Face Rect (X:Y Width X Height)	Jungo VuDrive	NNN:NNN NNNxNNN		Integer	pixels		Indicates the corner (NNN:NNN) and rectangle occupied by the face (NNNxNNN), separated by a space when the face is being tracked.
10	Face Rect Confidence	Jungo VuDrive	decimal	0 to 1	Decimal			Confidence in the Face Rectangle values provided in the relevant fields above.
11	EyeState Right	Jungo VuDrive	freeform	opened or closed	Text		Unknown	State of the right eyelid.
12	EyeState Left	Jungo VuDrive	freeform	opened or closed	Text		Unknown	State of the left eyelid.
13	EyeState Right Confidence	Jungo VuDrive	decimal	0 to 1	Decimal		0	Confidence that the right eyelid state has been properly identified with 1 being perfect confidence.
14	EyeState Left Confidence	Jungo VuDrive	decimal	0 to 1	Decimal		0	Confidence that the left eyelid state has been properly identified with 1 being perfect confidence.
15	Eyewear	Jungo VuDrive	freeform	none, glasses, sunglasses, dark SG	Text		none	Indicates the type of eyewear detected on the driver.
16	Eyewear Confidence	Jungo VuDrive	decimal	0 to 1				Confidence in the indication of the eyewear condition.
17	EyeGaze Horizontal Left (deg)	Jungo VuDrive	decimal	-90 to 90	Decimal	degrees	9999	Left eye horizontal diversion measure.
18	EyeGaze Horizontal Right (deg)	Jungo VuDrive	decimal	-90 to 90	Decimal	degrees	9999	Right eye horizontal diversion measure.
19	EyeGaze Vertical Left (deg)	Jungo VuDrive	decimal	-90 to 90	Decimal	degrees	9999	Left eye vertical diversion measure.

Item	Data Name	Source	Format	Range	Data Type	Units	Default	Description
20	EyeGaze Vertical Right (deg)	Jungo VuDrive	decimal	-90 to 90	Decimal	degrees	9999	Right eye vertical diversion measure.
21	Iris RadiusL (mm)	Jungo VuDrive				millimeters	9999	Left eye iris radius measure.
22	Iris RadiusR (mm)	Jungo VuDrive				millimeters	9999	Right eye iris radius measure.
23	Eye Aperture Right (mm)	Jungo VuDrive				millimeters	9999	Right eyelid open measure.
24	Eye Aperture Left (mm)	Jungo VuDrive				millimeters	9999	Left eyelid open measure.
25	Eye Aperture Right Confidence	Jungo VuDrive	decimal	0 to 1			0	Confidence that the right eyelid open measure is correct with 1 being perfect confidence.
26	Eye Aperture Left Confidence	Jungo VuDrive	decimal	0 to 1			0	Confidence that the left eyelid open measure is correct with 1 being perfect confidence.
27	Eye Lids Closed Ratio (%)	Jungo VuDrive				percent	9999	The average ratio of eyelid open between both eyes expressed as a percentage.
28	Eye Center Left (X:Y) (mm)	Jungo VuDrive					9999:9999	The location of the center of the left eye as an X:Y coordinate.
29	Eye Center Right (X:Y) (mm)	Jungo VuDrive					9999:9999	The location of the center of the right eye as an X:Y coordinate.
30	Drowsiness Level (0-10)	Jungo VuDrive					9999	Drowsiness score as inferred from measures of PERCLOS, blink frequency, blink length, heavy blinks, microsleeps, head bobs, head movements, closed eyes, and yawns.

Item	Data Name	Source	Format	Range	Data Type	Units	Default	Description
31	Age	Jungo VuDrive					9999-9999	Age that the lid open measure is correct with 100 being perfect age.
32	Gender	Jungo VuDrive					N/A	Gender that the lid open measure is correct with Female being perfect gender.
33	Emotion	Jungo VuDrive					N/A	Emotion that the lid open measure is correct with Surprise being perfect emotion.
34	Frame Time	Jungo VuDrive	YYYY-MM-DDThh:mm:ss.000		Date/Time			Date and time of the frame to milliseconds. This is currently being reported in the data as Israel time (whose daylight saving time schedule does not sync with ours). Perhaps we can get this to standardize on GMT?

The following table (split across 3 pages) lists the elements associated with raw Jungo trip data. The naming convention of the following table: [Trip ID].mp4.csv – where Trip ID consists of the start time of the trip in the format YYYYMMDDhhmmss_[unique random UUID]

Table 13. Jungo VuDrive Raw Trip Data Summary

Item	CreateDate	Source	Format	Range	Data Type	Units	Default	Description
1	TimeFromStart	Jungo VuDrive	YYYY-MM-DDThh:mm:ss.000		Date/Time			Date and time of the frame to milliseconds. This is currently being reported in the data as Israel time (whose daylight saving time schedule does not sync with ours). Perhaps we can get standardize on GMT?
2	FrameNumber	Jungo VuDrive	[NNNNNNNNN]N	0 to 9999999999	Integer	milliseconds		Time in milliseconds since the beginning of the trip.
3	TripUUID	Jungo VuDrive	[NNNNNNNNN]N	1 to 9999999999	Integer	frames		The sequential frame number within this frame-by-frame listing for the trip.
4	Yaw	Jungo VuDrive	freeform		Text			Unique character string identifying the trip.
5	Pitch	Jungo VuDrive	[-N]N[.N]	-90 to 90	Decimal	degrees	9999	Forward pitch of the head in degrees from horizontal.
6	Roll	Jungo VuDrive	[-N]N[.N]	-90 to 90	Decimal	degrees	9999	Lateral yaw of the head in degrees from straight forward.
7	GazeHLeft	Jungo VuDrive	[-N]N[.N]	-90 to 90	Decimal	degrees	9999	Tilt of the head in degrees from straight up and down.
8	GazeVLeft	Jungo VuDrive					0	Indication of left eye horizontal gaze direction.

Item	CreateDate	Source	Format	Range	Data Type	Units	Default	Description
9	GazeHRight	Jungo VuDrive					0	Indication of left eye vertical gaze direction.
10	GazeVRight	Jungo VuDrive					0	Indication of right eye horizontal gaze direction.
11	Speed	Jungo VuDrive					0	Indication of right eye vertical gaze direction.
12	Direction	Jungo VuDrive	[NN]N[.NNN]	0 to 200	Decimal	kph	0	Vehicle speed in kilometers per hour
14	AccelerometerX	Jungo VuDrive	[-]0.[NNNNNNN]	-1 to 1	Decimal	G's	0	Acceleration along the X axis of the VuDrive device measured in G's.
15	AccelerometerY	Jungo VuDrive	[-]0.[NNNNNNN]	-1 to 1	Decimal	G's	0	Acceleration along the Y axis of the VuDrive device measured in G's.
16	AccelerometerZ	Jungo VuDrive	[-]0.[NNNNNNN]	-1 to 1	Decimal	G's	0	Acceleration along the Z axis of the VuDrive device measured in G's.
17	GyroX	Jungo VuDrive	[-]0.[NNNNNN]	-2π to 2π	Decimal	radians	0	The tilt of the VuDrive device around the X axis measured in radians.
18	GyroY	Jungo VuDrive	[-]0.[NNNNNN]	-2π to 2π	Decimal	radians	0	The tilt of the VuDrive device around the Y axis measured in radians.
19	GyroZ	Jungo VuDrive	[-]0.[NNNNNN]	-2π to 2π	Decimal	radians	0	The tilt of the VuDrive device around the Z axis measured in radians.
20	Latitude*	Jungo VuDrive	[-N]N[.NNNN]	-90 to 90	Decimal	degrees	0	Latitude measured in decimal degrees above the Equator.
21	Longitude*	Jungo VuDrive	[-NN]N[.NNNN]	-180 to 180	Decimal	degrees	0	Longitude measured in decimal degrees East of the Greenwich Meridian.
22	Heading	Jungo VuDrive	[NN]N	0 to 360	Integer	degrees	0	Travel direction in degrees measured clockwise from North.

Item	CreateDate	Source	Format	Range	Data Type	Units	Default	Description
23	Events	Jungo VuDrive	freeform	HELLO START-RIDE, MUTUAL-GAZE, CALIBRATED, READY-TO-TAKE-CONTROL, LEFT-MIRROR-CHECK, RIGHT-MIRROR-CHECK, DISTRACTION, RAPID-MOVE, HEAD-DISTRACTION, NO-MIRROR-CHECKED, USER-EVENT, MICRO-SLEEP	Text		blank	Normally blank, this field provides an indication when a given driver state/event is detected. Each indication is tied to a given frame of the full drive video. The USER-EVENT is triggered by holding the input button for 3 seconds. Other events are related to head pose changes. Specific parameters are configurable to tweak false alarm levels.
24	Frame Time	Jungo VuDrive	YYYY-MM-DDThh:mm:ss.000		Date/Time			Date and time of the frame to milliseconds. This is currently being reported in the data as Israel time (whose daylight saving time schedule does not sync with ours). Perhaps we can get this to standardize on GMT?

*- Sensitive PII variable.

The following table (spread across 3 pages) lists the elements of the proposed 15-minute Jungo & SmartCap aggregated data: The naming convention of the following table is: [Trip ID]Epoch_Data.csv – where Trip ID consists of the start time of the trip in the format YYYYMMDDhhmmss_[unique random UUID]

Table 14. Jungo & SmartCap Epoch Tally Data Summary

Item	Data Name	Source	Format	Range	Data Type	Units	Default	Description
1	EpochEnd	Jungo VuDrive	YYYY-MM-DDT hh:mm:ss		Date/Time			Date and time of the end of a 15-minute epoch. This is currently being reported in the data as Israel time (whose daylight saving time schedule does not sync with ours). Perhaps we can get this to standardize on GMT?
2	TripID	Jungo VuDrive	freeform		Text			Unique identity of each trip logged by the VuDrive.
3	TripStart	Jungo VuDrive	YYYY-MM-DDThh:mm:ss.000		Date/Time			Date and time start of a trip as identified by an ignition ON event. This is currently being reported in the data as Israel time (whose daylight saving time schedule does not sync with ours). Perhaps we can get this to standardize on GMT?
4	TripEnd	Jungo VuDrive	YYYY-MM-DDThh:mm:ss.000		Date/Time			Date and time of the end of a trip as identified by an ignition OFF event. This is currently being reported in the data as Israel time (whose daylight saving time schedule does not sync with ours). Perhaps we can get this to standardize on GMT?
5	Distractions	Jungo VuDrive	[NN]N		Integer		0	Count of distraction events in the 15 minutes prior to the EpochEnd time.

Item	Data Name	Source	Format	Range	Data Type	Units	Default	Description
6	MicroSleeps	Jungo VuDrive	[NN]N		Integer		0	Count of micro-sleep events in the 15 minutes prior to the EpochEnd time.
7	Headwear Label	SmartCap LifeHub	AAAAAA		Hexadecimal			Unique identity of each LifeBand device.
8	Headwear ID	SmartCap LifeHub	AAAAAAAA AAAAAAAA		Text			Includes Headware Label plus some other ID.
9	FatigueCount	SmartCap LifeHub	N[.N]	1 to 2	Integer		0	The count of high fatigue periods within the 15 minutes prior to the EpochEnd time. That is, the number of "Level 4 for 3 min" indications in the Alarm Name field of the raw SmartCap data.
10	AlertCount	SmartCap LifeHub	freeform	Level 4 for 0 min, Level 4 for 3 min	Text			The count of high alertness periods within the 15 minutes prior to the EpochEnd time. That is, the number of "Level 4 for 0 min" indications in the Alarm Name field of the raw SmartCap data.
11	EpochSCSum	SmartCap LifeHub	freeform				None	The sum of the Alarm Rule ID values from the SmartCap raw alarm data during the 15-minute epoch immediately prior to the EpochEnd time. Not sure that this is a valid measure, but it seemed like it could be.

Item	Data Name	Source	Format	Range	Data Type	Units	Default	Description
14	EpochLatitude*	Jungo VuDrive	[-N]N[.NNNN NNNNNNN]	-90 to 90	Decimal	degrees	0	Latitude measured in decimal degrees above the Equator at the EpochEnd time.
15	EpochLongitude*	Jungo VuDrive	[-NN]N[.NNNN NNNNNNN]	-180 to 180	Decimal	degrees	0	Longitude measured in decimal degrees East of the Greenwich Meridian at the EpochEnd time.
16	EpochHeading	Jungo VuDrive	[NNNNN]N.N		Decimal	degrees	0	Travel direction in degrees measured clockwise from North at the EpochEnd time.

*- Sensitive PII variable.

Chapter 4. Data Reporting and Analysis

This section describes how the data described in the previous section would be reported out to USDOT and the IE during the life of the project. It also describes how PATH intended to analyze the data to answer the key research questions of the project during the evaluation phase of the project.

4.1 Data Reporting

Several different kinds of data were to be collected, for a variety of purposes, and these in turn lead to different kinds of reporting. Some data are only collected at a few specific times during the project (for example, surveys of driver and fleet operator attitudes), while others are collected almost continuously throughout the duration of the testing (technical data on vehicle performance and driver behavior) and others are collected on an event-driven basis throughout the testing (driver concerns about adverse performance, crash and near-crash events). The data discussed in this report are the data that are intended for archiving and analysis, to be used to evaluate the impacts of truck platooning. In addition to this data reporting, small amounts of diagnostic data would be collected in real time to monitor the condition of the CACC and data acquisition systems; and relayed to PATH via cellular data modem. These would be used to identify potential malfunctions that corrupt the data collection and that call for real-time corrective action to maximize the useful data that can be collected for the remaining duration of the affected round trip.

Tables 15 through 17 list the broad categories of data to be collected during the Phase 2 field test including data collected at specific milestones, abnormal event data, fleet operator data, and various types of truck onboard data. They also identify the expected data sets associated with each category of data and the frequency for the data to be collected, uploaded to PATH's server and ultimately reported out to USDOT and the IE. Note that an asterisk is shown next to the examples of data that have potential privacy or ethical concerns.

Table 15. Data Categories, Collection, Upload, & Reporting Strategies - Non Regular Event Data

Data Category	Data Sets	Collection rate and approach	Upload rate and approach	Approach to share and report
Data Only Collected at Specific Project Milestones	Surveys of driver attitudes before and after test Fleet dispatcher and manager surveys Baseline truck characteristics Data associated with driver training	At test beginning At the start and end of each cohort of drivers At the end of the testing	Whenever data is available	Reported separately for each milestone, within two weeks of occurrence Trends reported after longitudinal data are available Through Shared folder or SDC
Abnormal events	• Crash events • Significant failures or serious concerns by drivers	• Reports by drivers and fleet operator via email or phone • Crash events must be reported immediately • Other events reported daily or whenever available • Check remotely through modem daily	• Initial notification within a day of occurrence, so people are aware and corrective action can be taken • More detailed analysis findings upon completion of analysis	• Summary report emailed bi-weekly • Analyses of significant events in subsequent letter reports • Detailed data through SDC

Table 16. Data Categories, Collection, Upload, & Reporting Strategies - Regular Event-Based Data

Data Category	Data Sets	Collection rate and approach	Upload rate and approach	Approach to share and report
Fleet operator off-board data	• Fueling and maintenance • Inspections • Dispatch schedules and loads • Driver logs: position, hours of service, changes to routing	• Collect weekly from fleet operator by email or direct web access	• Weekly • Data aggregation	• Bi-weekly report • Through shared folder or SDC

Data Category	Data Sets	Collection rate and approach	Upload rate and approach	Approach to share and report
Truck onboard data	• Voice recordings of driver concerns, minor incidents, disengagements and other observations • Transcripts of Voice Recordings	• Activated by a button on the DVI screen for each event • Automatically saved on a data drive on each truck • Use speech-to-text and translation tools to create initial transcripts/translations and then have them reviewed and refined by native Spanish speakers	• Uploads of the saved data at the end of each trip (approximately weekly) • Processing continuous data to flag the key events • Aggregate/process data, if necessary	• Bi-weekly report • Through SDC

Table 17. Data Categories, Collection, Upload, & Reporting Strategies - Continuously Recorded Data

Data Category	Data Sets	Collection rate and approach	Upload rate and approach	Approach to share and report
Truck onboard driver behavior related data	• Facial video of driver* • Driver attention and fatigue monitoring*	• Fatigue and attention metrics reported periodically (every 15 minutes). • Facial video captured per event or continuously • Automatically saved on a data drive on each truck and transferred to PATH storage	• Event-based and periodic upload from trucks to Jungo, SmartCap, and PATH servers automatically or manually. • Scanned by analyst the following day to flag abnormal events.	• Bi-weekly or monthly for driver video and monitoring data, depending on the processing time needed • Through SDC

* data with possible privacy, ethical, or confidentiality concerns

The choice of data reporting processes and frequency are driven primarily by the intended use for the data, the practical considerations associated with reporting the data (cost and labor effort required), and the time when the accumulated data become sufficient to tell a meaningful story. There are also significant differences between data that are recorded in verbal form (questionnaire responses, vehicle and dispatch event logs, driver recordings about problems) and data that are recorded as images (still or video) and as numerical streams (vehicle operating status, sensor measurements, etc.).

The remainder of this section describes the PATH team's data reporting process for the following categories of data: data reported at specific milestones, abnormal event-based data, regular event-based data, continuously-recorded truck onboard engineering data and driver behavior data. Discussion of the analyses of the data to estimate performance measures follows in the subsequent section.

4.1.1 Data Reported at Specific Project Milestones

The smallest category of data is the special milestone-specific data that are collected only a few times during the project. These are important for understanding changes that occur during the course of the testing, but typically they do not become meaningful for analysis until the testing (or a major phase of the testing) is complete, when the "before" and "after" data can be compared. These data include:

- Surveys of driver attitudes about truck platooning – at the start of each driver's involvement in the experiment, after first experience with CACC (within first week of CACC use), and at the end of the driver's participation in the test.
- Surveys of fleet operation personnel (managers and dispatchers) attitudes about truck platooning – at the start of the experiment, after the first full week of platoon operations, after a few months of platoon operations, at the end of the test.
- Baseline data describing the equipped truck tractors – mass, dimensions, weight distribution by axle – at the start of the test.
- Time spent training each driver on use of CACC (and potentially retraining, if needed) – at the time of training each driver cohort, then updated if retraining is needed.
- The surveys of drivers and fleet operators were finalized during the IRB approval process. The survey data would be reported after each survey is completed so that the independent evaluator has access to the results, within a few weeks of the survey completion, but they should not be released for public access until after the completion of the test, when they can be properly interpreted. The information in this category is in the form of written documents (Excel files), either emailed to the IE, put in a shared folder or uploaded to the SDC.

4.1.2 Abnormal Event-based Data

Abnormal events are to be expected during a field test of prototype versions of a new technology system, but by definition their precise character and timing cannot be predicted in advance. These events would be tracked by the fleet operator and the PATH team. Because these could have important implications for safety or operational viability of the truck platooning system, they would be reported promptly after their occurrence by e-mail (with attachment documents as appropriate) so that USDOT and the independent evaluator are aware of the issues. Examples of these abnormal events are expected to include:

- Serious driver concerns about performance of the CACC system
- Driver decision to withdraw from participation in the field test
- Decision to suspend CACC field testing (by fleet operator or project team)
- Identification of a significant technical flaw in the CACC or data acquisition system performance

- Near-crash incident involving any of the test trucks
- Crash involving any of the test trucks
- These types of events may require repair to the trucks, modifications to the CACC system or changes to the design of the experiment to try to ensure that the remainder of the testing can be done as safely and efficiently as possible.

4.1.3 Regular Event-Based Data

Throughout the experiment, many kinds of data would be recorded regularly on an event basis, either periodic or irregular. These need to be further subdivided based on how they are recorded.

Fleet operator off-board data:

These electronic records would be obtained from Roly's Trucking on a weekly basis (frequent enough to keep close track on progress, but not so frequent that it becomes intrusive) for uploading to the data repository:

- Refueling – amount of fuel in gallons and accumulated mileage on each truck at each refueling
- Maintenance actions taken on each truck
- Inspections, including any inspections done proactively between trips or any pull-overs by law enforcement while en route
- Times of departure and arrival for each trip, including any extra time to wait for other trucks to be ready to go.
- Reasons for cancellation of any planned trips (unavailability of driver or load or problem with vehicle).
- Weather condition reports from the fleet dispatchers (especially for adverse conditions that affect dispatching decisions or that impose delays along the way)
- Driver logs of hours of service, time spent doing other things and any noteworthy (non-safety critical) events encountered while driving. This could include minor system failures, disengagements, near crashes, adverse weather conditions, or anything else out of the ordinary. We expect safety critical events like crashes or major failures of the CACC to be reported to dispatch immediately.

None of these data elements were expected to require urgent attention by USDOT or the independent evaluator. They would be uploaded to a shared folder or the SDC and USDOT and the independent evaluator would be notified by e-mail when that has been done.

Truck Onboard Engineering and Video Data:

This was expected to be by far the largest quantity of data collected during the testing, including a combination of event-based data and continuous operation data (to be discussed more in Chapter 4.1.4).

Because of the large quantity of data, it must be transmitted by uploading to the SDC. After each such upload has been completed, USDOT and the independent evaluator would be notified by e-mail.

The combination of event-based data and continuously recorded data includes:

- Many channels of digital data captured from the vehicle data buses, including vehicle condition, sensor data, CACC control data, wireless communication data, and actuator commands and responses.
- Video data from video cameras added to capture information needed to diagnose problems or characterize events and to track motions of adjacent vehicles
- Lidar data used to track adjacent vehicles
- Driver voice data recordings associated with any concerns experienced along the way
- Driver monitoring system data (including facial video), capturing information about fatigue and distraction.
- These data are logged in the data acquisition system on each truck and uploaded at the end of each round trip when the trucks return to Roly's Trucking headquarters.
- The project team planned to monitor a small subset of the data on a continuing basis to look for indications of problems that need immediate attention. These would be based on simple diagnostic tests to verify that data are being recorded on some key data channels and to cross-check a few key data elements for reasonableness to make sure that key sensors are producing usable output data. These diagnostic data would be transmitted to PATH via a cellular data transfer system while the trucks are in operation, and PATH staff would monitor the diagnostic outputs to determine how to respond in case of:
- Control system problems
- DVI, DSRC, sensor detection and perception, and GPS problems
- Missing digital data channels
- Anomalous data indicating possible sensor problems (by running scripts to conduct reasonableness checks on values of some key sensor outputs)
- Missing video or video image quality problems.

Depending on the severity of the problems that are identified from this initial scan, diagnostic testing, maintenance or repair actions would be recommended for a truck that has problems, and the Roly's fleet operations staff would be contacted to discuss whether the affected truck needs to be pulled from service until the corrective action is completed, or assigned to the "reference truck" role rather than operating within the platoon (if its data acquisition system is working properly). Before the data are archived, the problem(s) would be identified in a meta-data file associated with the primary data files for the affected truck and trip, and those data flagged so that they can be excluded from use in computing the performance measures until the implications of the problem(s) are sufficiently well understood that the project team can determine which performance measures can be estimated for that truck/trip with high validity and which cannot.

The event-based portion of these data are a small, but important, fraction of the total. This includes the driver voice recording events most prominently, but it also includes some events that would have to be identified through processing of the entire body of quantitative data, such as:

- Driver disengagements and re-engagements
- Cut-in and cut-through events by other vehicles
- Platoon split and re-join maneuvers
- Estimates of potentially hazardous situations based on TTC values below specific threshold levels.

4.1.4 Continuously-Recorded Truck Onboard Engineering Data

The large majority of the data recorded on the trucks is sampled periodically during all the time that the trucks are being driven. These were already described above in Chapter 4.1.3 for “truck onboard data”. They would be uploaded to PATH’s server at the end of each trip and scanned the following day to identify any problems.

For the data that pass the initial scan without evidence of problems, a series of scripts would be run to use the recorded data to compute the continuous performance measures. Since these operations are applied to data that are not subject to failures or other problems, this information should not be time-critical for the evaluation of system performance. When this processing is completed, the data and performance measures would be uploaded to the SDC and e-mail notifications sent to USDOT and the independent evaluator.

4.1.5 Driver Fatigue and Alertness Data

Driver fatigue and alertness would be monitored throughout the FOT by using two separate systems, Jungo and SmartCap. The data collected by these two systems would be combined with the engineering data collected on the trucks to associate fatigue and alertness with the truck platooning operational aspects (such as trip duration, lighting and weather conditions, traffic conditions, position within platoon).

The Jungo system includes a camera that records the driver’s face continuously and provides measurements of head position and eye closure and automatically identifies epochs of potentially distracted driving when the driver is not attending to the forward roadway or micro-sleep events. This system runs automatically and does not require the driver to do anything to initiate data collection. Drivers would not have access to the data collected by the Jungo system. Additionally, although the potential exists for audible indications of distraction and closed eyes, all audible indications would be disabled during data collection. Since other naturalistic data collection studies have shown that drivers pretty quickly ignore and/or forget about the camera [12, 13], we would expect minimal influence on their behavior or acceptance.

The SmartCap system is used to measure driver fatigue levels. This system is more personally invasive than the Jungo system because drivers are required to wear a sensor band on their head while driving. The sensor band contains dry EEG electrodes to monitor brain activity and has been designed to be worn alone or integrated into a hat. It is important to have a proper fit of the band on the head and to reliably have drivers wear and maintain it to collect data. Maintenance should be a function of ensuring that it remains properly seated in the hat in which it is installed and charging it as needed. Drivers would be trained to use this system, including a set of “dos and don’ts” for collecting valid data. This system, like the Jungo system, is configured to be silently collecting data. However, if it detects an impending sleep episode, it would provide a notification for the driver to hear (and see) on the companion mobile data terminal. With the level of maturity and industry experience with these alerts, we were confident that false alarms would be minimal and that the provided alerts would be useful and provide an extra layer of safety. Like the output from the Jungo system, SmartCap provides 15-minute epochs of fatigue data. These data are combined with those from the Jungo system in the same trip-based files as tallies of the fatigue level indications within each epoch.

Performance Measure S-006 (in Appendix A) aims to determine level of driver attention and vigilance from the Jungo camera data. Westat proposed to analyze 15-minute epochs to determine eyes away from roadway, etc. The system effectively flags distraction events based on the amount of time that a driver’s head pose strays from the forward view. Parameters associated with the horizontal and vertical head orientation bounds and the amount of time within a detection window are required before an event is flagged are configurable prior to collection. Their default values are informed based on substantial data collected in both passenger vehicles and heavy trucks, which would obviously have quite different geometries and perhaps different expected operational windows within which normal glances would be expected to fall.

Researchers would review the distraction event videos (currently each is 30 seconds long) to confirm and code aspects of the events (e.g., validity, nature of distraction, direction of gaze). We anticipated adding columns to the CSV files that list the events within each “trip” (bounded by ignition ON/OFF events) to document those aspects for filtering and grouping of events during analysis. As for the 15-minute epochs, we anticipated doing a simple count by event types (i.e., distraction, micro-sleeps, etc.) for each 15-minute period within a given drive. This would be accomplished by way of an R script that ingests the CSV event files and performs the tally, resulting in another data file with those tally figures by category listed at the quarter hour for the period directly preceding it. Like the event files, these tallies are tied to “trips” with file naming that follows the trip-based convention of the video and vehicle engineering data files. This aggregate file is defined in the data dictionary alongside the raw file formats we expect to see from the Jungo and SmartCap systems.

With respect to using the driver monitoring systems to monitor driver safety during the FOT, the SmartCap system provides feedback to drivers directly, if it detects a critical fatigue situation. The Jungo system is intended to be silent (to the drivers) throughout the study. Problems with excessive distraction, headband misuse, etc. that might affect study safety, progress, or outcomes would be addressed as they come up to avoid dangerous or data loss situations.

4.2 Data Analysis Methodology

The preceding sections covered the recording and uploading of the raw data and the use of those data to estimate the performance measures as a continuous function of time or for the individual trucks/trips that are reported on each week.

Answering the important research questions requires a broader reporting and analysis of performance measures, combining the measures recorded at the individual truck/trip level to identify trends, comparisons based on platoon versus individual driving, position in platoon, and various other independent variables. Because many of these effects are subtle, large samples of data are needed to produce statistically viable comparisons, and some of the variations (weather conditions, for example) are only likely to be evident over the longer term (with seasonal changes). This means that it can be dangerous to make premature comparisons based on insufficient data.

The practical challenges of uploading and processing the large quantities of data to be collected during the testing limit the data uploads to once per truck round trip (approximately weekly). The performance measures of interest are expected to show up as rather subtle differences between trucks driven individually and in platoon, so they would have to be estimated based on large samples in order to reveal statistically significant differences. Since each cohort of test drivers is expected to drive for a three-month period, this is expected to be the minimum increment of testing to support interim reporting of findings. This 3-month interval of reporting performance measures is long enough to produce statistically valid data on one group of drivers and truck operations within the same seasonal traffic and weather conditions. The interim reporting of findings for each 3-month period was planned to be a very brief letter report with tabulations of several key performance measures and salient qualitative observations based on the experience of platoon operations during that period. The determination of the most revealing performance measures to report would be made at the time of reporting (about one month after the end of the data collection period), based on what appeared to be the most significant findings at that time.

The analyses of the data collected during the test would be focused on developing answers to the fundamental research questions associated with widespread potential use of truck platooning on Interstate-class highways. We intended to report out on our preliminary analysis at the fourth milestone meeting, with a final analysis at end of the project in the Evaluation Report.

The performance measures to be assessed in our analysis are listed in Table A.1 and cited by number here. In each case, we planned to analyze the data we are able to collect during the test to inform each of our performance measures and to develop answers to the questions that follow. These questions are formulated as neutral inquiries about the practical effects of truck platooning on long-haul truck fleet operations, rather than being stated as specific hypotheses to be proven or disproven, which would tend to imply specific presumed outcomes.

4.2.1 What are the human factors impacts on truck drivers in long-haul operation of a truck platoon?

By continuously recording and analyzing the data about truck driver state and performance, we expected to shed light on the impacts of truck platooning driving on the drivers, both short term and long term. The data to be collected and analyzed to determine the values of the relevant performance measures are defined in performance measures S-005, S-006, FLT-004, FLT-005 and FLT-006 and VED-001 and VED-003. The continuous monitoring of driver alertness and fatigue states in S-005 and S-006 would make it possible to show how these change over the course of a day of driving when the drivers are driving an isolated truck or driving in different positions in a platoon, and also to compare the results for daytime and nighttime driving. By comparing the results for each driver throughout the period of the field test (FLT-004), it would also be possible to learn how these effects evolve as the drivers gain more experience with the platoon operations (to what extent they improve or perhaps become complacent). These measures would also be compared across the different driving positions for the entire driver population to identify whether there are significant differences in alertness or fatigue for driving in platoon leading or following positions versus driving the reference truck apart from the platoon.

The drivers complete a round trip on the California-Texas route in the instrumented trucks without using CACC before the CACC system is made available to them to establish baseline driving behavior. Their driving performance in the reference truck toward the end of their period of driving would be compared to their baseline driving to learn about whether their use of CACC changed their driving performance (FLT-007).

The drivers' subjective attitudes with regard to truck platooning would be revealed as described in S-006, VED-001, VED-003 and FLT-005 and objective measurements of changes in their driving behavior over time would be revealed as described in S-005, FLT-004 and FLT-007, including both their usage of the CACC system and their car following behavior when driving under manual or conventional ACC control. The subjective measures would be obtained through the drivers' responses to the questionnaires. The objective measures would focus on the distributions of their chosen vehicle-following time gaps when they are not using CACC.

4.2.2 How are the other road users' behavior impacted in the presence of truck platoon operations?

The behavior of other road users can only be measured indirectly, since there is no effective way of instrumenting the vehicles of a large sample of other road users sharing the roads with the platooned trucks. The motions of the other vehicles would be tracked using the side-looking and forward-looking video and lidar sensors on the trucks, enabling the estimation of target tracks for each of the other vehicles, as described in M-002. Estimation and analyses of those target tracks, combining the data from the two or three trucks in the platoon, and comparing it with the target tracks detected by the single reference truck, is sufficiently complicated that it could not be done within the available budget for the project, so the video and lidar data would be made available for use by future analysts in other projects.

4.2.3 How does the gap between the trucks impact the costs / benefits of platooning?

The effect of the gap on fuel consumption, the most direct connection to economic benefits of platooning, has already been measured in our carefully controlled test track experiments under ideal conditions. The new knowledge to be gained here would extend that knowledge into real-world road and traffic conditions in a more diverse range of weather conditions and road geometries, but with less rigorous experimental controls. The more important contribution to knowledge would be understanding how normal fleet truck drivers prefer to use the platooning technology and what gap settings they choose to use under various conditions. This would lead to the ability to produce more realistic predictions of how platooning would be used in practice, and how much of the long-haul driving is likely to be done at each gap setting, with its respective fuel/cost savings.

The comparison with non-platooned operation would be made by driving a non-platooned truck on the same route at about the same time and recording its fuel consumption for comparison, as described in EE-001. The connection to actual operating costs is explained in FLT-002, while noting that potential compensating costs of any fleet logistical complications arising from the need to synchronize truck departures to enable platooning, would be accounted for in FLT-001. The engineering data from the trucks show which portions of each trip were driven manually and under ACC and CACC control and at which ACC and CACC gap settings. These control mode and gap setting data would be correlated with weather, traffic, grade, and lighting condition data to identify which of those independent variables influence the drivers' selections of control mode and gap. The correlations between control mode and gap and fuel consumption rate (normalized for vehicle loading) would also be analyzed.

4.2.4 What are the benefits of truck platooning to fleet owners?

The benefits to fleet owners are tied directly to the savings in fuel consumption and fuel costs addressed above. An added potential benefit could be gained if the drivers are sufficiently enthusiastic about platooning that it leads to higher job satisfaction and lower turnover of the driver labor force, but this would be difficult to assess in this test because of the extra incentives that need to be offered to the drivers to motivate them to take on some of the extra responsibilities involved in participating. This could only be addressed indirectly by assessing the drivers' responses to the surveys about their attitudes toward platooning, and especially any significant changes in the favorable direction as they gain more experience with platoon driving (addressed in FLT-005). The fuel consumption savings effects discussed in Chapter 4.2.3 would also be important inputs to this assessment.

Other fleet operator considerations that could potentially weigh against use of truck platooning include any extra time needed to coordinate dispatching of trucks together in a platoon (OP-001), inability to take full advantage of platooning throughout the duration of a long-haul trip (OP-003), and any extra delays encountered enroute to keep the platooned trucks together (M-001),

Finally, the surveys of fleet operator satisfaction with truck platooning, addressed in FLT-006, would shed light on the net perceived benefits of truck platooning to the fleet operators.

4.2.5 What are the policy, operational and safety impacts of truck platooning?

The safety impacts would be studied by comparing the frequency of occurrence of potentially hazardous situations Time-to-Collision (TTC) values below a couple of critical threshold levels) between platoon driving and driving the reference truck individually under the same operating conditions, since crashes were expected to be so rare during the field test that they could not produce statistically significant results. These measures are addressed in S-007, -008, -009 and -010, calculated from the real-time measurements of closing speed and range to the target objects.

The operational impacts are subtler and qualitative, and would have to be judged based on the assessments of the truck fleet operations personnel (managers and dispatchers) in their survey responses (FLT-006, with supporting quantitative information from FLT-001 and -002).

One of the operational unknowns is associated with the frequency and severity of cut-ins by drivers of other vehicles during normal public truck platoon operations, measured in OP-004. The cut-in events would be flagged so that their frequency of occurrence can be estimated, and the severity of the cut-ins estimated using the ratio of the speed differential to the clearance gap between the cut-in vehicle and the following truck (TTC) at the start of the cut-in event. There have also been questions about the extent to which platoon operations may be restricted based on road conditions such as grades and curves or urban traffic, which are covered in II-002. These would be determined by the drivers' real-time decisions about when to use CACC, revealed from the data about operating modes. The operational considerations associated with inspections and law enforcement interactions are addressed in SL-001 and SL-003 (with an emphasis on the delays that these impose on the trucks).

Policy impacts were not expected to be measurable based on the data collection and analysis, but they could become apparent at the conclusion of the project if the reporting of the results stimulated policy actions to facilitate platoon operations.

4.2.6 Technical Performance and Limitations of the Truck Platooning System

Although the technical performance of truck platooning was not a primary focus of this project, it is important to understand the performance capabilities and limitations of the platooning technology because this influences driver and fleet acceptance, as well as some of the impacts on traffic and the environment. This FOT would be the first opportunity to reveal technical issues that may not have been evident during prior limited-duration tests on test tracks, but that can only be revealed through sustained use by diverse drivers in diverse conditions while coexisting with general public traffic. The lessons learned here could be applied to make future improvements to the technology.

The tabulations of rates of occurrence of automatic disengagements (S-001), driver-initiated disengagements (S-002), platoon system failures (S-003), false positive collision avoidance braking (S-011) and overall reliability and availability (S-004) would provide general indicators of the robustness of the system and of potential needed improvements. Measures of the errors in maintaining the correct following gap (S-012) and V2V communication reliability (VED-002) would reveal a couple of specific aspects of system performance and measures of aggregate emissions (EE-002) comparing the platooned trucks with the reference truck could give an indication of potential emissions impacts of truck platooning, but this measure was unlikely to have sufficient precision to lead to definitive conclusions. Drivers' opinions about the effectiveness of the specific truck platooning implementation used for these tests would be captured in VED-001 and VED-003, providing potential guidance regarding future design improvements.

4.2.7 Synthesis of Lessons Learned

The lessons to be learned from the project would represent a synthesis of the key findings in each of the topic areas covered above, as well as other insights that arise unexpectedly in the course of the project. It was expected to be most efficient to synthesize these near the end of the project because premature attempts to do this could be unproductive (observations early in the course of the FOT might be artifacts of specific conditions at that stage rather than being more generally applicable over the full year of field testing). These lessons would be highlighted in the final project deliverables (after the FOT) so that they can be communicated to the broader stakeholder community.

Appendix A. Truck Platooning Performance Measures

The following abbreviations, CACC system parameters and key platooning terms are used in Table 18, 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

Key Platooning Terms:

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)

ID	Requirement	Prio rity	Performance Measures	Definition	Data Needed	Sorting Criteria
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 manual or ACC and truck 2 is in CACC divided by total time/distance.	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
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

ID	Requirement	Prio rity	Performance Measures	Definition	Data Needed	Sorting Criteria
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 would 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

ID	Requirement	Prio rity	Performance Measures	Definition	Data Needed	Sorting Criteria
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 vehicle trips that can be dispatched with properly working CACC system)	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 divided by total # of truck trips dispatched, expressed in percent.	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.)
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 would 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.

ID	Requirement	Prio rity	Performance Measures	Definition	Data Needed	Sorting Criteria
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, 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.)	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 would 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 would be recorded continuously, but the Jungo AI system would provide measures of distraction and attention to elements other than the road on a periodic basis. The AI engine would 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 would be performed on epochs identified as distraction events.	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-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; 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, traffic density, and driver voice recording causes.

ID	Requirement	Priority	Performance Measures	Definition	Data Needed	Sorting Criteria
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.

ID	Requirement	Prio rity	Performance Measures	Definition	Data Needed	Sorting Criteria
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

ID	Requirement	Priority	Performance Measures	Definition	Data Needed	Sorting Criteria
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 truck per trip.	Total travel time of platoon minus total travel time of reference truck from origin to destination.	Platoon and reference truck would be dispatched at about the same time and the differences in their arrival times at the destination would 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 would be available to enable other analysts to 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.	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 would be complicated and not affordable within project budget.	N/A

ID	Requirement	Priority	Performance Measures	Definition	Data Needed	Sorting Criteria
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 would be available for others to try to use to calibrate traffic simulation models	N/A	Side-mounted sensors on trucks would capture motions of traffic in adjacent lanes.	N/A
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 truck	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 would 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 would keep within the line of sight (150 ~ 200 m) of platoon so that the traffic would be similar.	Sort by gap setting, front vehicle range/relative distance, total mass, road grade, truck position in platoon.

ID	Requirement	Prio rity	Performance Measures	Definition	Data Needed	Sorting Criteria
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 platooning (per trip)	Difference between dispatch time of platoon trucks and dispatch time of reference truck per trip Difference between logistics cost of platoon trucks and logistics of reference truck per trip	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.
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 would 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.

ID	Requirement	Prio rity	Performance Measures	Definition	Data Needed	Sorting Criteria
FLT-003	Performance measure(s) should capture impacts of training on truck platoon drivers' performance as well as Fleet Operators operations.	D	No quantitative performance measure would be reported. A qualitative assessment would be reported at the end of the test.	Qualitative assessment would be based on results of driver questionnaires.	Drivers and fleet operators would complete questionnaires before and after training. Pre-training questionnaires would 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 would address the same topics to determine how training changed comprehension, expectations, etc. Additional questions would assess perceived benefits and limitations of the training itself. Similar questions would be administered as drivers gain on-road experience (see FLT-004 and FLT-005).	N/A

ID	Requirement	Priority	Performance Measures	Definition	Data Needed	Sorting Criteria
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 related activities	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) would be recorded for each driver. Subjective measures would 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

ID	Requirement	Prio rity	Performance Measures	Definition	Data Needed	Sorting Criteria
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 would be interviewed and would 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 would 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

ID	Requirement	Prio rity	Performance Measures	Definition	Data Needed	Sorting Criteria
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 would be interviewed and would 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 would 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

ID	Requirement	Priority	Performance Measures	Definition	Data Needed	Sorting Criteria
II-001	Performance measures should capture the impact of truck platoon on bridge structures.	MI	The PATH team is not planning to report a specific performance measure for this requirement; however, truck characteristics and speed profiles can be provided for USDOT analysis	N/A	Relevant truck characteristics that are static may include axle weights, gross vehicle 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.	N/A
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.)

ID	Requirement	Priority	Performance Measures	Definition	Data Needed	Sorting Criteria
II-003	Performance measure(s) should capture impacts of truck platoon on roadway pavements.	D	The PATH team does not plan to have a performance measure for this requirement since it is impractical.	N/A	N/A	N/A
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 would 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)

ID	Requirement	Priority	Performance Measures	Definition	Data Needed	Sorting Criteria
SL-003	Performance measure(s) should capture impacts/differences (if any) in truck inspection and enforcements for truck platooning	D	Measures listed above for SL-001 plus: Delay time due to being pulled over by law enforcement	Measures listed above for SL-001 plus: Total amount of time each truck is delayed by pull overs, separately tabulated for platooned trucks and reference truck, and normalized by hours of driving in each mode.	Each driver would make a log entry about each inspection or enforcement action that he or she encounters, with specific information about the length of the stop. When this involves a truck driving in platoon, the extra delay time would also be logged for the other trucks in the platoon that would not have had to stop otherwise.	Sort by platooning vs non-platooning (reference truck)
VED-001	Performance measure(s) should provide information regarding drivers' opinions on truck platoon equipment design deficiencies observed	I	No quantitative performance measure would be reported. A qualitative assessment would be reported at the end of the test.	Qualitative assessment would 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 would be flagged, including T-Gap selection; speed; specific location, road geometry (curvature and grade, number of lanes).	N/A

ID	Requirement	Priority	Performance Measures	Definition	Data Needed	Sorting Criteria
VED-002	Performance measure(s) should capture the reliability of V2V communications between trucks in a platoon.	MI	Rate of DSRC failures Count of handshake 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. Number of times when DSRC failed to connect at start of platoon trip	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.
VED-003	Performance measure(s) should capture the effectiveness of information provided to drivers of following trucks	I	No quantitative performance measure would be reported. A qualitative assessment would be reported at the end of the test.	Qualitative assessment would be based on results of driver questionnaires.	Driver survey data, including questions about differences based on position in platoon.	Sort by position in platoon

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