Connected Vehicle Pilots Phase 2 Interoperability Test

Test Report

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16. Abstract

The Connected Vehicle Pilot Deployment Program Cooperative Agreement calls for a Stakeholder Outreach activity that includes an interoperability activity showing successful interaction between the local Connected Vehicle Pilot Deployment site and in-vehicle devices from one or more of the other Connected Vehicle Pilot sites. The United States Department of Transportation (USDOT) and the three Connected Vehicle Pilot sites – New York City, Tampa Hillsborough Expressway Authority (THEA), and Wyoming – in collaboration with the USDOT's Technical Support Contractor, and the Saxton Transportation Operations Laboratory (STOL) conducted Interoperability Testing at the Federal Highway Administration (FHWA) Turner-Fairbank Highway Research Center (TFHRC) in McLean, Virginia on June 25-28, 2018. The Connected Vehicle Pilot Deployment Program's definition of interoperability is: "*A vehicle with an Onboard Unit (OBU) from one of the three CV Pilot sites is able to interact with OBUs and Roadside Units (RSUs) from each of the other sites in accordance with the key connected vehicle interfaces and standards*."

This document outlines a summary of the test cases that were tested, the results that were reported, and the recommendations for future Interoperability Testing. This report is intended for early adopters of CV application concepts, ITS professionals, CV application developers, States and local DOTs, transit agencies, Original Equipment Manufacturers (OEMs), and other stakeholders that can benefit from the results of the Interoperability Test.

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Executive Summary

Over four days in the summer of 2018, a watershed moment in the maturation of connected vehicle technologies occurred at the Turner-Fairbank Highway Research Center (TFHRC), a federally owned and operated national research facility in McLean, Virginia. Through a collaborative effort, the United States Department of Transportation (USDOT) and three Connected Vehicle (CV) Pilot Demonstration sites—New York City, Wyoming, and the Tampa Hillsborough Expressway Authority (THEA)—conducted an interoperability test to demonstrate if a vehicle with an onboard device from one of the sites was able to receive messages from onboard units (OBUs) and roadside units (RSUs), between each CV Pilot site, in accordance with the key connected vehicle interfaces and standards. A test of this nature, involving three deployment sites and five device vendors had never been done before.

Working with the USDOT and its contractors, the CV Pilot sites collaborated to harmonize the data elements that would make such interactions possible, establish the security profiles, and agree on interpretations of the various standards for connected vehicle systems. Coming into the test, participants were eager to see if all the planning and coordination over six months paid off—and it did.

In total, over one hundred interoperability test runs were conducted for four test application-based cases—Forward Collision Warning (FCW), Intersection Movement Assist (IMA), Emergency Electronic Brake Lights (EEBL), and reception of vehicle-to-infrastructure (V2I) signal phase and timing (SPaT) and MAP messages. Results of the testing indicated successful transfer of messages between devices located on six vehicles—from five different vendors—and between in-vehicle devices and roadside units (RSUs). All devices used for the test were enrolled with a commercial Security Credential Management System (SCMS) and used test certificates from the SCMS to ensure trusted communication between OBUs and RSUs. Based on the testing, it was concluded that all vendors and CV Pilot site deployment configurations were interoperable and could trigger warnings in each others' devices.

The Connected Vehicle Pilot Deployment Program

Connected vehicles are poised to transform how we travel providing the potential for immediate benefits including—saving lives, improving personal mobility, enhancing economic productivity, and transforming public agency operations. The USDOT is leading research to move connected vehicle technology closer to widescale, national deployment. Working with its partners, the USDOT is working with state and local agencies to accelerate the deployment of this emerging technology, demonstrate its potential benefits, and help to overcome potential barriers and challenges along the way.

The CV Pilot Deployment Program was launched in September 2015 to deploy, test, and operationalize cutting-edge mobile and roadside technologies and to enable multiple connected vehicle applications. Sponsored by the Intelligent Transportation Systems (ITS) Joint Program Office (JPO), the Department awarded cooperative agreements to three agencies: New York City DOT, Tampa Hillsborough Expressway Authority (THEA), and the Wyoming DOT. During Phase 1 that lasted 12 months, each site prepared a comprehensive deployment concept plan that addressed all aspects of deployment including applications, security, operation and maintenance, procurement, and testing. In Phase 2, the three sites designed, built, and tested the nation's most complex and extensive deployment of integrated wireless in-vehicle, mobile device, and roadside technologies. In Phase 3, the current phase, the CV Pilot sites will operate and maintain their pilot deployment, assess impacts, and evaluate deployment performance.

While each CV Pilot site set out to address their specific local needs, the sites have been working with the USDOT to develop interoperable connected vehicle devices and equipment that leverage industry standards.

Interoperability

Connected vehicle standards support interoperability which will allow vehicles and the roadside **infrastructure** to exchange information and use the information in a consistent manner, regardless of the manufacturer of the vehicle, device, or the roadside equipment. With dozens of communities across the country planning to deploy connected vehicle technologies, all elements in a connected vehicle environment must work together in a safe, trusted, interoperable, and efficient manner. Adhering to key connected vehicle interfaces and standards allows vehicles from one manufacturer to communicate with vehicles from another manufacturer. From a practical perspective, interoperability ensures drivers utilizing connected vehicle technologies realize a safe, consistent experience with connected vehicle technologies as they travel from coast to coast.

To pave the way for a successful nationwide deployment of connected vehicle technology, a major goal of the CV Pilot Deployment Program is to test and demonstrate the current level of interoperability among still-maturing connected vehicle technologies. In a series of USDOT-facilitated technical roundtable meetings, the three CV Pilot sites settled on a definition of interoperability and an approach to conduct the interoperability test in the summer of 2018. For purposes of the interoperability activity, the USDOT and CV Pilot sites defined interoperability as:

“A vehicle with an onboard unit (OBU) from one of the three CV Pilot sites is able to interact with OBUs and/or roadside units (RSUs) from the other sites in accordance with the key connected vehicle interfaces and standards.”

Leading up to the Interoperability Test, the CV Pilot sites collaborated to harmonize the data elements that would make such interactions possible, establish the security profiles, and agree on interpretations of the various standards for connected vehicle systems.

Planning for the Interoperability Test

With a clear definition of interoperability in place, the sites next worked with the USDOT and its technical support contractor to develop a plan to conduct the CV Pilots Phase 2 Interoperability Test. The CV Pilots Phase 2 Interoperability Test Plan, available at the USDOT’s National Transportation Library (NTL), served as the official planning document for Connected Vehicle Pilots Phase 2 Interoperability Test. The document describes the objectives, test equipment, test environment (or facility), roles and responsibilities, test preconditions, schedule, test cases, and test procedures necessary to conduct the Interoperability Test.

The scope of the CV Pilots Phase 2 Interoperability Test was to test vehicle-to-vehicle (V2V) interactions between different site’s OBUs and vehicle-to-infrastructure (V2I) interactions between selected OBUs and RSUs. OBUs were expected to:

- Receive Basic Safety Messages (BSMs) transmitted by each of the other sites’ OBUs,

- Authenticate messages, as needed (i.e., when acting on the data or hearing a device for the first time),
- Parse messages (i.e., decode messages to the individual data element level), and
- Process messages (i.e., use the data as an input to applications, triggering responses according to the device's own application).

The interoperability test leveraged three V2V applications to demonstrate interoperability: FCW, EEBL, and IMA. In addition, V2I communications was demonstrated to test the ability for an OBU from one CV Pilot site to receive signal phase and timing (SPaT) and MAP messages being broadcast from another CV Pilot or vendor's RSU. New York City devices also demonstrated the Red-Light Violation Warning (RLVW) application. These applications were selected because they were common across the three CV Pilot sites and interoperability was a critical requirement for these to function as designed.

ES-Table 1. Applications and Their Definitions (Source: USDOT, 2018)

Application	Description
Forward Collision Warning (FCW)	An application where alerts are presented to the driver to help avoid or mitigate the severity of crashes into the rear end of other vehicles on the road. Forward crash warning responds to a direct and imminent threat ahead of the host vehicle.
Emergency Electronic Brake Lights (EEBL)	An application where the driver is alerted to hard braking in the traffic stream ahead. This provides the driver with additional time to look for, and assess situations developing ahead.
Intersection Movement Assist (IMA)	An application that warns the driver when it is not safe to enter an intersection—for example, when something is blocking the driver's view of opposing or crossing traffic. This application only functions when the involved vehicles are each V2V-equipped.
Red Light Violation Warning (RLVW)	An application that broadcasts signal phase and timing (SPaT) and other data to the in-vehicle device, allowing the in-vehicle device to generate warnings for impending red-light violations

Prior to the Connected Vehicle Pilots Phase 2 Interoperability Test, a Test Readiness Review (TRR) was conducted to review key preconditions. The TRR ensured that all parties agreed to the Test Plan; all devices were available and ready for testing; all devices had demonstrated their required functionality during their respective local CV Pilot project testing; and the test environment was available and ready for Connected Vehicle Pilot site device installation. Progress toward test readiness was reviewed during Technical Roundtable Meetings, however the TRR was held as a formal meeting where all stakeholders agreed that they were ready to conduct the Phase 2 Interoperability Test. This step ensured that all parties showed up to the test understanding their roles and responsibilities and all equipment was ready to support testing efforts.

Testing

Testing was conducted at TFHRC on June 25-28, 2018 with the first day allowing time for the CV Pilot sites to finalize installation of their devices in TFHRC-provided vehicles and configure their applications. Key to successful execution of the test was the support from Federal Highway Administration (FHWA) TFHRC staff, and its Saxton Transportation Operations Laboratory (STOL) contractor who provided technical support to the CV Pilot sites and the facility and supporting equipment for the testing. This support included installing the same RSU models as used by the sites to allow them to replicate their configurations, installing OBUs from the sites in vehicles, and providing trained drivers to operate the vehicles during the interoperability test runs. In addition to the USDOT and CV Pilot sites, representatives of the CV Pilots' Independent Evaluation team were present to observe in support of the broader independent evaluation effort.

Each of the six TFHRC-provided vehicles were outfitted with an OBU from one of the CV Pilot site's OBU vendors. In addition, the New York City and THEA sites each loaded their software on TFHRC-supplied RSUs from a single vendor. In total, two RSUs—both from the same vendor but with software from New York City and THEA—were used. All devices used test certificates and were enrolled with a commercial SCMS.

Over four days, more than one hundred tests were conducted at TFHRC. Over 10 GB of data was collected for all tests and then sent to the cloud-based system—the Secure Data Commons (SDC)—where it is available to support future research activities. Results of the testing indicated successful interoperable transfer of V2V messages between the six vehicles from five different vendors – four that used dedicated short-range communications (DSRC) and one that used a combination of DSRC and satellite communications. Additionally, equipment from each vendor demonstrated the successful transfer of messages between RSUs and each sites' OBUs.

Lessons Learned

Several lessons learned were identified that the team found to be valuable and may serve beneficial for future Interoperability Testing activities.

- **Coordinate regularly in the months leading up to the actual test date.** Coordination in the months leading up to the Interoperability Testing test date allowed for CV Pilot sites, vendors, and stakeholders to work together, procure equipment, develop a schedule, provide feedback, etc. This coordination was done via a bi-weekly technical roundtable. A clear definition of roles and responsibilities was important to support planning and execution of the test. Personnel should be clearly identified, and all roles should have backups in the case of unexpected events.
- **Coordinate with test beds to make sure all equipment and software is received well in advance before Interoperability Testing is conducted.** The CV Pilots sites mailed all their testing equipment to TFHRC two weeks before testing was conducted. This allowed time for TFHRC to set up OBUs in designated vehicles and make sure the software was working as designed. This allowed time for the installation process to be verified by responsible CV Pilot site representatives.
- **Schedule a full day for setup, checkout and dry runs.** Having an extra day to make sure equipment was installed properly, applications run as expected, etc. was beneficial come the day of running the Interoperability Testing. CV Pilot sites and vendors were able to do last minute updates, study the test bed, and make changes to the test plan to accommodate for a successful execution.
- **Make conservative estimates for test runs.** A basic assumption of 10-minutes per test run was assumed for the Interoperability Testing through discussions with the sites. However, this was based on the location of where the test was conducted, and accommodated for the start time, the test run, and data collection activities. This should be revised for future interoperability tests based on how long it takes to run through a test bed with an added buffer time.

- **Include pre-meeting and set aside 20-30-minutes for dry runs before conducting individual tests.** While running the individual tests, it was found to be beneficial to run through the test procedures for each application's test a few times so that drivers, vendors, and stakeholders were informed and knew what to expect. Additionally, time should be included at the end of each day to identify what tests need to be retested and to discuss any issues the drivers and other individuals encountered during testing.
- **Have walkie-talkies to communicate with drivers, test leads, USDOT representatives, etc. during test runs.** Walkie-talkies were found to be indispensable during the Interoperability Test. USDOT representatives were able to communicate the start time of each test with in-vehicle personnel, as well as flaggers. End time for each test was also communicated via walkie-talkies.

Conclusion

Overall, the three-day testing event was a major success that went above and beyond the event's original testing objectives, with time allotted on the last day for some impromptu tests by the sites. Results of the testing indicated successful transfer of messages between the six vehicles fit with devices from five different OBU vendors. In addition, equipment from New York City and THEA's vendors demonstrated the successful transfer of messages between the site-configured RSUs and the sites' OBUs. The Interoperability Test was a major step forward and showed that collaboratively working together and organizing around current standards can produce a relatively high level of interoperability. As the CV Pilot sites move into their deployment phase, and dozens of state and local agencies across continue to deploy connected vehicle technologies across the country, continued collaboration is necessary to ensure that the systems are interoperable so that drivers have the same experience when using devices as they travel from coast to coast. And by continuing to collaborate in shaping and adhering to industry standards, we're get closer to out-of-the-box plug and play interoperability.

1 Introduction

On September 1, 2016, the United States Department of Transportation (USDOT) awarded three cooperative agreements to New York City, Tampa Hillsborough Expressway Authority (THEA), and Wyoming worth more than $45 million to initiate a Design/Build/Test phase of the Connected Vehicle (CV) Pilot Deployment Program. Sponsored by the USDOT Intelligent Transportation Systems (ITS) Joint Program Office (JPO), the CV Pilot Deployment Program is a national effort to deploy, test, and operationalize cutting-edge mobile and roadside technologies and enable multiple connected vehicle applications. These innovative technologies and applications have the potential for immediate beneficial impacts. The technologies are designed to save lives, improve personal mobility, enhance economic productivity, reduce environmental impacts, and transform public agency operations. During Phase 1, each site prepared a comprehensive deployment concept to ensure that all aspects of CV deployment including applications, security, operation and maintenance, procurement and testing were addressed. In Phase 2—the current phase of the program—the three sites are finalizing a 20-month phase to design, build, and test the nation's most complex and extensive deployment of integrated wireless in-vehicle, mobile device, and roadside technologies.

To pave the way for a nationwide deployment, a major long-term goal of the CV Pilot Deployment Program is for the connected vehicle devices and equipment to be interoperable, meaning that they would be able to operate as designed anywhere in the country, regardless of where they were built. The cooperative agreements between the USDOT and the CV Pilot Deployment sites included a requirement for the sites to perform an activity that shows the devices from the three sites being interoperable.

Leveraging a series of technical roundtable meetings, the USDOT and the three CV Pilot sites settled on a definition of interoperability and an approach to conduct a limited test of interoperability. For purposes of the interoperability activity, the USDOT and CV Pilot sites defined interoperability as:

> *"A vehicle with an onboard unit (OBU) from one of the three CV Pilot sites is able to interact with OBUs and/or roadside units (RSUs) from the other sites in accordance with the key connected vehicle interfaces and standards."*

Over a period of several months, the CV Pilot sites collaborated to harmonize the data elements that would make such interactions possible. Some of these collaborations included establishing the security profiles, and agreeing on the interpretations of the various standards for CV systems. The sites next worked with the USDOT and its support contractor to develop a plan to conduct the CV Pilots Phase 2 Interoperability Test that took place at Turner-Fairbank Highway Research Center (TFHRC) in McLean, Virginia on June 25-28, 2018. In addition to testing interoperability among connected vehicle devices from the three sites, the testing also served to identify potential interoperability issues that may require resolution prior to the sites advancing to an operational phase of the CV Pilot Deployment Program later in 2018.

Planning for the testing event was jointly led by the CV Pilot sites in coordination with TFHRC and USDOT staff. TFHRC staff, and its Saxton Transportation Operations Laboratory (STOL) contractor, provided support to the CV Pilot sites as well as the facility and supporting equipment for the testing. This support included installing the same roadside unit (RSU) models used by New York City and Wyoming to allow them to replicate their configurations, installing onboard units (OBUs) from the sites in vehicles, and providing trained drivers to operate the vehicles during the interoperability test runs. In addition to the USDOT and sites, representatives of the CV Pilots Program Independent Evaluation (IE) team were present to observe in support of the broader independent evaluation effort. Six TFHRC-provided vehicles were used for the testing with each vehicle being outfitted with an OBU from one of the CV Pilot site's OBU vendors. Additionally, New York City and Tampa sites each loaded their software on TFHRC-supplied RSUs.

This test report summarizes the test cases that were tested, the results that were reported, lessons learned, and recommendations for future Interoperability Testing. The report is intended to inform and support knowledge and technology transfer (KTT) with early adopters of connected vehicle technologies including ITS professionals, state and local DOTs, transit agencies, connected vehicle vendors and application developers, Original Equipment Manufacturers (OEMs) and other stakeholders that can benefit from the results of the CV Pilots Phase 2 Interoperability Test.

1.1 Test Objectives and Expectations

The CV Pilots Phase 2 Interoperability Test goals consisted of testing vehicle-to-vehicle (V2V) interactions between different site's OBUs and vehicle-to-infrastructure (V2I) interactions between selected OBUs and RSUs. OBUs from all sites were able to:

- Receive SAE J2735 Basic Safety Messages (BSMs) transmitted by each of the other sites' OBUs using over-the-air (OTA) IEEE 802.11p based dedicated short-range communications (DSRC) in the 5.9 GHz spectrum,
- Authenticate messages (IEEE 1609.2) as needed (i.e., when acting on the data or hearing a device for the first time),
- Parse messages (i.e., decode J2735 message to individual data element level), and
- Process them (i.e., use the data as an input to applications, triggering responses according to the device's own application) in accordance with SAE J2945/1 (potentially augmented as necessary for trucks to specify treatment of trailers/articulation, etc.).

Specific V2V testing included:

- The Forward Collision Warning (FCW) application hosted by OBU equipped vehicles (i.e., TFHRC-owned vehicles, each equipped with a different CV Pilot site's OBU/vehicle-based equipment) from each site was able to interact with equipped lead vehicles from each of the other sites in an "open-sky" environment, and demonstrate a response (e.g., alert). Open sky is understood to be a condition where the OBU will have an unobstructed aerial view to obtain global positioning system (GPS) information without corrections or other refinements for location accuracy and precision. The CV Pilot sites determined whether their FCW application (as the following vehicle) needs tuning beyond their own deployment configuration.
- The V2V Electronic Emergency Brake Light (EEBL) and V2V Intersection Movement Assist (IMA) applications on OBUs from Tampa and New York City were able to interact with equipped vehicles from the other sites in an open-sky environment to demonstrate a response.

Specific V2I testing included:

- Interactions between selected OBUs and RSUs from New York City and Tampa, and

- V2I testing focused on applications that utilize Signal Phase and Timing (SPaT) and MAP (e.g., the red-light violation warning application).

1.2 Document Overview

Sections included in this Test Report include:

- **Section 1: Introduction** – Provides an overview of the purpose of the test as well as the test objectives and expectations.
- **Section 2: References** – Includes a list of references that were used to develop the CV Pilots Phase 2 Interoperability Test – Test Report.
- **Section 3: Test Overview –** Discusses scope of the Interoperability Test, applications leveraged for testing, test environment, test notebooks and documentation, and real-time data capture efforts.
- **Section 4: Roles and Responsibilities** – Summarizes the various roles and responsibilities of personnel and teams that were critical to make the Interoperability Test a success
- **Section 5: Test Schedule and As-Run Test Times** – Provides the detailed start times for each of the individual test runs.
- **Section 6: Test Cases** – Provides an overview of the test cases and summarizes any modifications that were made to the test plan.
- **Section 7: Test Results** – Provides a summary of the test results for all test runs.
- **Section 8: Best Practices, Observations, and Lessons Learned** – Identifies best practices for running future interoperability tests and observations from the Independent Evaluator, from the focus group discussion conducted on June 28th and from others involved in testing.
- **Section 9: Recommendations for Future Testing** – Provides recommendations for future Interoperability Testing.
- **Appendix A** – Includes a Sample Test Log that was used to collect data for the Interoperability Test.
- **Appendix B** – Provides a list of individuals that contributed to the success of the Interoperability Test.

2 References

Table 1 includes a list of references that were used to develop the CV Pilots Phase 2 Interoperability Test – Test Report.

Table 1. List of References **(Source: USDOT, 2018)**

No.	Document Name	Version	Description	Date
1	CV Pilots Phase 2 Interoperability Testing Test Plan FHWA-JPO-18-691 https://rosap.ntl.bts.gov/view/dot/36715	Final	A test plan to capture the collective understanding of the planned steps and progress being made over time during Phase 2.	8/13/2018
2	4s12_V2I Interoperability Level Test Procedure_Sys-v3	3	Level Test Procedure (Siemens)	--
3	121617 – Interoperability Demo Playbook	--	Joint Connected Vehicle Pilot / USDOT Playbook for Interoperability Demonstration	12/16/2017
4	Interoperability Test Cases.zip (Multiple files)	--	Wyoming Interoperability Test Cases	--
5	Technical Report – Plan and Test Procedures for Vehicle Awareness Devices (VADs) and Aftermarket Safety Devices.pdf	--	Vehicle-to-Vehicle Safety System Light Vehicle Builds and Model Deployment Support (V2V-MD) Test Plan and Test Procedures for Vehicle Awareness Devices and Aftermarket Safety Devices (NHTSA)	--
6	IEEE 1609.2 https://standards.ieee.org/standard/1609_2-2016.html	2017	IEEE Standards for Wireless Access in Vehicular Environments – Security Services for Applications and Management Messages	--
7	IEEE 802.11p https://standards.ieee.org/standard/802_11p-2010.html	2012	IEEE Standard for Information Technology – Local and Metropolitan Area Networks – Specific Requirements – Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amendment 6: Wireless Access in Vehicular Environments	--
8	SAE J2735	2009	Dedicated Short Range Communications (DSRC) Message	--

No.	Document Name	Version	Description	Date
	https://www.sae.org/standards/content/j2735_200911/		Set Dictionary	
9	SAE J2945/1 https://www.sae.org/standards/content/j2945/1_201603/	2016	On-Board System Requirements for V2V Safety Communications	--

3 Test Overview

Interoperability testing was conducted in accordance with the CV Pilots Phase 2 Interoperability Test – Test Plan (publication number FHWA-JPO-18-691). Iterative development of the Test Plan was led by the USDOT and its technical support contractor with inputs from the CV Pilots sites, their vendors, and the STOL contractor. Prior to the CV Pilots Phase 2 Interoperability Test, a Test Readiness Review (TRR) was conducted to review key preconditions that had to be met before the test could be held and to officially approve the Test Cases and Test Procedures. Progress toward test readiness was reviewed at the CV Pilot Technical Roundtable Meetings—held bi-weekly leading up to the Interoperability Test. This section provides an overview of the CV Pilots Phase 2 Interoperability Test including its scope, applications leveraged for testing, an overview of the test environment, and the test equipment used.

3.1 Scope of Testing

The scope of the CV Pilots Phase 2 Interoperability Test focused on the reception of OTA messages between two vehicles (V2V communications) and between infrastructure and vehicles (V2I communications). Messages broadcast for the interoperability test included basic safety messages (BSMs), SPaT, and MAP messages.

While specific applications were demonstrated during the Interoperability Test, the intent of the Interoperability Test was not to test the applications' performance. All CV Pilot sites were required to conduct performance testing of their applications within their own test programs prior to the start of deployment operations. Performance testing, in this context, includes how accurately OBUs are reporting their positioning, how quickly applications alert drivers after receiving a triggering event, etc.

A total of six test cases were conducted. The first test case consisted of a baseline OBU / aftermarket safety device (ASD) Data Collection test to collect data from OBUs / ASDs from each site installed on a vehicle to create a baseline of how devices perform in relation to each other. The specific test case included:

- **Test Case 1:** Baseline OBU / ASD Data Collection

BSM based scenarios were selected because they were common across the three CV Pilot sites and interoperability was a critical requirement for these to function as designed. Specific BSM-based test cases conducted as part of the Interoperability Test included:

- **Test Case 2:** FCW with a Stationary Vehicle in the Same Lane
- **Test Case 3:** FCW with a Stationary Remote Vehicle in the Adjacent Lane
- **Test Case 4:** FCW and EEBL with a Moving Remote Vehicle
- **Test Case 5:** IMA with the Host Vehicle Stopped

V2I/SPaT/MAP-based test cases conducted as part of the Interoperability Test included:

- **Test Case 6:** Reception of SPaT and MAP messages (New York City and Tampa vehicles) and Red-Light Violation Warning (RLVW) at Signalized Intersection (only for New York City vehicles).

3.2 Applications Leveraged for Testing

Table 2 includes a list of the applications that were tested during the Interoperability Testing and a brief definition.

Table 2. Applications and Their Definitions (Source: USDOT, 2018)

Application	Description
Forward Collision Warning (FCW)	An application where alerts are presented to the driver to help avoid or mitigate the severity of crashes into the rear end of other vehicles on the road. Forward crash warning responds to a direct and imminent threat ahead of the host vehicle.
Emergency Electronic Brake Lights (EEBL)	An application where the driver is alerted to hard braking in the traffic stream ahead. This provides the driver with additional time to look for, and assess situations developing ahead.
Intersection Movement Assist (IMA)	An application that warns the driver when it is not safe to enter an intersection—for example, when something is blocking the driver's view of opposing or crossing traffic. This application only functions when the involved vehicles are each V2V-equipped.
Red Light Violation Warning (RLVW)	An application that broadcasts signal phase and timing (SPaT) and other data to the in-vehicle device, allowing the in-vehicle device to generate warnings for impending red-light violations

To demonstrate interoperable connected vehicle applications, many supporting connected vehicle technology elements are necessary including:

- OBUs and RSUs need to use credentials obtained from the same security credential management system (SCMS)—with common root—to include signatures with messages and validate received messages as necessary. The CV Pilot sites used the commercial Green Hills/ISS Test SCMS system for the interoperability test.
- Positioning accuracy has to satisfy SAE J2945/1 for V2V. It was agreed that the tests and demonstration of V2V interoperability would take place in an "open sky" environment with no site-specific position augmentation.
- The presence of optional data content in device messages designed for trucks or other vehicle classes should not affect basic interoperability of messages and credentials. Although the focus of the Phase 2 Interoperability Test was on light-duty vehicle interoperability, additional optional message content cannot disrupt the functioning of these applications.

3.3 Test Environment

Testing was conducted at the USDOT's TFHRC—located in McLean, Virginia. Figure 1 depicts a map of the test facility including key infrastructure (e.g., location of traffic signals and cabinets) currently located at TFHRC. The test bed includes three traffic signal cabinets near the first intersection and one near the second intersection as shown by the blue boxes on the map. The RSUs used for the interoperability test were mounted on Poles D and F. Traffic sensors are installed throughout the FHWA Circulation Road with a GPS station located near the second intersection to the left of North Driveway and denoted by a green box. Four pedestal poles and a gantry are also shown on the map.

Note that TFHRC has an “open-sky” GPS environment, although in some cases vegetation may have caused some interference with the GPS signals. There was no attempt to deal with WAAS correction since the RTCM message and infrastructure was not available or used. Finally, there was no real-time connection to the SCMS. Although the certificates all came from the same SCMS and the same root, there was no live connection to the SCMS allowing vehicles to “top-off” their certificates at the RSU.

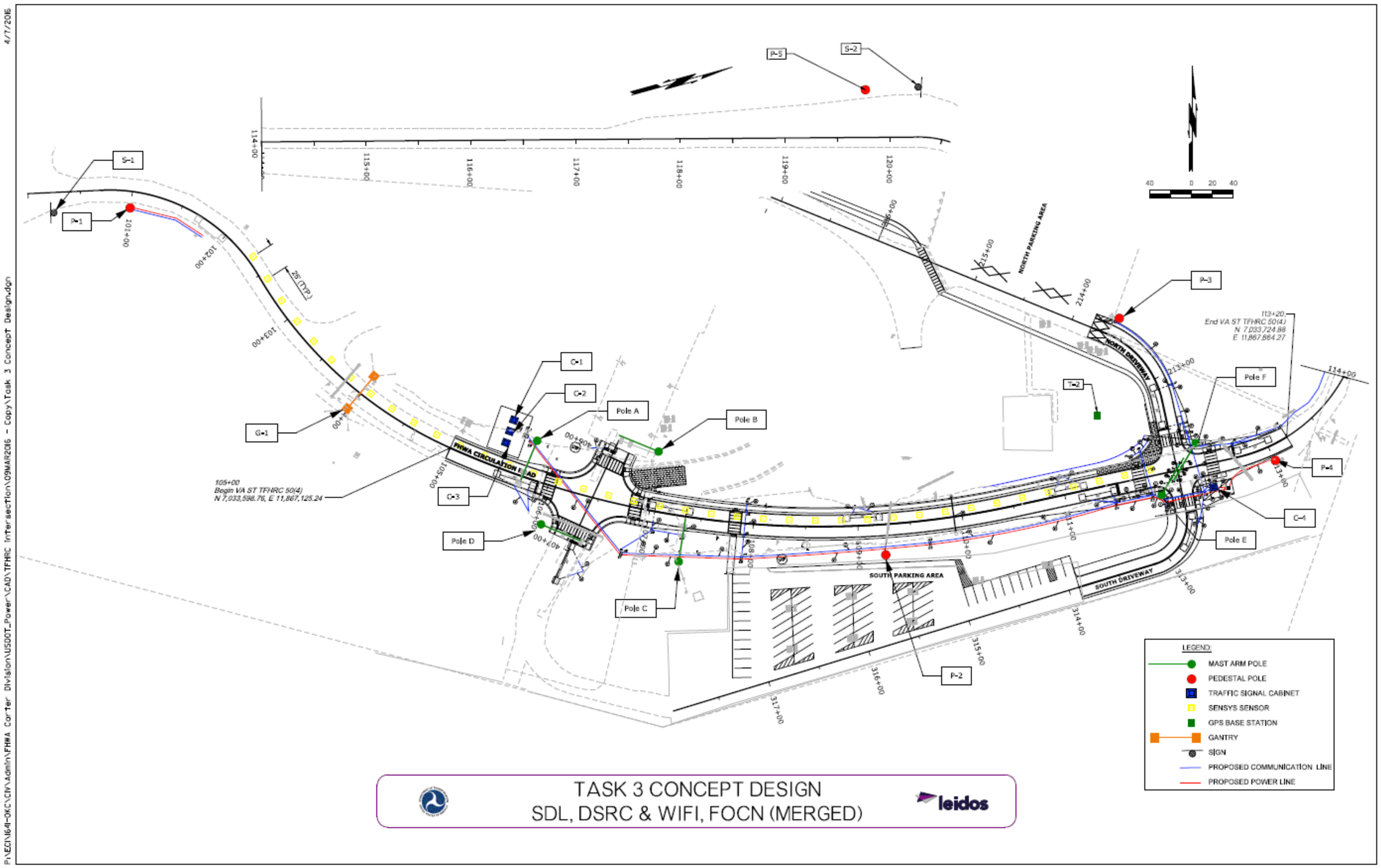

Figure 1. Map of the TFHRC Facility **(Source: USDOT, 2018)**

Figure 2 depicts the location of key staff and equipment used to support the Interoperability Test. All vehicles were staged near the *Test Director* behind the TFHRC facility. Tests began at the *Starter* area and proceeded along the test path. Upon completion of the test, the drivers of the vehicles reported their results to the individuals at the *Agreement Officer Representative (AOR) and Official Record Keeper Station.* The vehicles then returned to the staging area where CV Pilot site representatives downloaded the data collected from the test run. Finally, while the road was closed for testing, two *Flaggers*—provided by the STOL team— were used to direct traffic at the entrances and exits to the parking lots to allow TFHRC staff and visitors to enter or exit the parking lot. The *Flaggers* communicated with the rest of the team when the remote vehicles were in position to start the test.

To enable communication between the key individuals leading and conducting the test, handheld walkie-talkies were used. The Test Director, Starter, Flaggers, and AOR station had walkie-talkies for all tests. Walkie-talkies were also available for use by each of the six test vehicles for most of the tests. Walkie-talkies allowed the team to ensure that vehicles were in place and ready to start each test. Additionally, the team used the walkie-talkies to communicate the start time of the test, verify that the correct vehicles were participating in the test, and to note when vehicles left the AOR station and whether a retest was required.

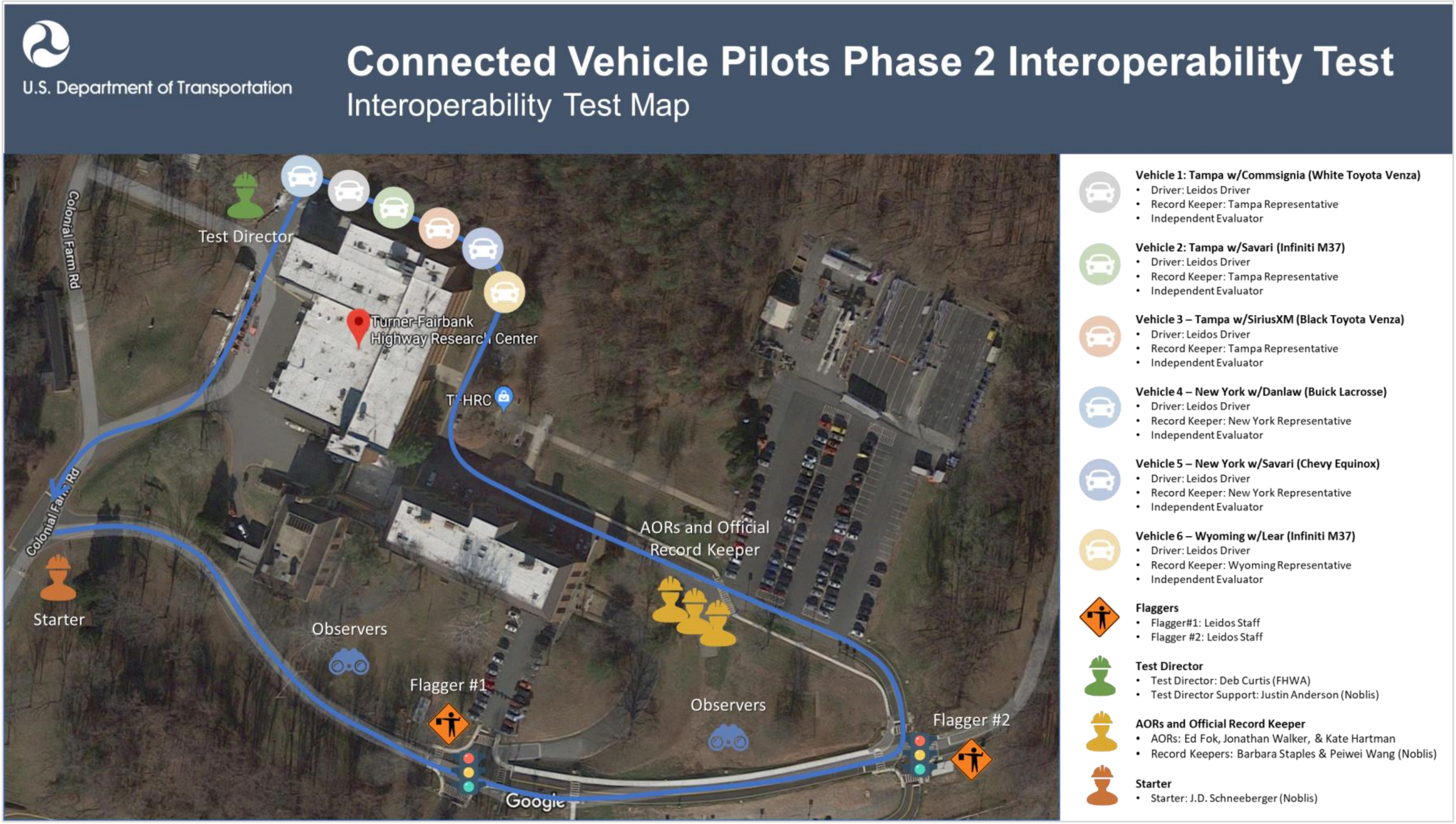

Figure 2. Detailed CV Pilots Phase 2 Interoperability Test Map **(Source: USDOT, 2018)**

3.4 Test Equipment

Devices used during the Interoperability Test are included in Table 3 below.

Table 3. Test Equipment **(Source: USDOT, 2018)**

CV Pilot Site	Device Type	Vehicle	Vendor
New York City	OBU	Buick Lacrosse	Danlaw
New York City	OBU	Chevrolet Equinox	Savari
New York City	RSU	N/A	Siemens
Tampa	OBU	White Toyota Venza	Commsignia
Tampa	OBU	Infiniti M37	Savari
Tampa	OBU	Black Toyota Venza	SiriusXM
Tampa	RSU	N/A	Siemens
Wyoming	OBU	Infiniti M37	Lear

Table 4 shows the types of equipment used in each application test.

Table 4. Test Equipment Mapped to Test Cases **(Source: USDOT, 2018)**

CV Pilot Site	Equipment	Baseline	FCW	IMA	EEBL	
New York City	OBU - Danlaw	•	•	•	•	•
New York City	OBU - Savari	•	•	•	•	•
New York City	RSU - Siemens	-	-	-	-	•
Tampa	OBU – Commsignia	•	•	•	•	•
Tampa	OBU – Savari	•	•	•	•	•
Tampa	OBU - SiriusXM	•	•	•	•	•
Tampa	RSU - Siemens	-	-	-	-	•
Wyoming	OBU - Lear	•	•	-	-	-

• Tested; - Not Tested

3.5 Test Notebooks and Documentation

Test Notebooks were created for the Test Director, Starter, Test Coordinator, each test vehicle, each of the three AORs, and the Independent Evaluator. The Test Notebooks included the agenda for the Interoperability Test, test procedures, and logs (see Appendix A) to record the results of the test. A representative from each site was responsible for riding in the test vehicle and recording the results of the test. At the completion of the test run, the vehicle stopped at the AOR and Official Record Keeper station and reported the results to the USDOT. The USDOT recorded the official results in a notebook. At the end of the CV Pilots Phase 2 Interoperability Test, all notebooks were collected by the USDOT and its technical support contractor.

3.6 Real-Time Data Capture

Each CV Pilot site followed predefined procedures to set up, configure, and/or collect data from their OBUs and RSUs. Data from vehicle's OBUs were collected after every test run in accordance with the CV Pilots data collection plans—outlined in the CV Pilots Phase 2 Interoperability Test – Test Plan. Primary data collected across most devices was raw packet capture (pcap) from each of the radios with most also capturing GPS data. Some devices also captured system logs (syslogs).

Wyoming collected and analyzed data in real-time throughout the test. All data routed through their Operational Data Environment (ODE) (see www.its.dot.gov/code) and was deposited into the cloud-based Secure Data Commons (SDC) which houses all CV Pilot evaluation data. In addition, the data was structured in a way to enable on-demand analysis by evaluators in the future. This is the same data architecture Wyoming will use during Phase 3 operations.

At the end of each day of testing, the USDOT collected data from each sites' devices using USB thumb drives. The USDOT and its technical support contractor consolidated the data and uploaded the data to the SDC. Approximately 5 GB of data was collected in total and is available on SDC. Access to the data is restricted to the CV Pilot projects and the Independent Evaluator.

4 Roles and Responsibilities

The CV Pilots Phase 2 Interoperability Test was a collaborative effort requiring a diverse group of staff to execute. Table 5 includes a list of the roles and responsibilities of personnel and teams that were critical to make the Interoperability Test a success. Appendix B includes a list of individuals that participated in the Interoperability Test on June 26-28, 2018 at TFHRC.

Table 5. Roles and Responsibilities **(Source: USDOT, 2018)**

Role	Personnel	Responsibility
Test Director	Deb Curtis (FHWA)	• Approving the completion and initiation of a phase; • Suspending/resuming testing during test execution; • Approving changes to the test schedule; • Approving the end of testing.
Test Coordinator	Justin Anderson (Noblis)	• Maintaining and updating the Test Plan; • Working with the applicable stakeholders to get inputs for gaps/updates to the test plan; • Tracking the status of Test Planning/Test Readiness; • Supporting the execution of interoperability testing; • Coordinating the development of Test Report.
Starter	J.D. Schneeberger (Noblis)	• Starting the tests according to the schedule and Test Director and Test Coordinator Inputs; • Supporting the execution of interoperability testing.

Role	Personnel	Responsibility
CV Pilot Site Test Leads	Hisham Khanzada (New York City), Steve Novosad (Tampa), Tony English (Wyoming)	• Providing site specific inputs to the Test; • Reviewing the Test Plan and providing comments; • Providing site specific devices, installation kits, and other necessary equipment for the demonstration; • Approving the installation and functional checkout of site-specific devices; • Troubleshooting issues found with site specific devices and/or identifying the subject matter experts necessary to troubleshoot their site-specific devices; • Collecting data from site specific devices; • Providing site specific inputs to the Test Report; • Reviewing the Test Report.
Support Personnel	STOL staff	• Providing inputs to the Interoperability Test Plan; • Preparing the test environment; • Driving the vehicles through the test environment; • Conducting test support roles such as Flagger and Manual Signal Operator; • Operating test environment specific devices/equipment.
USDOT Technical Support Staff	Noblis staff	• Official record keepers
USDOT Representative Team	Jonathan Walker (New York City), Ed Fok (filling in for Govind Vadakpat, Tampa), Kate Hartman (Wyoming)	• Reviewing, commenting and approving the Test Plan; • Witnessing the execution of the tests; • Coordinating/Approving test support; • Reviewing, commenting and approving the Test Report.
Independent Evaluator	Texas A&M Transportation Institute (TTI)	• Witnessing the execution of the tests; • Recording observations and lessons learned; • Interviewing key test stakeholders; • Developing an independent evaluation; • Reviewing, commenting and providing input for the Test Report.
CV Device Vendors	Commsignia, Danlaw, Lear, Savari, Siemens, SiriusXM	• Providing test support and assistance to the Connected Vehicle Pilot Site Test Leads; • Supporting device installation and checkout; • Supporting troubleshooting of issues.

5 Test Schedule and As-Run Times

The CV Pilots Phase 2 Interoperability Test – Test Plan included a schedule for the test cases over the four-day period. For planning purposes, it was assumed each test would take approximately ten minutes. The following schedule was followed as part of the Test Plan.

- **Monday June 25, 2018**
  - 8:30 AM – 5:00 PM - Sites Set-up Devices and Verified they are working properly
- **Tuesday June 26, 2018**
  - 10:00 AM – 2:30 PM - Test Case 2: FCW Stationary Remote Vehicle in the Same Lane
  - 2:30 PM – 4:30 PM - Test Case 3: IMA Host Vehicle Stopped
- **Wednesday June 27, 2018**
  - 9:00 PM – 10:00 PM - Test Case 4: V2I / RLVW
  - 10:00 AM – 1:00 PM - Test Case 5: FCW Moving Remote Vehicle and EEBL
  - 1:30 PM – 5:10 PM - Test Case 6: FCW Stationary Remote Vehicle in the Adjacent Lane
  - TBD - Test Case 1: Baseline OBU / ASD Data Collection
- **Thursday June 28, 2018**
  - 8:30 AM – 10:30 AM - Complete Retests (as needed)
  - Ad hoc – Stationary Remote Vehicle in the Same Lane with Parallel Platoon Test Case

The plan assumed that the three CV Pilot sites would send all their equipment to TFHRC / STOL staff two weeks prior to the start of the Interoperability Testing. All devices would be received by the STOL team for installation over the two-week period. The sites were expected to be enrolled in the commercial Green Hills/ISS Test SCMS system for the interoperability test. According to the plan, Test Case 1: Baseline OBU / ASD Data Collection was to be conducted the week of June 18th; however due to delays in shipping devices, Test Case 1 could not be conducted as scheduled. Instead the test was conducted on Tuesday June 26th.

The original schedule included time on Monday June 25th for the CV Pilot sites to finalize the set-up of their devices and to verify that the devices were working properly. Additionally, this preparation day allowed the sites to perform ad hoc testing to help make the three test days run smoothly. This allowed for the sites to configure their devices accordingly and to become familiar with the test facility and review the test procedures with their drivers.

Two test cases were conducted on Tuesday June 26th— Test Case 2: FCW Stationary Remote Vehicle in the Same Lane and Test Case 3: IMA Host Vehicle Stopped. In general, it took less than 10 minutes to run each test. The schedule called for conducting several tests back-to-back. Because the test took less time than originally planned, the test administrators were able to conduct pre-test meetings with the testers prior to switching to a new test. As part of these pre-test meetings, the test administrators reviewed the test protocols and procedures with the drivers and the developers to ensure that the tests were conducted the same way for each system and to promote coordination among the testers. After the pre-test meetings, the drivers could practice the test until they were comfortable with the test procedures. All tests for both test cases were completed on Tuesday June 26th and because the time to run each test was shorter than expected, the testers were able to conduct all required retests for the two test cases.

The plan called for three test cases to be conducted on Wednesday June 27th— Test Case 4: V2I / RLVW, Test Case 5: FCW Moving Remote Vehicle and EEBL, and Test Case 6: FCW Stationary Remote Vehicle in the Adjacent Lane. As with the test on the previous day, each test run took less than 10 minutes to perform allowing for additional time for pre-meetings and retests. The additional time also permitted the testers to conduct Test Case 1: Baseline OBU / ASD Data Collection in the afternoon. Again, all tests as well as any required retests were conducted during the timeframe.

The original plan set aside time on Thursday June 28th for necessary retests; however, all retests were completed on the previous days. Thus, on the final day of testing, an ad hoc test was added to the test regime. The purpose of this ad hoc test was to determine if a connected vehicle could trigger a positive FCW alert when traveling next to a platoon of connected vehicles in the adjacent lane. In this test, all six vehicles were used, and the drivers of the Host and Remote vehicles followed the same test procedures as identified for the FCW test case. The idea behind this test was to see if the host vehicle could correctly identify the stopped vehicle in its lane when other vehicles were also transmitting their BSMs next to the vehicle. While no formal observations were made of this test, vehicles were successful at issuing FCW for a stopped vehicle in its lane, even though other vehicles broadcasting BSMs were traveling adjacent to it.

Table 6 includes details of the schedule and the as-run test times from the CV Pilots Phase 2 Interoperability Test. It details the schedule and the actual run time for each test that was conducted. In total, there were total of 102 interoperability test runs conducted across the various test cases. Note that the Test IDs with Greek numerals are retests that were conducted. Test IDs with the beta numeral had retests conducted once, and those with the gamma numeral had been tested twice.

Table 6. Interoperability Test Schedule and As-Run Test Times (Source: USDOT, 2018)

Test ID	Test Case	Host Vehicle	Remote Vehicle	Date	Schedule	As-Run Time
1	FCW Stationary Remote Vehicle in the Same Lane	Tampa - Commsignia	New York City - Savari	6/26/2018	10:00 AM	10:10 AM
2	FCW Stationary Remote Vehicle in the Same Lane	New York City - Danlaw	Tampa - Savari	6/26/2018	10:10 AM	10:16 AM
3	FCW Stationary Remote Vehicle in the Same Lane	Tampa - SiriusXM	Wyoming - Lear	6/26/2018	10:20 AM	10:19 AM
4	FCW Stationary Remote Vehicle in the Same Lane	New York City - Savari	Tampa - Commsignia	6/26/2018	10:30 AM	10:23 AM
5	FCW Stationary Remote Vehicle in the Same Lane	Wyoming - Lear	New York City - Danlaw	6/26/2018	10:40 AM	10:28 AM

Test ID	Test Case	Host Vehicle	Remote Vehicle	Date	Schedule	As-Run Time
6	FCW Stationary Remote Vehicle in the Same Lane	Tampa - Savari	New York City - Savari	6/26/2018	10:50 AM	10:33 AM
7	FCW Stationary Remote Vehicle in the Same Lane	Wyoming - Lear	Tampa - SiriusXM	6/26/2018	11:00 AM	10:38 AM
8	FCW Stationary Remote Vehicle in the Same Lane	New York City - Savari	Tampa - Savari	6/26/2018	11:10 AM	10:48 AM
9	FCW Stationary Remote Vehicle in the Same Lane	Wyoming - Lear	Tampa - Commsignia	6/26/2018	11:20 AM	11:00 AM
10	FCW Stationary Remote Vehicle in the Same Lane	Tampa - Savari	New York City - Danlaw	6/26/2018	11:30 AM	11:05 AM
11	FCW Stationary Remote Vehicle in the Same Lane	New York City - Savari	Tampa - SiriusXM	6/26/2018	11:40 AM	11:07 AM
12	FCW Stationary Remote Vehicle in the Same Lane	New York City - Danlaw	Wyoming - Lear	6/26/2018	12:30 PM	12:38 PM
13	FCW Stationary Remote Vehicle in the Same Lane	Tampa - SiriusXM	New York City - Savari	6/26/2018	12:40 PM	12:41 PM
14	FCW Stationary Remote Vehicle in the Same Lane	Tampa - Savari	Wyoming - Lear	6/26/2018	12:50 PM	12:48 PM
15	FCW Stationary Remote Vehicle in the Same Lane	New York City - Danlaw	Tampa - Commsignia	6/26/2018	1:00 PM	12:50 PM
16	FCW Stationary Remote Vehicle in the Same Lane	Wyoming - Lear	New York City - Savari	6/26/2018	1:10 PM	12:55 PM
17	FCW Stationary Remote Vehicle in the Same Lane	New York City - Danlaw	Tampa - SiriusXM	6/26/2018	1:20 PM	1:01 PM
18	FCW Stationary Remote Vehicle in the Same Lane	Wyoming - Lear	Tampa - Savari	6/26/2018	1:30 PM	1:05 PM
19	FCW Stationary Remote Vehicle in the Same Lane	Tampa - Commsignia	New York City - Danlaw	6/26/2018	1:40 PM	1:09 PM
20	FCW Stationary Remote Vehicle in the Same Lane	New York City - Savari	Wyoming - Lear	6/26/2018	1:50 PM	1:13 PM

Test ID	Test Case	Host Vehicle	Remote Vehicle	Date	Schedule	As-Run Time
21	FCW Stationary Remote Vehicle in the Same Lane	Tampa - SiriusXM	New York City - Danlaw	6/26/2018	2:00 PM	1:17 PM
22	FCW Stationary Remote Vehicle in the Same Lane	Tampa - Commsignia	Wyoming - Lear	6/26/2018	2:10 PM	1:22 PM
1 beta	FCW Stationary Remote Vehicle in the Same Lane	Tampa - Commsignia	New York City – Savari	6/26/2018	N/A	2:00 PM
4 beta	FCW Stationary Remote Vehicle in the Same Lane	New York City - Savari	Tampa - Commsignia	6/26/2018	N/A	2:07 PM
10 beta	FCW Stationary Remote Vehicle in the Same Lane	Tampa - Savari	New York City - Danlaw	6/26/2018	N/A	2:20 PM
17 beta	FCW Stationary Remote Vehicle in the Same Lane	New York City - Danlaw	Tampa - SiriusXM	6/26/2018	N/A	2:27 PM
19 beta	FCW Stationary Remote Vehicle in the Same Lane	Tampa - Commsignia	New York City - Danlaw	6/26/2018	N/A	2:33 PM
22 beta	FCW Stationary Remote Vehicle in the Same Lane	Tampa - Commsignia	Wyoming - Lear	6/26/2018	N/A	2:40 PM
7 beta	FCW Stationary Remote Vehicle in the Same Lane	Wyoming - Lear	Tampa - SiriusXM	6/26/2018	N/A	2:51 PM
23	IMA Host Vehicle Stopped	Tampa - Commsignia	New York City - Danlaw	6/26/2018	2:30 PM	3:43 PM
24	IMA Host Vehicle Stopped	New York City - Savari	Tampa - SiriusXM	6/26/2018	2:40 PM	3:47 PM
25	IMA Host Vehicle Stopped	New York City - Danlaw	Tampa - Savari	6/26/2018	2:50 PM	3:52 PM
26	IMA Host Vehicle Stopped	Tampa - SiriusXM	New York City - Savari	6/26/2018	3:00 PM	3:57 PM
27	IMA Host Vehicle Stopped	Tampa - Savari	New York City - Danlaw	6/26/2018	3:10 PM	4:01 PM
28	IMA Host Vehicle Stopped	New York City - Savari	Tampa - Commsignia	6/26/2018	3:20 PM	4:06 PM
29	IMA Host Vehicle Stopped	New York City - Danlaw	Tampa - SiriusXM	6/26/2018	3:30 PM	4:09 PM
30	IMA Host Vehicle Stopped	Tampa - Commsignia	New York City - Savari	6/26/2018	3:40 PM	4:12 PM

Test ID	Test Case	Host Vehicle	Remote Vehicle	Date	Schedule	As-Run Time
31	IMA Host Vehicle Stopped	Tampa - SiriusXM	New York City - Danlaw	6/26/2018	3:50 PM	4:23 PM
32	IMA Host Vehicle Stopped	New York City - Savari	Tampa - Savari	6/26/2018	4:00 PM	4:27 PM
33	IMA Host Vehicle Stopped	New York City - Danlaw	Tampa - Commsignia	6/26/2018	4:10 PM	4:31 PM
34	IMA Host Vehicle Stopped	Tampa - Savari	New York City - Savari	6/26/2018	4:20 PM	4:37 PM
35	V2I – Red Light Violation Warning	Tampa - Commsignia	N/A (V2I)	6/27/2018	9:00 AM	9:43 AM
36	V2I – Red Light Violation Warning	New York City - Savari	N/A (V2I)	6/27/2018	9:10 AM	9:51 AM
37	V2I – Red Light Violation Warning	Tampa - Savari	N/A (V2I)	6/27/2018	9:20 AM	9:54 AM
38	V2I – Red Light Violation Warning	New York City - Danlaw	N/A (V2I)	6/27/2018	9:30 AM	9:56 AM
39	V2I – Red Light Violation Warning	Tampa - SiriusXM	N/A (V2I)	6/27/2018	9:40 AM	9:59 AM
40	FCW with Moving Remote Vehicle and EEBL	New York City - Savari	Tampa - SiriusXM	6/27/2018	10:00 AM	10:42 AM
41	FCW with Moving Remote Vehicle and EEBL	Wyoming - Lear	New York City - Danlaw	6/27/2018	10:10 AM	10:47 AM
42	FCW with Moving Remote Vehicle and EEBL	New York City - Savari	Tampa - Commsignia	6/27/2018	10:20 AM	10:49 AM
43	FCW with Moving Remote Vehicle and EEBL	New York City - Danlaw	Tampa - Savari	6/27/2018	10:30 AM	10:51 AM
44	FCW with Moving Remote Vehicle and EEBL	Tampa - SiriusXM	New York City - Savari	6/27/2018	10:40 AM	10:54 AM
45	FCW with Moving Remote Vehicle and EEBL	Wyoming - Lear*	Tampa - Savari	6/27/2018	10:50 AM	10:56 AM
46	FCW with Moving Remote Vehicle and EEBL	Tampa - SiriusXM	New York City - Danlaw	6/27/2018	11:00 AM	11:01 AM
47	FCW with Moving Remote Vehicle and EEBL	Wyoming - Lear*	Tampa - Commsignia	6/27/2018	11:10 AM	11:03 AM

Test ID	Test Case	Host Vehicle	Remote Vehicle	Date	Schedule	As-Run Time
48	FCW with Moving Remote Vehicle and EEBL	New York City - Savari	Tampa - Savari	6/27/2018	11:20 AM	11:06 AM
49	FCW with Moving Remote Vehicle and EEBL	Tampa - Commsignia	New York City – Danlaw	6/27/2018	11:30 AM	11:08 AM
50	FCW with Moving Remote Vehicle and EEBL	Wyoming - Lear*	Tampa - SiriusXM	6/27/2018	11:40 AM	11:11 AM
51	FCW with Moving Remote Vehicle and EEBL	New York City - Danlaw	Tampa - Commsignia	6/27/2018	11:50 AM	11:13 AM
52	FCW with Moving Remote Vehicle and EEBL	Tampa - Savari	New York City - Savari	6/27/2018	12:00 PM	11:16 AM
53	FCW with Moving Remote Vehicle and EEBL	New York City - Danlaw	Tampa - SiriusXM	6/27/2018	12:10 PM	11:19 AM
54	FCW with Moving Remote Vehicle and EEBL	Tampa - Commsignia	New York City - Savari	6/27/2018	12:20 PM	11:22 AM
55	FCW with Moving Remote Vehicle and EEBL	Tampa - Savari	New York City – Danlaw	6/27/2018	12:30 PM	11:24 AM
56	FCW with Moving Remote Vehicle and EEBL	Wyoming - Lear*	New York City - Savari	6/27/2018	12:40 PM	11:26 AM
40 beta	FCW with Moving Remote Vehicle and EEBL	New York City - Savari	Tampa - SiriusXM	6/27/2018	N/A	11:32 AM
49 beta	FCW with Moving Remote Vehicle and EEBL	Tampa - Commsignia	New York City – Danlaw	6/27/2018	N/A	11:34 AM
55 beta	FCW with Moving Remote Vehicle and EEBL	Tampa - Savari	New York City – Danlaw	6/27/2018	N/A	11:40 AM
57	FCW Stationary Remote Vehicle in the Adjacent Lane	Wyoming - Lear	New York City - Danlaw	6/27/2018	1:30 PM	1:45 PM
58	FCW Stationary Remote Vehicle in the Adjacent Lane	New York City - Savari	Tampa - Commsignia	6/27/2018	1:40 PM	1:51 PM

Test ID	Test Case	Host Vehicle	Remote Vehicle	Date	Schedule	As-Run Time
59	FCW Stationary Remote Vehicle in the Adjacent Lane	New York City - Danlaw	Tampa - SiriusXM	6/27/2018	1:50 PM	1:54 PM
60	FCW Stationary Remote Vehicle in the Adjacent Lane	Wyoming - Lear	Tampa - Savari	6/27/2018	2:00 PM	1:59 PM
61	FCW Stationary Remote Vehicle in the Adjacent Lane	Tampa - Commsignia	New York City - Savari	6/27/2018	2:10 PM	2:03 PM
62	FCW Stationary Remote Vehicle in the Adjacent Lane	Tampa - SiriusXM	Wyoming - Lear	6/27/2018	2:20 PM	2:05 PM
63	FCW Stationary Remote Vehicle in the Adjacent Lane	Tampa - Savari	New York City - Savari	6/27/2018	2:30 PM	2:09 PM
64	FCW Stationary Remote Vehicle in the Adjacent Lane	Wyoming - Lear	Tampa - Commsignia	6/27/2018	2:40 PM	2:12 PM
65	FCW Stationary Remote Vehicle in the Adjacent Lane	New York City - Savari	Tampa - SiriusXM	6/27/2018	2:50 PM	2:15 PM
66	FCW Stationary Remote Vehicle in the Adjacent Lane	New York City - Danlaw	Wyoming - Lear	6/27/2018	3:00 PM	2:18 PM
67	FCW Stationary Remote Vehicle in the Adjacent Lane	Tampa - SiriusXM	New York City - Savari	6/27/2018	3:10 PM	2:21 PM
68	FCW Stationary Remote Vehicle in the Adjacent Lane	Tampa - Commsignia	New York City - Danlaw	6/27/2018	3:20 PM	2:23 PM
69	FCW Stationary Remote Vehicle in the Adjacent Lane	Tampa - Savari	Wyoming - Lear	6/27/2018	3:30 PM	2:26 PM
70	FCW Stationary Remote Vehicle in the Adjacent Lane	New York City - Danlaw	Tampa - Commsignia	6/27/2018	3:40 PM	2:28 PM

Test ID	Test Case	Host Vehicle	Remote Vehicle	Date	Schedule	As-Run Time
71	FCW Stationary Remote Vehicle in the Adjacent Lane	New York City - Savari	Tampa - Savari	6/27/2018	3:50 PM	2:31 PM
72	FCW Stationary Remote Vehicle in the Adjacent Lane	Wyoming - Lear	Tampa - SiriusXM	6/27/2018	4:00 PM	2:34 PM
73	FCW Stationary Remote Vehicle in the Adjacent Lane	New York City - Danlaw	Tampa - Savari	6/27/2018	4:10 PM	2:37 PM
74	FCW Stationary Remote Vehicle in the Adjacent Lane	New York City - Savari	Wyoming - Lear	6/27/2018	4:20 PM	2:40 PM
75	FCW Stationary Remote Vehicle in the Adjacent Lane	Tampa - Savari	New York City - Danlaw	6/27/2018	4:30 PM	2:42 PM
76	FCW Stationary Remote Vehicle in the Adjacent Lane	Tampa - Commsignia	Wyoming - Lear	6/27/2018	4:40 PM	2:45 PM
77	FCW Stationary Remote Vehicle in the Adjacent Lane	Tampa - SiriusXM	New York City - Danlaw	6/27/2018	4:50 PM	2:48 PM
78	FCW Stationary Remote Vehicle in the Adjacent Lane	Wyoming - Lear	New York City - Savari	6/27/2018	5:00 PM	2:54 PM
70 beta	FCW Stationary Remote Vehicle in the Adjacent Lane	New York City - Danlaw	Tampa - Commsignia	6/27/2018	N/A	2:56 PM
NA	Baseline OBU/ASD Test of GPS Accuracy	All Six (6) Vehicles	N/A	6/27/2018	N/A	3:14 PM
NA	Baseline OBU/ASD Test of GPS Accuracy (Opposite Direction	All Six (6) Vehicles	N/A	6/27/2018	N/A	3:23 PM
35 beta	V2I – Red Light Violation Warning	Tampa - Commsignia	N/A (V2I)	6/28/2018	N/A	9:06 AM

Test ID	Test Case	Host Vehicle	Remote Vehicle	Date	Schedule	As-Run Time
35 gamma	V2I – Red Light Violation Warning	Tampa - Commsignia	N/A (V2I)	6/28/2018	N/A	9:14 AM
36 beta	V2I – Red Light Violation Warning	New York City - Savari	N/A (V2I)	6/28/2018	N/A	9:17 AM
37 beta	V2I – Red Light Violation Warning	Tampa - Savari	N/A (V2I)	6/28/2018	N/A	9:20 AM
38 beta	V2I – Red Light Violation Warning	New York City - Danlaw	N/A (V2I)	6/28/2018	N/A	9:25 AM
39 beta	V2I – Red Light Violation Warning	Tampa - SiriusXM	N/A (V2I)	6/28/2018	N/A	9:28 AM
36 gamma	V2I – Red Light Violation Warning	New York City - Savari	N/A (V2I)	6/28/2018	N/A	9:34 AM
107	FCW Stationary Remote Vehicle in the Same Lane with Parallel Platoon	Wyoming –Lear	New York City – Savari Platoon: Tampa – Commsignia Tampa – Savari New York City – Danlaw Tampa – SiriusXM	6/28/2018	N/A	9:52 AM
108	FCW Stationary Remote Vehicle in the Same Lane with Parallel Platoon	New York City – Danlaw	Tampa – Savari Platoon: New York City – Savari Tampa – SiriusXM Tampa – Commsignia Wyoming - Lear	6/28/2018	N/A	10:00 AM
109	FCW Stationary Remote Vehicle in the Same Lane with Parallel Platoon	Tampa – SiriusXM	Wyoming – Lear Platoon: New York City – Danlaw New York City – Savari Tampa – Commsignia Tampa - Savari	6/28/2018	N/A	10:10 AM

Test ID	Test Case	Host Vehicle	Remote Vehicle	Date	Schedule	As-Run Time
110	FCW Stationary Remote Vehicle in the Same Lane with Parallel Platoon	New York City - Savari	Tampa – Commsignia Platoon: Tampa – Savari New York City – Danlaw Wyoming – Lear Tampa - SiriusXM	6/28/2018	N/A	10:18 AM

6 Test Cases

A total of six test cases were performed as part of the CV Pilots Phase 2 Interoperability Test with an addition of the Stationary Remote Vehicle in the Same Lane with Parallel Platoon Test Case that was conducted on Thursday June 28. This section provides an overview of the test cases and documents any modifications, if applicable, that were made to the test procedures in the Test Plan.

6.1 Baseline OBU / ASD Data Collection Test Case

6.1.1 Test Case Description

The objective of the Baseline OBU / ASD Data Collection test was to collect data from OBUs / ASDs from each site installed on a vehicle to create a baseline of how devices perform in relation to each other. In this test, the vehicles were to be driven around a pre-defined path at TFHRC three times. A DSRC packet sniffer would collect BSM data for all the OBUs/ASDs to show the path that the vehicles traveled. A post-study analysis was to be conducted to compare the “paths” of the vehicles to the actual test path. Figure 3 depicts the planned path for the Baseline OBU / ASD Data Collection test.

As previously noted, the CV Pilot Sites were expected to send their test equipment—OBUs and RSUs—to TFHRC and STOL staff two weeks prior to the Interoperability Test to allow for the equipment to be installed in the vehicles and on the roadside. The Test Plan called for the Baseline OBU / ASD Data Collection Test to be conducted the week of June 18th.

Figure 3. Baseline OBU/ASD Data Collection Path **(Source: USDOT, 2018)**

6.1.2 Modifications Made to the Test Procedures

Due to delays in receiving all test equipment two weeks prior to the start of the Interoperability Test, Test Case 1: Baseline OBU /ASD Data Collection could not be conducted the week of June 18th. Additionally, the data collection path was adjusted to accommodate incoming traffic from the George Washington (GW) Parkway to the TFHRC facility. The path was adjusted so that vehicles would not have to turn around at the gate closest to the GW Parkway blocking incoming traffic; instead the vehicles traveled a path around the TFHRC building as depicted in Figure 4.

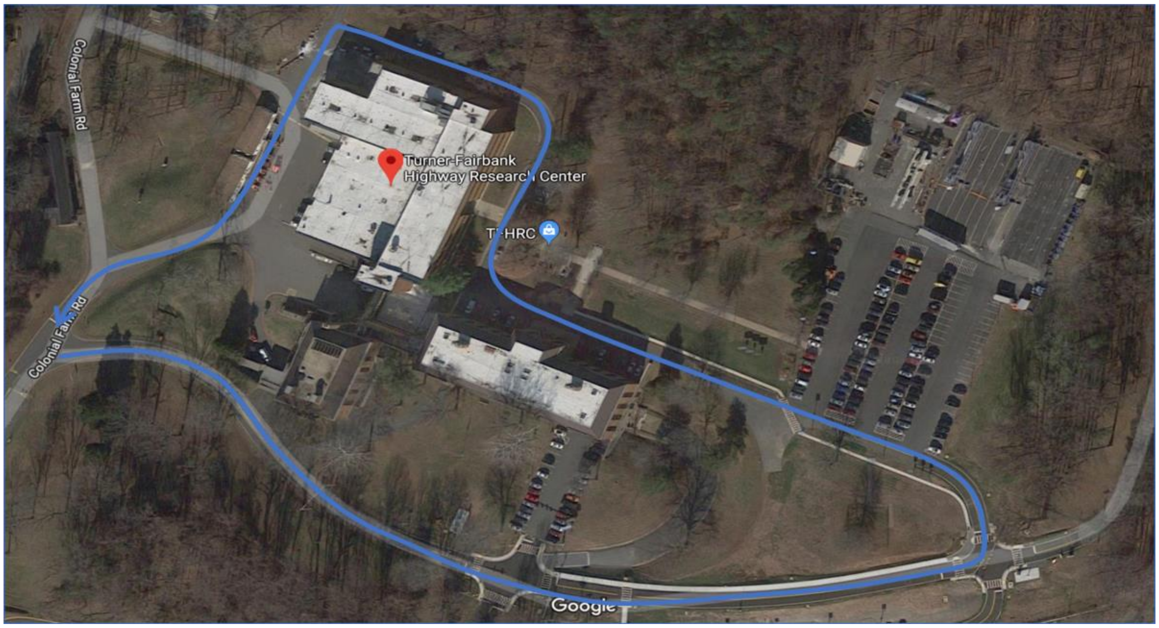

Figure 4. Modifications to the Baseline OBU/ASD Data Collection Path Test Case (Source: USDOT, 2018)

6.2 FCW – Stationary Remote Vehicle in the Same Lane Test Case 2

6.2.1 Test Case Description

The objective of FCW Stationary Remote Vehicle in the Same Lane test was to have OBUs / ASDs from each CV Pilot site demonstrate that they can issue an FCW notification to a driver when receiving BSMs from one of the other CV Pilot site devices and with the Host Vehicle approaching a stationary Remote Vehicle in the same lane. The test includes a Host Vehicle (depicted in Figure 5 as a red box) with an OBU from one CV Pilot site and a Remote Vehicle (depicted in Figure 5 as a yellow box) with an OBU from a different CV Pilot site. The plan required the Remote Vehicle to drive to location B (see Figure 5) and stop at the stop bar. The Host Vehicle would then drive to location A and stop. The Host Vehicle would accelerate to 35 mph and approach the Remote Vehicle at location B. When the Host Vehicle arrived at the Start Braking Point (approximately 150 feet from the Remote Vehicle and marked by a flag or cone) a warning should be provided to the Host Vehicle driver that a forward collision is imminent. The Host Vehicle would either stop behind the Remote Vehicle or drive around the Remote Vehicle. Traffic signals at each intersection would be put into manual mode with a person controlling each intersection to ensure they maintain the correct signal phase throughout the test.

The following criteria had to be met for this test to pass:

- The Host Vehicle must receive and process BSMs from the Remote Vehicle,
- The Host Vehicle must authenticate the BSMs from the Remote Vehicle triggering the alert, and
- The Host Vehicle driver must receive a forward collision warning.

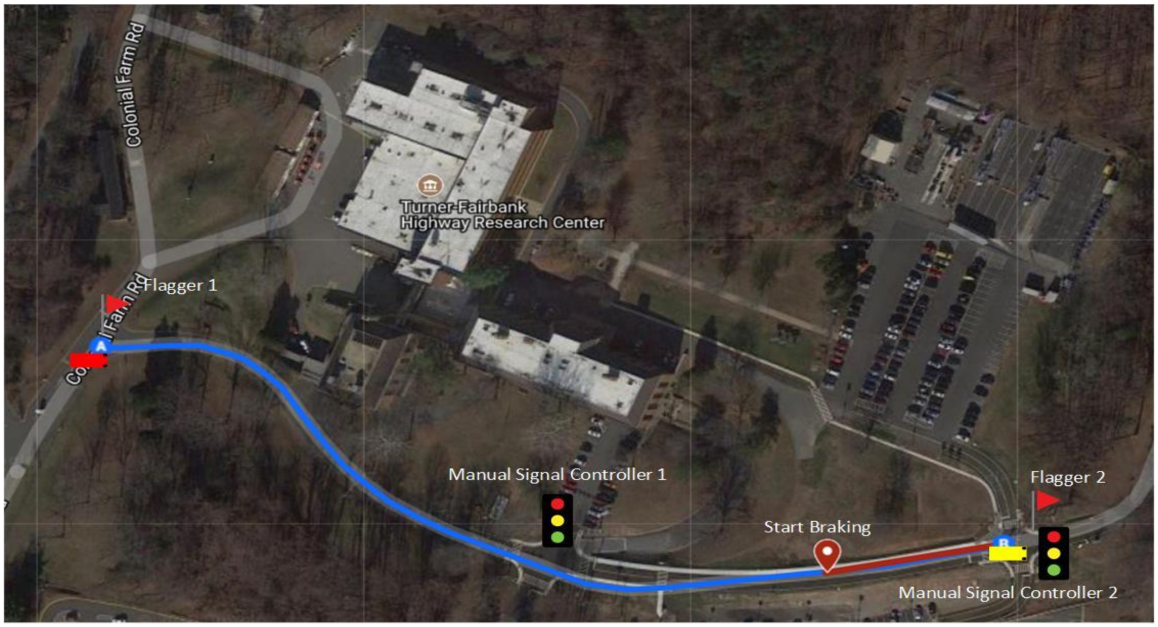

Figure 5. Original FCW Stationary Remote Vehicle in the Same Lane Test Case **(Source: USDOT, 2018)**

6.2.2 Modifications Made to the Test Procedures

There were no modifications to the test procedures for this test case.

6.3 FCW – Stationary Remote Vehicle in Adjacent Lane Test Case

6.3.1 Test Case Description

The objective of the FCW Stationary Remote Vehicle in the Adjacent Lane test was to have OBUs / ASDs from each CV Pilot site demonstrate that they do not produce an FCW notification when approaching another vehicle producing BSMs in an adjacent lane. The device(s) under test included the Host Vehicle (depicted in Figure 6 as a red box), with a different device from one of the other CV Pilot sites installed in the Remote Vehicle (depicted in Figure 6 as a yellow box). The plan called for the Remote Vehicle to drive to location C and stop in the cutaway area facing east as if it were in a lane adjacent to the normal road.

The Host Vehicle would then drive to location A and stop there. The Host Vehicle would accelerate to 35 mph and approach the Remote Vehicle at location C. The Host Vehicle would continue traveling past the Remote Vehicle to Location B. In the test, the Host Vehicle driver should not receive a forward collision warning when approaching or passing the Remote Vehicle. Flaggers (depicted in Figure 6 as red triangles) would be positioned at each end of this run to ensure no other vehicles enter the roadway. Additionally, the signals at each intersection would be put into manual mode with a person controlling each intersection to ensure they maintain the correct signal phase throughout the test.

The following criteria had to be met for this test to pass:

- The Host Vehicle must receive and process BSMs from the Remote Vehicle,
- The Host Vehicle must authenticate the BSMs from the Remote Vehicle and not trigger the alert, and
- The Host Vehicle driver does not receive a forward collision warning.

Figure 6: Original FCW Stationary Remote Vehicle in the Adjacent Lane Test Case **(Source: USDOT, 2018)**

6.3.2 Modifications Made to the Test Procedures

The geographic layout of the TFHRC test facility created an obstacle that required modifications to the original test plan. The original location of the Remote Vehicle (yellow vehicle at location C) was too close to a curve that had the Host Vehicle pointing at the Remote Vehicle. It was observed during pre-testing on Monday June 25th that the original location of the Remote Vehicle triggered a false FCW. As a result, the team decided to modify/update the test plan to accommodate a new location for the Remote Vehicle at location B in Figure 7.

In addition to moving the location of the Remote Vehicle, the CV Pilot sites also updated the setting in their applications to account for the actual lane widths at TFHRC. During the pre-test activities on Monday

June 25th, it was observed that the lanes at TFHRC were 10 feet wide which is narrower than standard 12 feet lane widths that the applications were designed for. To accommodate and provide more reliable results the CV Pilot sites updated their lane width settings, accordingly.

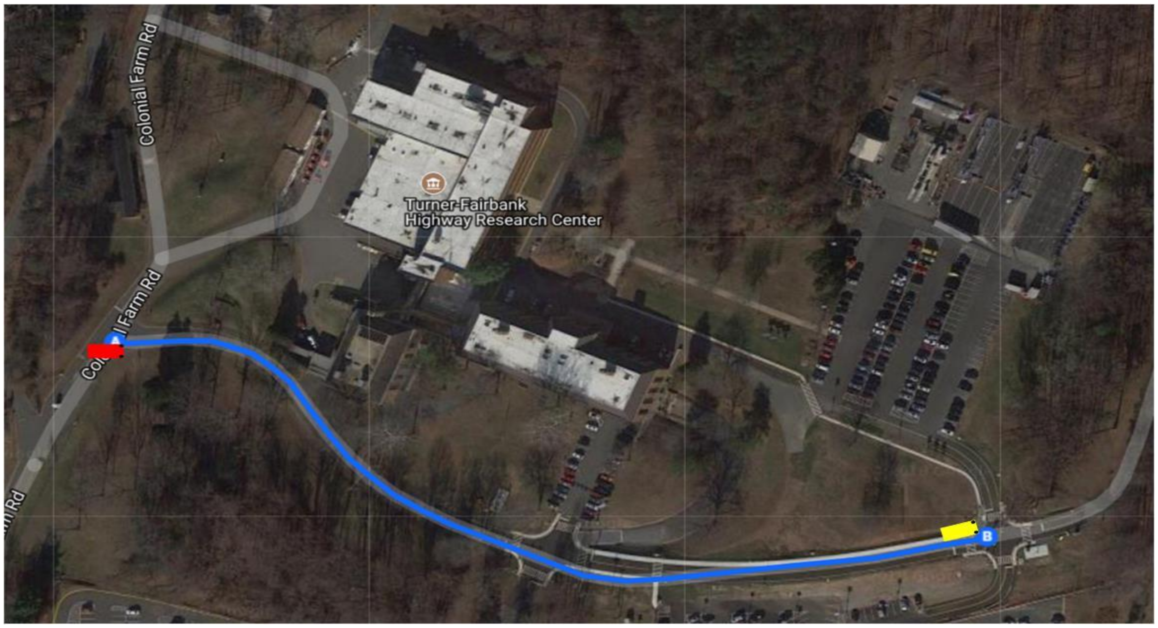

Figure 7. Modifications to the FCW Stationary Remote Vehicle in the Adjacent Lane Test Case
(Source: USDOT, 2018)

6.4 FCW – Moving Remote Vehicle and EEBL Test Case

6.4.1 Test Case Description

The objective of the FCW Moving Remote Vehicle and EEBL test was to demonstrate that the New York City and Tampa devices can issue an EEBL warning to a driver when receiving BSMs from one of the other CV Pilot site devices. Additionally, Wyoming, New York City, and Tampa devices should be able to produce forward collision warning as they get within FCW range of the Remote Vehicle. The device(s) under test would be the Host Vehicle's device (depicted in Figure 8 as a red box), and a different device from one of the other CV Pilot Sites installed in the Remote Vehicle (depicted in Figure 8 as a yellow box). The Host Vehicle would drive to Location A and the Remote Vehicle would position itself 150 feet in front of the Host Vehicle. Both the Host and Remote Vehicles would accelerate to 35 mph and maintain 150 feet distance between each other. At the Start Braking Point, the Remote Vehicle would start braking and come to a complete stop. The Host Vehicle driver would confirm that they received the EEBL warning and/or forward collision warning. As the Host Vehicle continues forward, the Host Vehicle driver would confirm that they received a forward collision warning after receiving the EEBL warning. Flaggers (depicted in Figure 8 as red triangles) would be positioned at each end of this run to ensure no other vehicles enter the roadway. Additionally, the signals at each intersection would be put into manual mode with a person controlling each intersection to ensure they maintain the correct signal phase throughout the test.

The following criteria had to be met for this test to pass:

- The Host Vehicle must receive and process BSMs from the Remote Vehicle,
- The Host Vehicle must authenticate the BSMs from the Remote Vehicle triggering the alert, and
- The Host Vehicle driver must receive an electronic emergency brake light warning followed by a forward collision warning.

Figure 8: Original FCW Moving Remote Vehicle and EEBL Test Case **(Source: ITS JPO, 2018)**

6.4.2 Modifications Made to the Test Procedures

There were no modifications to the test procedures for this test case.

6.5 IMA – Host Vehicle Stopped Test Case

6.5.1 Test Case Description

The objective of IMA Host Vehicle Stopped test was to have OBUs / ASDs from the New York City and Tampa CV Pilot sites demonstrate that they can issue an IMA warning to a driver when receiving BSMs from one of the other CV Pilot sites. The IMA warning is issued when the Host Vehicle, which is stopped at an intersection, starts to slowly move as the Remote Vehicle traverses the intersection. The device under test would be the Host Vehicle (depicted in Figure 9 as a red box), with a different device from one of the other CV Pilot sites installed in the Remote Vehicle (depicted in Figure 9 as a yellow box). The Remote Vehicle would drive to location A and stop there. The Host Vehicle would drive to Location C and stop there. The Remote Vehicle would accelerate to 35 mph, maintain that speed and travel along the path toward Location C. The Host Vehicle would remain stopped at Location C. With the Remote Vehicle within 25 feet of the intersection (which would be marked by flags or a cone), the Host Vehicle would release the brake and the driver would confirm they have received an intersection movement assist warning.

The following criteria had to be met for this test to pass:

- The Host Vehicle must receive and process BSMs from the Remote Vehicle,
- The Host Vehicle must authenticate the BSMs from the Remote Vehicle triggering the alert, and
- The Host Vehicle driver must receive an intersection movement assist warning.

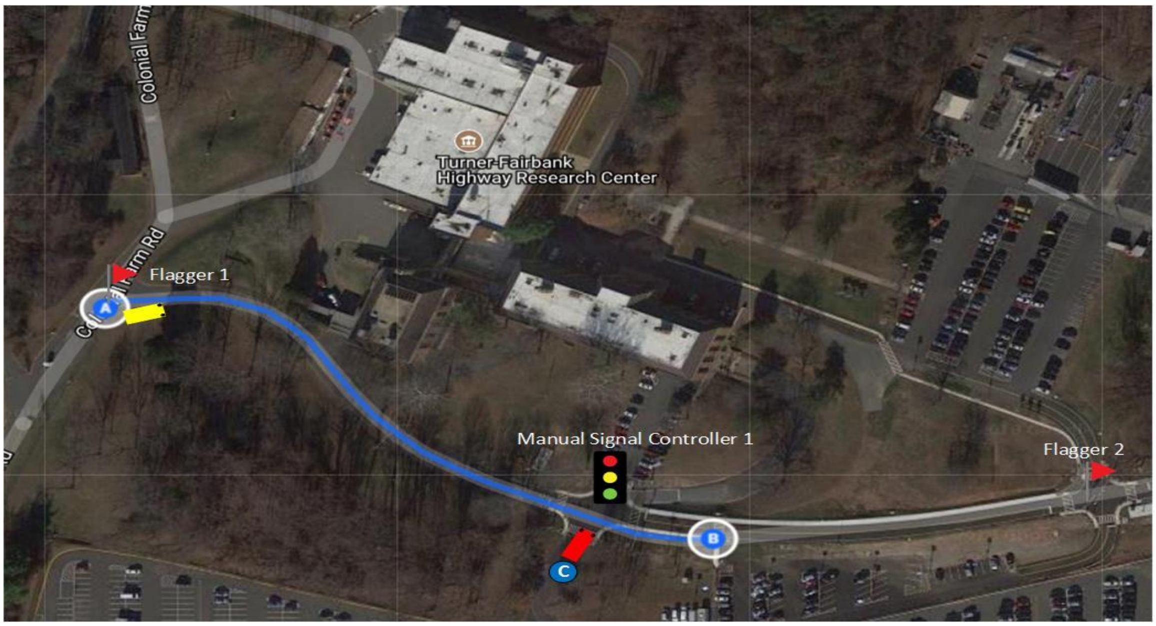

Figure 9: IMA Host Vehicle Stopped (Source: USDOT, 2018)

6.5.2 Modifications Made to the Test Procedures

The original test called for the Host Vehicle's driver to release the brake, however after conducting some preliminary tests it was observed that the Host Vehicle needed to be moving at a higher speed to trigger the alert. As a result, the test procedures needed to be updated to have the Host Vehicle traveling at a slow speed. Simply releasing the brake would not result in an IMA warning being issued to the driver of the Host Vehicle. To accommodate the change, the test procedures were updated to move the starting location of the Host Vehicle further back from the intersection (as seen in Figure 10 by the yellow line) and then have the vehicle accelerate towards the intersection when the Remote Vehicle was in range. It was found that the simulated condition had to be perceived to be real to trigger the alert/alarm. Speeds were higher than anticipated and cones were set out to assist the drivers in ensuring they initiated breaking to avoid a crash.

Figure 10. Modified IMA Host Vehicle Stopped (Source: USDOT, 2018)

6.6 V2I / RLVW Test Case

6.6.1 Test Case Description

The objective of the V2I / RLVW test was for OBUs / ASDs from the New York City and Tampa Connected Vehicle Pilot sites demonstrate that they can receive SPaT and MAP messages from the other CV Pilot site RSUs. As a stretch goal, the New York City OBUs / ASDs would provide a RLVW to the driver when participating in an RLVW Scenario. Two RSUs would be installed at locations RSU 1 and RSU 2 (see Figure 11). Table 7 shows the RSU model and Signal Controller model would be used at each location.

Table 7. V2I / RLVW RSUs and Traffic Signal Controllers (Source: USDOT, 2018)

Location	RSU	RSU Model
RSU 1	Siemens	Sitraffic ESCoS Roadside Unit V 1.0
RSU 2	Siemens	Sitraffic ESCoS Roadside Unit V 1.0

The Host Vehicle (depicted in Figure 11 as a red box) would travel to the Location of RSU 1 and stop. The Host Vehicle would then travel along the path to RSU 2, make a left turn into the parking lot, turn around and travel long the same path in reverse.

The following were the threshold criteria for passing the test:

- The Host Vehicle must receive, and process SPaT and MAP messages from the RSU, and
- The Host Vehicle must authenticate the SPaT and MAP messages from the RSU.

The following was the objective criteria for New York City to conduct the test:

- The Host Vehicle provides a red-light violation warning to the driver when entering an RLVW scenario.

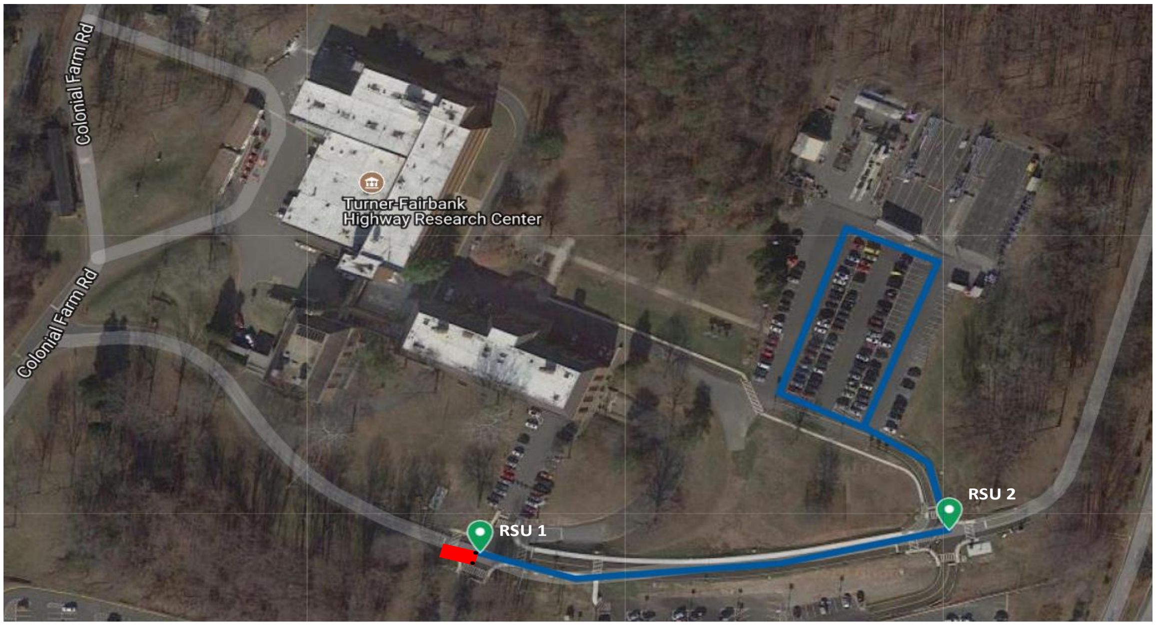

Figure 11: V2I / RLVW **(Source: ITS JPO, 2018)**

6.6.2 Modifications Made to the Test Procedures

A slight modification was made to the test plan. Instead of having the Host Vehicle turn around in the parking lot and travel along the same path in reverse, the Host Vehicle made a single pass through the intersections and circled back to the initial staging area (see Figure 12). Additionally, for the New York City Host Vehicles, the test procedures were updated to require the Host Vehicle to approach the RSU 1 intersection when the traffic signal showed a red light. The Host Vehicle then traveled through the intersection on a red-light to trigger the red-light violation warning.

While performing testing for the V2I / RLVW, it was observed in the data that SPaT / MAP signal indications that were received by the vehicle OBUs were inconsistent with the observed signal display (i.e. the signal phases were swapped). On Day 4 of the Interoperability Test, this test was retested after modifications were made to update the SPaT/MAP messages.

Figure 12. Modification to the V2I / RLVW Test Case **(Source: USDOT, 2018)**

6.7 FCW – Stationary Remote Vehicle in the Same Lane with Parallel Platoon Test Case

6.7.1 Test Case Description

As previously noted, because the required tests were completed ahead of schedule there was time on the last day of the Interoperability Test to perform an ad hoc test. As a result, the New York City CV Pilot Team developed an ad hoc test for a FCW Stationary Remote Vehicle in the Same Lane with Parallel Platoon test. The purpose of this ad hoc test was to determine if a connected vehicle could trigger a positive FCW alert when traveling next to a platoon of connected vehicles in the adjacent lane. In this test, all six vehicles were used, and the drivers of the Host and Remote vehicles followed the same test procedures as identified for the FCW test case (see Figure 13). The idea behind this test was to see if the host vehicle could correctly identify the stopped vehicle in its lane when other vehicles were also transmitting their BSMs next to the vehicle. While no formal observations were made of this test, vehicles were successful at issuing FCW for a stopped vehicle in its lane, even with other vehicles broadcasting BSMs traveling adjacent to it.

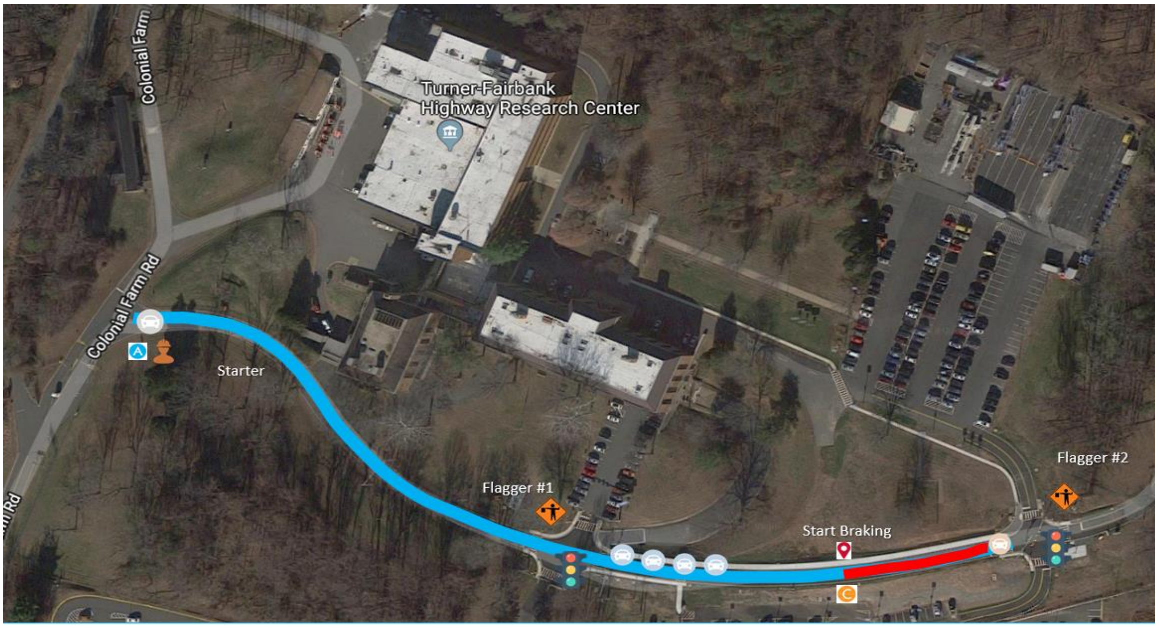

Figure 13. FCW Stationary Remote Vehicle in the Same Lane with Parallel Platoon **(Source: USDOT, 2018)**

7 Test Results

7.1 Summary of Test Results

Per the definition of interoperability (see Section 1), the goal of the Interoperability Test was to demonstrate OTA V2V interactions between different site's OBUs and V2I interactions between selected OBUs and RSUs. Based on the testing, it was concluded that all vendors and CV Pilot site deployment configurations were interoperable and could trigger warnings in each other's devices. OBUs from all sites were able to:

- Receive SAE J2735 BSMs transmitted by each of the other site's OBUs OTA via DSRC,
- Authenticate them as needed,
- Decode J2735 messages to individual data element levels, and
- Process them to result in an alert.

In addition, the security certificates that were obtained from a common source (Green Hills Test Certificates). There were no updates to the certificates—i.e. vehicles did not access the SCMS when they passed the RSU to "top off" their certificates.

All sites were able to test each of their application capabilities by exchanging V2V and V2I messages. There was a total of 102 tests that were run including 2 baseline tests, 78 originally planned interoperability tests, 18 retests, and 4 additional ad hoc tests.

The pass/retest criteria for each test was determined by the activation of warning and/or alert through the human machine interface (HMI) for the selected application. Representatives from the sites determined whether the test was successful, needed further investigation, or required a retest. The results were verified by the USDOT Representatives. Additionally, the Independent Evaluator was present to observe tests and document observations and lessons learned.

Table 8 summarizes the results of the interoperability test including results from the retests. Details on specific tests and retests are included in the Test Result sections for each Test Case (Sections 7.2 - 7.7).

Table 8. Summary of Interoperability Test Results (Source: USDOT, 2018)

Test Case	Type of Result	Initial Tests		Retests	
		Count	Percentage	Count	Percentage
Baseline OBU / ASD Data Collection	Pass	N/A	N/A	N/A	N/A
	Required a Retest	N/A	N/A	N/A	N/A
	**Investigate	N/A	N/A	N/A	N/A
FCW – Stationary Remote Vehicle in the Same Lane	Pass	16	73%	7	100%
	Required a Retest	5	23%	0	0%
	**Investigate	1	5%	0	0%
FCW – Stationary Remote Vehicle in Adjacent Lane	Pass	21	95%	1	100%
	Required a Retest	1	5%	0	0%
	**Investigate	0	0%	0	0%
FCW Moving Remote Vehicle and EEBL	Pass	14	82%	3	100%
	Required a Retest	3	18%	0	0%
	**Investigate	0	0%	0	0%
Intersection Movement Assist (IMA) Host Vehicle Stopped	Pass	6	50%	N/A	N/A
	Required a Retest	6	50%	N/A	N/A
	**Investigate	0	0%	N/A	N/A
Vehicle to Infrastructure (V2I) / Red Light Violation Warning (RLVW)	Pass	5	100%	5	100%
	Required a Retest	0	0%	0	0%
	**Investigate	0	0%	0	0%
Total	Pass	62	77%	16	100%
	Required a Retest	15	22%	0	0%
	**Investigate	1	1%	0	0%

Note: * This Table does not include the ad hoc tests that were conducted on Day 4
** These tests required the sites to look at the data and confirm whether a retest was needed.

From the 78 initial tests that were conducted, 62 tests met the pass criteria on the first try, 15 tests required a retest, and one test required the site to look at the data to confirm if a retest was needed. It should be noted that most of the retests were required because the tests were not run consistently or in accordance with the test procedures; however, post-test analysis indicated that OTA transmission of messages successfully occurred between vehicles and devices. For example, for the EEBL test some drivers did not activate the brakes hard enough to trigger a warning. Additionally, for the IMA test there were some instances where the Host Vehicle left too late or did not accelerate fast enough. During the first few runs, drivers were learning how to maneuver the test bed, learning how to brake, and drive aggressively to initiate alerts/warnings. Generally, once the human factor element was reduced, test run results were more positive. Thus, in these scenarios is it very likely that the application performed as expected and there is no reason to believe that OTA messages were not received.

7.2 Baseline OBU / ASD Data Collection Test Results

The Baseline OBU /ASD Data Collection Test did not include pass/fail criteria. Instead the purpose of the test was to collect data from OBUs / ASDs from each site installed on a vehicle simultaneously to create a baseline of how devices perform in relation to each other. In this test, the vehicles were to be driven around a pre-defined path at TFHRC three times.

Visualizations of the data collected during the CV Pilots Phase 2 Interoperability Test indicated that all the OBU devices performed consistently in relation to each other—meaning that positioning data from one CV Pilot device overlaid consistently with positioning data from the other CV Pilot devices. While consistent, data suggested that there was a variability of up to 7 meters in the position of the vehicle. As depicted in Figure 14 and Figure 15, the data indicated that the vehicles were traveling in the adjacent lane (left lane) to what they traveled during the testing. GPS coverage at TFHRC was good throughout testing. The STOL team reported that 8-11 GPS satellites were usually within view during testing. This was observed from the RSU and OBU readings at TFHRC. While discussed during the CV Pilot Technical Roundtable Meetings leading up to the Interoperability Test, testing did not include RTCM or RSU triangulation for improved location accuracy.

Figure 14. Example Showing Positioning Accuracy **(Source: New York City CV Pilot Site, 2018)**

Figure 15. Visualization of GPS Accuracy from a Wyoming Test Run **(Source: Wyoming CV Pilot Site, 2018)**

Following the Interoperability Test, the New York City Danlaw team returned to TFHRC to conduct additional testing to further investigate GPS accuracy concerns. The team updated the GPS chipset firmware from their vendor (including dead reckoning Kalman filters, etc.). They also changed the antenna on the vehicle, but do not believe that had much effect on the original GPS accuracy. It was noted that in prior testing, repeated left turns caused drift/degradation. For the retests, the team worked with TFHRC and STOL staff to run ten (10) repetitive loops of the same path as defined in the Test Plan. The runs were conducted at different times of day to try to replicate the afternoon “drifting” that they team observed during the Interoperability Test. The vendor’s updated results showed improvement—reducing error from approximately 7 meters to less than 1.5 meters (see Figure 16). It was noted that the firmware update improved location accuracy and it was reported to the other CV Pilots sites that there is a firmware update available for the GPS chipsets. Finally, it was noted that New York City software is being updated to accommodate the change.

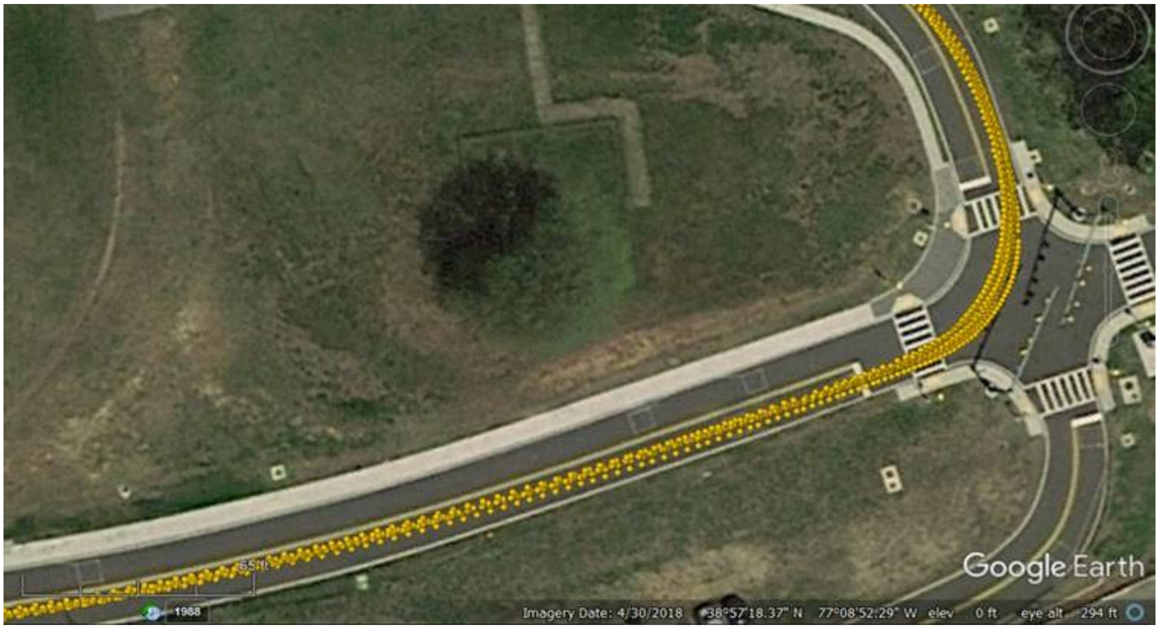

Figure 16. Results from New York City – Danlaw Retesting at TFHRC
(Source: New York City CV Pilot Site, 2018)

7.3 FCW – Stationary Remote Vehicle in the Same Lane Test Results

Table 9. Summary of FCW – Stationary Remote Vehicle in the Same Lane Test Results
(Source: USDOT, 2018)

Type of Result	Initial Tests		Retests	
	Count	Percentage	Count	Percentage
Pass	16	73%	7*	100%
Required a Retest	5	23%	0	0%
Investigate	1	4%	0	0%
Total	**22**	**100%**	**5**	**100%**

*Some CV Pilot Sites requested more than one retest, but all retested passed.

All sites and their OBUs were able to successfully provide a forward collision warning using BSM data from other vehicles. The results of the FCW – Stationary Remote Vehicle in the Same Lane indicated that CV Pilot OBUs were able to receive, parse, process, and trigger forward collision warnings using BSMs from other CV Pilots OBUs from other manufacturers/vendors. Of the total twenty-two initial interoperability tests that were conducted, sixteen (73 percent) successfully met the test criteria and showed interoperability. There were five initial test runs, where the Host/Remote combination did not successfully pass the test on the first try; however, all retests resulted in the Host/Remote combination meeting the pass criteria for the test. Three additional retests were conducted upon the request of CV Pilot site representatives for data collection purposes.

While there were four initial tests that did not result in the driver receiving forward collision warnings, without reviewing the data logs for those tests it is uncertain whether the vehicle received the OTA messages or not. It is possible the messages were received, parsed, and the applications acted on the messages and the application provided the appropriate response in not issuing a warning because certain threshold were not met to activate the warning. Additional analysis was conducted to understand the data logs associated with each "Required a Retest" tests to determine why a warning/alert was not issued. It was observed that some logs captured a full minute of BSMs with a speed value of 0. For example, the situation may have occurred where the Host Vehicle approached the Remote Vehicle at a speed less than the speed threshold prior to reaching the brake activation point. If this occurred, the application would have responded appropriately by not issuing an alert; however OTA interoperability was achieved if messages were sent and received between the vehicles.

Table 10 includes the detailed results for the FCW – Stationary Vehicle in the Same Lane test case.

Table 10. FCW - Stationary Remote Vehicle in the Same Lane Test Results (Source: USDOT, 2018)

Test ID	Date and Time	Vehicle	Warning Observed	Vehicle Notes / Comments	AOR Notes / Comments	Result
1	6/26/2018; 10:00 AM	**Host Vehicle:** Tampa - Commsignia	Audio	No visual alert. Received audio alert after passing cones.	Host received alert past the cone. Want to retest. Remote received no alert. See note on Test 22. Unclear if audio was from OBU or from MobilEye*	Investigate
		Remote Vehicle: New York City - Savari	None	Stop at light (2nd)		
2	6/26/2018; 10:16 AM	**Host Vehicle:** New York City - Danlaw	Audio	N/A	Alert received	Received Alert
		Remote Vehicle: Tampa - Savari	None	N/A		
3	6/26/2018; 10:19 AM	**Host Vehicle:** Tampa - SiriusXM	Audio and visual	N/A	N/A	Received Alert
		Remote Vehicle: Wyoming - Lear	None	N/A		
4	6/26/2018; 10:23 AM	**Host Vehicle:** New York City - Savari	None	Retest required	Host received no warning. Retest required.	Required a Retest
		Remote Vehicle: Tampa - Commsignia	None	N/A		
5	6/26/2018; 10:28 AM	**Host Vehicle:** Wyoming - Lear	Audio and visual	Stationary vehicle FCW 5 seconds to collision.	Host: Stationary warning at 10 seconds time to collision. FCW at 4 seconds to collision. Verify with vehicle notebook.	Received Alert
		Remote Vehicle: New York City - Danlaw	None	N/A		

Test ID	Date and Time	Vehicle	Warning Observed	Vehicle Notes / Comments	AOR Notes / Comments	Result
6	6/26/2018; 10:33 AM	**Host Vehicle:** Tampa - Savari	Audio and visual	Approach at 30 mph. Post test: Restart vehicle. Reboot took approximately 6 minutes. Checked connections in truck with OBU and reboot successful.	Remote vehicle received no warnings.	Received Alert
		Remote Vehicle: New York City - Savari	None	N/A		
7	6/26/2018; 10:38 AM	**Host Vehicle:** Wyoming - Lear	Audio and visual	No stationary vehicle warning.	FCW at 5 seconds to collision. No stationary warning.	Received Alert
		Remote Vehicle: Tampa - SiriusXM	None	SB, GB, IS in the car.		
8	6/26/2018; 10:48 AM	**Host Vehicle:** New York City - Savari	Audio	N/A	N/A	Received Alert
		Remote Vehicle: Tampa - Savari	None	N/A		
9	6/26/2018; 11:00 AM	**Host Vehicle:** Wyoming - Lear	Audio and visual	All good. 10 seconds to collision stationary vehicle warning. 5 seconds to collision FCW	Host: Stationary warning 10 seconds to collision. FCW 5 seconds to collision	Received Alert
		Remote Vehicle: Tampa - Commsignia	None	N/A		
10	6/26/2018; 11:05 AM	**Host Vehicle:** Tampa - Savari	None	Approach at 30 mph.	N/A	Required a Retest
		Remote Vehicle: New York City - Danlaw	None	N/A		
11	6/26/2018; 11:07 AM	**Host Vehicle:** New York City - Savari	Audio	TTI	N/A	Received Alert
		Remote Vehicle: Tampa - SiriusXM	None	GB, IS, SB, RR		
12	6/26/2018; 12:38 PM	**Host Vehicle:** New York City - Danlaw	Audio	N/A	N/A	Received Alert
		Remote Vehicle: Wyoming - Lear	None	Driver alerts. Logging fixed.		

Test ID	Date and Time	Vehicle	Warning Observed	Vehicle Notes / Comments	AOR Notes / Comments	Result
13	6/26/2018; 12:41 PM	**Host Vehicle:** Tampa - SiriusXM	Audio and visual	KB, SB, GB, IS in the car.	N/A	Received Alert
		Remote Vehicle: New York City - Savari	None	N/A		
14	6/26/2018; 12:48 PM	**Host Vehicle:** Tampa - Savari	Audio and visual	Speed at 30 mph. Alert at AOR station with vehicle in front (stopped). Approach speed minimum is 15 mph, so alert was not unexpected.	N/A	Received Alert
		Remote Vehicle: Wyoming - Lear	None	N/A		
15	6/26/2018; 12:50 PM	**Host Vehicle:** New York City - Danlaw	Audio	N/A	N/A	Received Alert
		Remote Vehicle: Tampa - Commsignia	None	N/A		
16	6/26/2018; 12:55 PM	**Host Vehicle:** Wyoming - Lear	Audio and visual	Driver alerts.	Stationary Vehicle warning at 10 seconds time to collision. FCW at 5 seconds time to collision.	Received Alert
		Remote Vehicle: New York City - Savari	None	N/A		
17	6/26/2018; 1:01 PM	**Host Vehicle:** New York City - Danlaw	None	N/A	N/A	Required a Retest
		Remote Vehicle: Tampa - SiriusXM	None	SB, GB, IS		
18	6/26/2018; 1:05 PM	**Host Vehicle:** Wyoming - Lear	Audio and visual	Driver alert. Log worked.	Stationary vehicle warning at 10 seconds to collision. FCW at 5 seconds to collision.	Received Alert
		Remote Vehicle: Tampa - Savari	None	N/A		
19	6/26/2018; 1:09 PM	**Host Vehicle:** Tampa - Commsignia	Audio	No visual, late audio, 2 seconds before collision.	Host: No visual received. Late audio received, 2 seconds before collision. See note on Test 22. Unclear if audio heard before was from OBU or MobilEye	Required a Retest
		Remote Vehicle: New York City - Danlaw	None	N/A		

Test ID	Date and Time	Vehicle	Warning Observed	Vehicle Notes / Comments	AOR Notes / Comments	Result
20	6/26/2018; 1:13 PM	**Host Vehicle:** New York City - Savari	Audio	With Justin	N/A	Received Alert
		Remote Vehicle: Wyoming - Lear	None	N/A		
21	6/26/2018; 1:17 PM	**Host Vehicle:** Tampa - SiriusXM	Audio and visual	KB, SB, IS, GB	N/A	Received Alert
		Remote Vehicle: New York City - Danlaw	None	N/A		
22	6/26/2018; 1:22 PM	**Host Vehicle:** Tampa - Commsignia	None	No visual. We believe the audio alerts from run 1 and 19 were caused by the device “Mobileye” that was on, not the OBU.	New York City Savari was approaching from the Turner building toward flagger 2. Host vehicle testers believe that global audio did not come from OBU.	Required a Retest
		Remote Vehicle: Wyoming - Lear	None	N/A		
1 beta	6/26/2018; 2:00 PM	**Host Vehicle:** Tampa - Commsignia	Audio and visual	N/A	N/A	Received Alert
		Remote Vehicle: New York City - Savari	None	N/A		
4 beta	6/26/2018; 2:07 PM	**Host Vehicle:** New York City - Savari	N/A	N/A	N/A	Received Alert
		Remote Vehicle: Tampa - Commsignia	N/A	N/A		
10 beta	6/26/2018; 2:20 PM	**Host Vehicle:** Tampa - Savari	Audio and visual	N/A	N/A	Received Alert
		Remote Vehicle: New York City - Danlaw	None	N/A		
17 beta	6/26/2018; 2:27 PM	**Host Vehicle:** New York City - Danlaw	Audio	N/A	N/A	Received Alert
		Remote Vehicle: Tampa - Commsignia	None	N/A		
19 beta	6/26/2018; 2:33 PM	**Host Vehicle:** Tampa - Commsignia	Audio and visual	N/A	N/A	Received Alert

Test ID	Date and Time	Vehicle	Warning Observed	Vehicle Notes / Comments	AOR Notes / Comments	Result
		Remote Vehicle: New York City - Danlaw	None	N/A		
22 beta	6/26/2018; 2:40 PM	**Host Vehicle:** Tampa - Commsignia	Audio and visual	N/A	Observed from more than person. Host vehicle driver braked after cone.	Received Alert
		Remote Vehicle: Wyoming - Lear	None	N/A		
7 beta	6/26/2018; 2:51 PM	**Host Vehicle:** Wyoming - Lear	Audio and visual	N/A	Wrongly required a retest. FCW received 5 seconds time to collision. Stationary vehicle warning received 10 seconds time to collision.	Received Alert
		Remote Vehicle: Tampa - SiriusXM	None	N/A		

*MobileEye is a real-time crash avoidance system.

7.4 FCW – Stationary Remote Vehicle in Adjacent Lane Test Results

Table 11. Summary of FCW – Stationary Remote Vehicle in Adjacent Lane Test Results
(Source: USDOT, 2018)

Type of Result	Initial Tests		Retests	
	Count	Percentage	Count	Percentage
Pass	21	95%	1	100%
Required a Retest	1	5%	0	0%
Investigate	0	0%	0	0%
Total	**22**	**100%**	**1**	**100%**

In this test case, the Host Vehicle was driven toward the Remote vehicle, which was stopped in the adjacent lane to the test vehicle. In this test case, the Host vehicle passed the test if, after receiving and processing the message, it did not produce a forward collision warning alert, as the vehicle was not located in the immediate pathway of the vehicle. In this test, twenty-one out of the total twenty-two tests successfully passed the test on the initial test. One test resulted in an alert being incorrectly issued. A detailed analysis of the vehicle data logs would be required to isolate potential causes for the failure in the initial test runs. While it is generally difficult to prove a negative, it appears that each site’s OBUs successfully used BSM data from other CV Pilot site OBUs to correctly identify when a vehicle is not located in its lane; thereby, not issuing a forward collision warning alert.

Table 12 includes the detailed results for the FCW – Stationary Vehicle in the Adjacent Lane test case.

Table 12. FCW - Stationary Remote Vehicle in Adjacent Lane Test Results (Source: USDOT, 2018)

Test ID	Date and Time	Vehicle	Warning Observed	Vehicle Notes / Comments	AOR Notes / Comments	Result
57	6/27/2018; 1:45 PM	**Host Vehicle:** Wyoming - Lear	None, as expected	N/A	N/A	No Alert (as expected)
		Remote Vehicle: New York City - Danlaw	None	N/A		
58	6/27/2018; 1:51 PM	**Host Vehicle:** New York City - Savari	None, as expected	N/A	N/A	No Alert (as expected)
		Remote Vehicle: Tampa - Commsignia	None	N/A		
59	6/27/2018; 1:54 PM	**Host Vehicle:** New York City - Danlaw	Audio	N/A	N/A	Received Alert
		Remote Vehicle: Tampa - SiriusXM	None	SB, IS, GB		
60	6/27/2018; 1:59 PM	**Host Vehicle:** Wyoming - Lear	None, as expected	N/A	N/A	No Alert (as expected)
		Remote Vehicle: Tampa - Savari	None	N/A		
61	6/27/2018; 2:03 PM	**Host Vehicle:** Tampa - Commsignia	None, as expected	N/A	N/A	No Alert (as expected)
		Remote Vehicle: New York City - Savari	None	N/A		
62	6/27/2018; 2:05 PM	**Host Vehicle:** Tampa - SiriusXM	None, as expected	GB, KB, SB, IS	N/A	No Alert (as expected)
		Remote Vehicle: Wyoming - Lear	None	N/A		
63	6/27/2018; 2:09 PM	**Host Vehicle:** Tampa - Savari	None, as expected	Approach speed between 30-35 mph	N/A	No Alert (as expected)
		Remote Vehicle: New York City - Savari	None	N/A		
64	6/27/2018; 2:12 PM	**Host Vehicle:** Wyoming - Lear	None, as expected	N/A	N/A	No Alert (as expected)
		Remote Vehicle: Tampa - Commsignia	None	N/A		

Test ID	Date and Time	Vehicle	Warning Observed	Vehicle Notes / Comments	AOR Notes / Comments	Result
65	6/27/2018; 2:15 PM	**Host Vehicle:** New York City - Savari **Remote Vehicle:** Tampa - SiriusXM	None, as expected None	N/A SB, GB, IS	N/A	No Alert (as expected)
66	6/27/2018; 2:18 PM	**Host Vehicle:** New York City - Danlaw **Remote Vehicle:** Wyoming - Lear	Audio None	N/A N/A	N/A	Received Alert
67	6/27/2018; 2:21 PM	**Host Vehicle:** Tampa - SiriusXM **Remote Vehicle:** New York City - Savari	None, as expected None	JM, SB, GB, IS N/A	N/A	No Alert (as expected)
68	6/27/2018; 2:23 PM	**Host Vehicle:** Tampa - Commsignia **Remote Vehicle:** New York City - Danlaw	None, as expected None	N/A N/A	N/A	No Alert (as expected)
69	6/27/2018; 2:26 PM	**Host Vehicle:** Tampa - Savari **Remote Vehicle:** Wyoming - Lear	None, as expected None	Approach speed between 30-34 mph. N/A	N/A	No Alert (as expected)
70	6/27/2018; 2:28 PM	**Host Vehicle:** New York City - Danlaw **Remote Vehicle:** Tampa - Commsignia	Audio None	N/A N/A	FCW	Required a Retest
71	6/27/2018; 2:31 PM	**Host Vehicle:** New York City - Savari **Remote Vehicle:** Tampa - Savari	None, as expected None	N/A N/A	N/A	No Alert (as expected)
72	6/27/2018; 2:34 PM	**Host Vehicle:** Wyoming - Lear **Remote Vehicle:** Tampa - SiriusXM	None, as expected None	N/A SB, GB, IS	N/A	No Alert (as expected)

Test ID	Date and Time	Vehicle	Warning Observed	Vehicle Notes / Comments	AOR Notes / Comments	Result
73	6/27/2018; 2:37 PM	**Host Vehicle:** New York City - Danlaw	Audio	N/A	N/A	Received Alert
		Remote Vehicle: Tampa - Savari	None	N/A		
74	6/27/2018; 2:40 PM	**Host Vehicle:** New York City - Savari	None, as expected	N/A	N/A	No Alert (as expected)
		Remote Vehicle: Wyoming - Lear	None	N/A		
75	6/27/2018; 2:42 PM	**Host Vehicle:** Tampa - Savari	None, as expected	Approach speed between 30-35 mph	N/A	No Alert (as expected)
		Remote Vehicle: New York City - Danlaw	None	N/A		
76	6/27/2018; 2:45 PM	**Host Vehicle:** Tampa - Commsignia	None, as expected	N/A	N/A	No Alert (as expected)
		Remote Vehicle: Wyoming - Lear	None	N/A		
77	6/27/2018; 2:48 PM	**Host Vehicle:** Tampa - SiriusXM	None, as expected	JM, SB, GB, IS	N/A	No Alert (as expected)
		Remote Vehicle: New York City - Danlaw	None	N/A		
78	6/27/2018; 2:54 PM	**Host Vehicle:** Wyoming - Lear	None, as expected	N/A	N/A	No Alert (as expected)
		Remote Vehicle: New York City - Savari	None	N/A		
70 beta	6/27/2018; 2:56 PM	**Host Vehicle:** New York City - Danlaw	None, as expected	N/A	N/A	No Alert (as expected)
		Remote Vehicle: Tampa - Commsignia	None	N/A		

7.5 FCW – Moving Remote Vehicle and EEBL Test Results

Table 13. Summary of FCW – Moving Remote Vehicle and EEBL Test Results (Source: USDOT, 2018)

Type of Result	Initial Tests		Retests	
	Count	Percentage	Count	Percentage
Pass	14	82%	3	100%
Required a Retest	3	18%	0	0%
Investigate	0	0%	0	0%
Total	**17**	**100%**	**3**	**100%**

The FCW – Moving Remote Vehicle and EEBL test case was successfully demonstrated by all sites in most test runs. Of the seventeen initial test runs, fourteen (82%) passed the test and three (18%) required a retest. It should be noted that this test was identified as being more difficult than others to conduct as triggering an EEBL warning in the Host Vehicle was highly dependent on the driver of Remote Vehicle executing a hard brake. Aggressive driving was typically required to trigger the warning/alert in this test. It should also be noted that this testing was conducted partly under rainy conditions, which could have made the driving task more difficult, but the tests appeared largely unaffected by the rain. For the three tests where warnings were not issued, the situation may have occurred where the application received the OTA messages and acted on them, and the application responded accordingly in not issuing a warning because the situation did not meet the threshold of the Remote Vehicle triggering an alert. Of the three tests that required a retest, all three of the retests resulted in a pass.

Table 14 includes the detailed results for the FCW – Moving Remote Vehicle and EEBL test case.

Table 14. FCW – Moving Remote Vehicle and EEBL Test Results (Source: USDOT, 2018)

Test ID	Date and Time	Vehicle	Warning Observed	Vehicle Notes / Comments	AOR Notes / Comments	Result
40	6/27/2018; 10:42 AM	**Host Vehicle:** New York City - Savari	None	Not hard braking received	No warnings.	Required a Retest
		Remote Vehicle: Tampa - SiriusXM	None	SC, IS, GB, CS		
41	6/27/2018; 10:47 AM	**Host Vehicle:** Wyoming - Lear	Audio and visual	FCA. FCW.	FCW received.	Received Alert
		Remote Vehicle: New York City - Danlaw	None	N/A		
42	6/27/2018; 10:49 AM	**Host Vehicle:** New York City - Savari	Audio	EEBL. Then FCW.	EEBL and FCW received.	Received Alert

Test ID	Date and Time	Vehicle	Warning Observed	Vehicle Notes / Comments	AOR Notes / Comments	Result
		Remote Vehicle: Tampa - Commsignia	None	N/A		
43	6/27/2018; 10:51 AM	**Host Vehicle:** New York City - Danlaw	Audio	No minimum speed for FCW. Both EEBL and FCW.	EEBL and FCW.	Received Alert
		Remote Vehicle: Tampa - Savari	None	N/A		
44	6/27/2018; 10:54 AM	**Host Vehicle:** Tampa - SiriusXM	Audio and visual	EEBL only no FCW. JM, IS, CS, GB	EEBL. No FCW. Rain.	Received Alert
		Remote Vehicle: New York City - Savari	None	N/A		
45	6/27/2018; 10:56 AM	**Host Vehicle:** Wyoming - Lear	Audio and visual	FCA. Driver alert file. Light and rain.	FCW only. Rain.	Received Alert
		Remote Vehicle: Tampa - Savari	None	N/A		
46	6/27/2018; 11:01 AM	**Host Vehicle:** Tampa - SiriusXM	Audio and visual	EEBL. JM, IS, CS, GB	EEBL. No FCW. Rain.	Received Alert
		Remote Vehicle: New York City - Danlaw	None	N/A		
47	6/27/2018; 11:03 AM	**Host Vehicle:** Wyoming - Lear	Audio and visual	EEBL. FCA. Light rain.	FCW. Rain.	Received Alert
		Remote Vehicle: Tampa - Commsignia	None	N/A		
48	6/27/2018; 11:06 AM	**Host Vehicle:** New York City - Savari	Audio	Got both EEBL and FCW.	EEBL and FCW. Rain.	Received Alert
		Remote Vehicle: Tampa - Savari	None	N/A		
49	6/27/2018; 11:08 AM	**Host Vehicle:** Tampa - Commsignia	None	We believe the remote vehicle did not brake hard enough.	N/A	Required a Retest
		Remote Vehicle: New York City - Danlaw	None	N/A		
50	6/27/2018; 11:11 AM	**Host Vehicle:** Wyoming - Lear	Audio and visual	Raining hard. EEBL. FCA.	FCW. Rain.	Received Alert

Test ID	Date and Time	Vehicle	Warning Observed	Vehicle Notes / Comments	AOR Notes / Comments	Result
		Remote Vehicle: Tampa - SiriusXM	None	CS, IS, GB		
51	6/27/2018; 11:13 AM	**Host Vehicle:** New York City - Danlaw	Audio	N/A	EEBL and FCW. Rain.	Received Alert
		Remote Vehicle: Tampa - Commsignia	None	N/A		
52	6/27/2018; 11:16 AM	**Host Vehicle:** Tampa - Savari	Audio	EEBL then FCW. 30 mph maintained at 150 ft spacing.	EEBL and FCW. Rain.	Received Alert
		Remote Vehicle: New York City - Savari	None	N/A		
53	6/27/2018; 11:19 AM	**Host Vehicle:** New York City - Danlaw	Audio	EEBL only.	EEBL. No FCW received. Rain.	Received Alert
		Remote Vehicle: Tampa - SiriusXM	None	CS, IS, GB		
54	6/27/2018; 11:22 AM	**Host Vehicle:** Tampa - Commsignia	Audio and visual	EEBL alert received. No FCW – as expected.	EEBL. No FCW. Rain.	Received Alert
		Remote Vehicle: New York City - Savari	None	N/A		
55	6/27/2018; 11:24 AM	**Host Vehicle:** Tampa - Savari	Audio and visual	Less than 25 mph. Maintained 150 ft spacing.	Rain.	Required a Retest
		Remote Vehicle: New York City - Danlaw	None	N/A		
56	6/27/2018; 11:26 AM	**Host Vehicle:** Wyoming - Lear	Audio and visual	EEBL. FCA. Light rain.	EEBL and FCW. Rain.	Received Alert
		Remote Vehicle: New York City - Savari	None	N/A		
40 beta	6/27/2018; 11:32 AM	**Host Vehicle:** New York City - Savari	Audio	N/A	EEBL and FCW. No rain.	Received Alert
		Remote Vehicle: Tampa - SiriusXM	None	N/A		
49 beta	6/27/2018; 11:34 AM	**Host Vehicle:** Tampa - Commsignia	Audio and visual	N/A	EEBL and FCW.	Received Alert

Test ID	Date and Time	Vehicle	Warning Observed	Vehicle Notes / Comments	AOR Notes / Comments	Result
		Remote Vehicle: New York City – Danlaw	None	N/A		
55 beta	6/27/2018; 11:40 AM	**Host Vehicle:** Tampa - Savari	Audio and visual	N/A	EEBL. No FCW.	Received Alert
		Remote Vehicle: New York City - Danlaw	None	N/A		

7.6 IMA – Host Vehicle Stopped Test Results

Table 15. Summary of IMA - Host Vehicle Stopped Test Results (Source: USDOT, 2018)

Type of Result	Initial Tests		Retests	
	Count	Percentage	Count	Percentage
Pass	6	50%	N/A	N/A
Required a Retest	6	50%	N/A	N/A
Investigate	0	0%	N/A	N/A
Total	**12**	**100%**	**N/A**	**N/A**

The FCW IMA – Host Vehicle Stopped test case was successfully demonstrated. The test case proved to be the most difficult test to perform, as generating the alert required proper timing between the Host and Remote Vehicle and the vehicles had to come close to a collision to trigger a warning. While executing the IMA test, it became apparent that the window for the Host Vehicle to start moving towards the intersection to trigger the warning was very narrow (approximately 1-2 seconds). Of the twelve OBU combinations tested, the test was successful only half the time. In this case, all sites proved able to perform the application, but repeatability was a significant issue. Different comfort levels of the drivers appeared to contribute to the inconsistent outcomes. No retests were done on this application given the human-factor's complexity is executing consistent tests to trigger a warning; however, post-test analysis indicated that OTA transmission of messages occurred for all tests.

Table 16 includes the detailed results for the IMA – Host Vehicle Stopped test case.

Table 16. IMA – Host Vehicle Stopped Test Results (Source: USDOT, 2018)

Test ID	Date and Time	Vehicle	Warning Observed	Vehicle Notes / Comments	AOR Notes / Comments	Result
23	6/26/2018; 3:43 PM	**Host Vehicle:** Tampa - Commsignia	None	Driver started to accelerate then slowed down. We believe the system recognized there was no danger and suppressed the alerts.	No audio and visual received. Was expecting both.	Required a Retest
		Remote Vehicle: New York City - Danlaw	None	N/A		
24	6/26/2018; 3:47 PM	**Host Vehicle:** New York City - Savari	None	Required a Retest	No audio. Launched too late.	Required a Retest
		Remote Vehicle: Tampa - SiriusXM	None	N/A		
25	6/26/2018; 3:52 PM	**Host Vehicle:** New York City - Danlaw	Audio	N/A	N/A	Received Alert
		Remote Vehicle: Tampa - Savari	None	Speed approximately 35 mph.		
26	6/26/2018; 3:57 PM	**Host Vehicle:** Tampa - SiriusXM	None	N/A	Late launch. No audio. No visual. Expected both audio and visual.	Required a Retest
		Remote Vehicle: New York City - Savari	None	N/A		
27	6/26/2018; 4:01 PM	**Host Vehicle:** Tampa - Savari	None	Acceleration was normal. Possible late start.	Expected audio and visual. Driver was hesitant.	Required a Retest
		Remote Vehicle: New York City - Danlaw	None	N/A		
28	6/26/2018; 4:06 PM	**Host Vehicle:** New York City - Savari	Audio	N/A	Alerts were received late.	Received Alert
		Remote Vehicle: Tampa - Commsignia	None	N/A		
29	6/26/2018; 4:09 PM	**Host Vehicle:** New York City - Danlaw	Audio	N/A	Remote also received an alert.	Received Alert

Test ID	Date and Time	Vehicle	Warning Observed	Vehicle Notes / Comments	AOR Notes / Comments	Result
		Remote Vehicle: Tampa - SiriusXM	Audio and visual	GB, SB, IS		
30	6/26/2018; 4:12 PM	**Host Vehicle:** Tampa - Commsignia	Audio and visual	N/A	N/A	Received Alert
		Remote Vehicle: New York City - Savari	Audio	Received Audio alert. (No issue) Data file has logs for test #24, 26, 28, 30.		
31	6/26/2018; 4:23 PM	**Host Vehicle:** Tampa - SiriusXM	None	GB, SB, IS, KB	Expected audio and visual. Late launch.	Required a Retest
		Remote Vehicle: New York City - Danlaw	None	N/A		
32	6/26/2018; 4:27 PM	**Host Vehicle:** New York City - Savari	Audio	N/A	N/A	Received Alert
		Remote Vehicle: Tampa - Savari	None	Speed at 35 mph		
33	6/26/2018; 4:31 PM	**Host Vehicle:** New York City - Danlaw	Audio	N/A	N/A	Received Alert
		Remote Vehicle: Tampa - Commsignia	Audio and visual	N/A		
34	6/26/2018; 4:37 PM	**Host Vehicle:** Tampa - Savari	None	Stopping too soon? (Not sure)	N/A	Required a Retest
		Remote Vehicle: New York City - Savari	Audio	N/A		

7.7 V2I / RLVW Test Results

Table 17. Summary of V2I / RLVW Test Results (Source: USDOT, 2018)

Type of Result	Initial Tests		Retests	
	Count	Percentage	Count*	Percentage
Pass	5	100%	5	100%
Required a Retest	0	0%	0	0%
Investigate	0	0%	0	0%
Total	**5**	**100%**	**6**	**100%**

The V2I / RLVW test case demonstrated that Tampa and New York OBUs were able to receive SPaT and MAP messages being broadcast by RSU from the other CV Pilot sites. Five tests were initially run, and all sites indicated the successful receipt of the messages based on the data that was collected and observed after each test run; however, during the initial testing the sites indicated that there was an issue with the MAP message configuration, in that the map data was not being transmitted correctly. The signal group data was rotated by 90 degrees according to the testers. Retests were conducted on the last day of testing where three out of four test cases were successful. It should be noted that only the New York City OBUs included the RLVW application. Tampa only tested the receipt of the messages for this Test Case through the data that was collected and observed. New York City did test RLVW during some of their tests and one retest required further investigation because warning was not issued as expected.

Table 18 includes the detailed results for the V2I / RLVW test case.

Table 18. V2I / RLVW Test Results (Source: USDOT, 2018)

Test ID	Date and Time	Vehicle	Warning Observed	Vehicle Notes / Comments	AOR Notes / Comments	Result
35	6/27/2018; 9:43 AM	Tampa - Commsignia	None	N/A	Arrived on green. SPaT/MAP 90° off (received).	Messages Received
36	6/27/2018; 9:51 AM	New York City - Savari	None	We are matching the map data with the lane number. But we are not getting SPaT messages.	No alert received. Arrived on yellow. SPaT/MAP 90° off.	N/A
37	6/27/2018; 9:54 AM	Tampa - Savari	None	25 mph at red light.	Arrived on red. SPaT/MAP 90° off.	Messages Received
38	6/27/2018; 9:56 AM	New York City - Danlaw	None	Ran test twice. Getting the red-light warning on green.	Arrived on red. SPaT/MAP 90° off.	Messages Received
39	6/27/2018; 9:59 AM	Tampa - SiriusXM	None	KB, SB, IS, GB. Arrived on red at 1st intersection, green on 2nd intersection.	Arrived on green. SPaT/MAP 90° off.	Messages Received

Test ID	Date and Time	Vehicle	Warning Observed	Vehicle Notes / Comments	AOR Notes / Comments	Result
35 gamma	6/28/2018; 9:14 AM	Tampa - Commsignia	None	N/A	Data Collection exercise.	Messages Received
36 beta	6/28/2018; 9:17 AM	New York City - Savari	None	N/A	36b Red on first light, no warning. Green on second light. 36b-1 vehicle calibrated. First intersection ran red light, no warning received. Second intersection arrived on red, no warning received.	Investigate
37 beta	6/28/2018; 9:20 AM	Tampa - Savari	None	N/A	Data Collection: stopped at red light on first intersection. Stopped at red at second intersection.	Messages Received
39 beta	6/28/2018; 9:28 AM	Tampa - SiriusXM	None	N/A	First intersection red, vehicle stopped. Second intersection red vehicle stopped. Data collection.	Messages Received

8 Best Practices, Observations, and Lessons Learned

This section includes best practices for running future interoperability tests and observations from the Independent Evaluator and others involved in testing based on discussions that were conducted on Thursday June 28.

8.1 Interoperability Testing Best Practices

The success of the Interoperability Test was due to many contributing factors. This section provides a summary of some of the best practices that were valuable and may serve beneficial for future Interoperability Testing activities.

- **Coordinate regularly in the months leading up to the actual test date.** Coordination in the months leading up to the Interoperability Testing test date allowed for CV Pilot sites, vendors, and stakeholders to work together, procure equipment, develop a schedule, provide feedback, etc. This coordination was done via a bi-weekly technical roundtable. A clear definition of roles and responsibilities is important to support planning and execution of the test. Personnel should be clearly identified, and all roles should have backups in the case of unexpected events.
- **Coordinate with test beds to make sure all equipment and software is received weeks before Interoperability Testing is conducted.** The CV Pilots sites mailed all their testing equipment to TFHRC two weeks before testing was conducted. This allowed time for TFHRC to set up OBUs in designated vehicles and make sure the software was working as designed. This allowed time for the installation process to be verified by responsible CV Pilot site representatives.
- **Schedule a full day for setup, checkout and dry runs.** Having an extra day to make sure equipment was installed properly, applications run as expected, etc. was beneficial come the day of running the Interoperability Testing. CV Pilot sites and vendors were able to do last minute updates, study the test bed, and make changes to the test plan to accommodate for a successful execution.
- **Make conservative estimates for test runs.** A basic assumption of 10-minutes per test run was assumed for the Interoperability Testing through discussions with the sites. However, this was based on the location of where the test was conducted, and accommodated for the start time, the test run, and data collection activities. This should be revised for future interoperability tests based on how long it takes to run through a test bed with an added buffer time.
- **Include pre-meeting and set aside 20-30-minutes for dry runs before conducting individual tests.** While running the individual tests, it was found to be beneficial to run through the test procedures for each application’s test a few times so that drivers, vendors, and stakeholders were informed and knew what to expect. Additionally, time should be included at the end of each day to identify what tests need to be retested and to discuss any issues the drivers and other individuals encountered during testing.

- **Have walkie-talkies to communicate with drivers, test leads, USDOT representatives, etc. during test runs.** Walkie-talkies were found to be indispensable during the Interoperability Test. USDOT representatives were able to communicate the start time of each test with in-vehicle personnel, as well as flaggers. End time for each test was also communicated via walkie-talkies.

8.2 Observations

The following observations were identified by the team and the Independent Evaluator during the Interoperability Test.

8.2.1 GPS Accuracy

The GPS inaccuracy in the vehicle devices impacted some of the tests. Positional accuracy is very important to how well the V2V safety applications functioned. GPS coverage at TFHRC was good throughout testing, with 8-11 GPS satellites usually within view during testing.

The following include observations that could have impacted the test runs.

- The roads at TFHRC are narrower than average roadways, lane widths measured 10 feet 7 inches at the locations testing was conducted.
- Initial test runs had issues triggering warnings at the correct times consistently; however, consistency was greatly improved by updating the lane width configurations in the devices. It should be noted that the test team discussed the use of Radio Technical Commission for Maritime Services (RTCM) corrections or RSU triangulation for improved location accuracy (for Tampa and Wyoming vehicles), but ultimately decided not to implement these corrections for the Interoperability Test.

As noted earlier, subsequent testing by New York City with one of the vendors utilizing a firmware update to the GPS chip in their device showed improved performance of GPS accuracy. The device vendor conducted numerous runs around the baseline test run. The vendor's updated results showed a lot of improvement—reducing variability from approximately 7 meters to less than 1.5 meters which is required by SAE J2945.

8.2.2 Driver Behavior and Ensuring Repeatability

For some of the tests—IMA and EEBL in particular—the thresholds within the applications to trigger a warning/alert required some aggressive driver behavior including hard braking for EEBL and coordination/timing for IMA for the vehicles to come close to a collision. Repeatability for some of the tests proved somewhat difficult. In some cases, this could potentially be solved by loosening the configuration of the applications parameters. Another approach would be to use additional/more specific cones along the test track to instruct the drivers on how to behave (e.g., a "start braking here" cone and a "stop here" cone).

8.2.3 OBU Installations and Vehicle Configurations

Based on feedback from participants from the various sites, installation procedures should also be well documented and precise, and installations should be inspected to ensure they are correct. For example, GPS performance may be affected by GPS antenna placement. The location of the GPS system needs to be calibrated based on antenna position to provide vehicle location in compliance with J2945/1. Concerns regarding configuration control, antenna installation, positioning accuracy, and the needs of each application (e.g., absolute vs. relative positioning) were expressed by sites. As mentioned, common performance criteria would go a long way toward solving this potential challenge.

In addition, the applications appeared to have been optimized for the test site during the ad hoc testing day. While optimization is to be expected during integration and testing, applications should work on most roadways without optimization for that particular roadway. Solving this issue for a commercial system is critical. Vehicles of the New York, Tampa and Wyoming Pilots will eventually have to function in other geographies.

9 Recommendations for Future Testing

This section includes recommendations for future Interoperability Testing. This list is not all inclusive and the USDOT is not planning to conduct any additional/future testing for CV Pilots at this time. As more Interoperability Testing is conducted by early adopter sites, recommendations for future testing will need to be updated.

- **RTCM or Other Positioning Correction Enabled Interoperability Testing**
  - The Interoperability Testing relied on continuous localization, i.e., positioning for accurate data collection. However, the position information contained in the DSRC used was not always accurate or reliable.
  - A recommendation is for early adopter sites to conduct the same interoperability tests with either RTCM or another positioning correction technology such as New York City's RSU triangulation solution being broadcast via RSU to determine if there is improved reliability and accuracy with the tested applications. The positioning capability of devices can also be a solution for the lane width adjustments (discussed below) that sites were having to do during the Interoperability Testing.
- **Application Tuning Optimization**
  - Each of the vendors had different configuration parameters for each of the applications tested. These parameters included lane widths and the triggering points for warnings within the application (e.g., the vehicle must be traveling at least 15 mph to trigger a forward collision warning).
  - As tested during Day 1 of the testing, tuning the applications (in this case adjusting lane width) improved the consistency of application performance. Conducting additional testing using the Interoperability Test procedures for each application but varying application tuning for additional configuration parameters may provide insight into what settings provide the greatest consistency.
- **IMA Testing with Visual Cue for Host Vehicle Release**
  - While executing the IMA test, it became apparent that the window for the Host Vehicle to start moving towards the intersection to trigger the warning was very narrow (approximately 1-2 seconds). Removing the human factor variable and testing with a visual cue that alerts the Host Vehicle's driver to start moving towards an intersection can produce better results for future Interoperability Testing.
- **Lane Width Adjustments in Operational Environment**
  - CV Pilot sites needed to adjust the application lane width setting to accommodate for the narrow lanes at TFHRC (10 ft). Applications were designed for standard width (12 ft) lanes. Future tests should consider the implications of lane width changes in various jurisdictions and locations as this creates issues for vehicles to receive alerts in operational environments where application setting cannot be adjusted in real time. In addition, lane width adjustments relate to the device's positioning capability.

- **Device Certifications**
    - Prior to the Interoperability Testing, all devices were intended to be certified. However, due to time constraints, not all devices were certified in time. Although the intent of this Interoperability Testing was not to test conformance to current baseline standards, it is beneficial for adopter sites to participate in certification services to support continued V2V communications testing.
- **Connected Vehicle PlugFest**
    - The USDOT holds a CV PlugFest to provide a venue for vendor-to-vendor connected vehicle testing as needed to develop certification services for multi-vendor connected vehicle networks. Prior to conducting Interoperability Testing, sites should consider attending these events to assess vendor capabilities.

Appendix A. Sample Test Log

Table 19. Sample Test Log Sheet **(Source: USDOT, 2018)**

<table>
<tr><td>Test ID: 1</td><td colspan="4">Test Name: 13.2 FCW Stationary Remote Vehicle Same Lane</td></tr>
<tr><td colspan="2">Test Date: 6/26/2018</td><td colspan="3">Start Time:</td></tr>
<tr><td colspan="2">Host Vehicle: Tampa - Commsignia</td><td colspan="3">Remote Vehicle: New York City - Savari</td></tr>
<tr><td>Observed Warning/Alert:

(select applicable)</td><td colspan="4">☐ None ☐ Audio ☐ Visual</td></tr>
<tr><td>Alert Anomalies:</td><td colspan="4">☐ N/A (as expected) ☐ No alert received ☐ Unexpected alert received</td></tr>
<tr><td>Data Logging and Download:

(vehicle only)</td><td>Data Captured & Downloaded?

☐ Yes ☐ No</td><td colspan="2">File Name:</td><td>Time Saved:</td></tr>
<tr><td colspan="5">Notes:</td></tr>
<tr><td>Run Result:

(AOR Notebook only)</td><td colspan="2">☐ Pass ☐ Investigate ☐ Fail</td><td>Retest Required?

☐ Yes ☐ No</td><td>Initials:</td></tr>
</table>

Appendix B. Individuals that Participated in the Interoperability Test

Table 20 includes a list of individuals that participated in the CV Pilots Phase 2 Interoperability Test.

Table 20. List of Individuals Participating in the Interoperability Test (Source: USDOT, 2018)

First	Last	Organization	Site / Role
Justin	Anderson	Noblis	CVDTA Contractor
Sampson	Asare	Noblis	CV Pilot Technical Support
Rojer	Babu	Danlaw	New York CV Pilot
Kevin	Balke	TTI	Independent Evaluator
Krishna	Bandi	Savari	Tampa CV Pilot
Nader	Barhoum	TransCore	New York CV Pilot
David	Benevelli	TransCore	New York CV Pilot
Wolfgang	Buckel	Siemens	New York CV Pilot / Tampa CV Pilot
Mary (Ginny)	Burcham	HNTB	Tampa CV Pilot
Sisinnio	Concas	CUTR	Tampa CV Pilot
Deb	Curtis	FHWA	FHWA
Wessam	Daraghmeh	NYC DOT	New York CV Pilot
Maulikbhai	Dineshbhai Patel	Savari	Tampa CV Pilot
Walter	During	FHWA	FHWA
Tony	English	Neaera Consulting Group	Wyoming CV Pilot
Debbie	English	Neaera Consulting Group	Wyoming CV Pilot
Volker	Fessmann	FHWA	FHWA
Ed	Fok	FHWA	FHWA
Bob	Frey	THEA	Tampa CV Pilot
Maggie	Hailemariam	Noblis	CV Pilot Technical Support
Veeranna	Halanannavar	Savari	New York CV Pilot / Tampa CV Pilot
Jacob	Harel	Savari	Tampa CV Pilot
Kate	Hartman	ITS JPO	Wyoming CV Pilot AOR
Zach	Hershey	Student Intern	FHWA
Rafal	Ignatowicz	Brandmotion	Tampa CV Pilot
Mafruhatl	Jannat	Leidos	STOL

First	Last	Organization	Site / Role
Steve	Johnson	HNTB	Tampa CV Pilot
Jeffrey	Kane	SiriusXM	Tampa CV Pilot
Navin	Katta	Savari	Tampa CV Pilot
Hisham	Khanzada	NYC DOT	New York CV Pilot
Goutham	Lingannagari	Siemens	Tampa CV Pilot
Mike	Lukuc	TTI	Independent Evaluator
Justin	McNew	JMC Rota, Inc.	Independent Evaluator
Dave	Miller	Siemens	New York CV Pilot / Tampa CV Pilot
Louri	Nemirovski	Siemens	New York CV Pilot / Tampa CV Pilot
Michelle	Noch	ITS JPO	CVDTA PM
Steve	Novosad	HNTB	Tampa CV Pilot
Steve	Novosad	HNTB	Tampa CV Pilot
Miao	Peijie	Lear	Wyoming CV Pilot
Mike	Pina	ITS JPO	FHWA
Anna	Quinones	THEA	Tampa CV Pilot
Bob	Rausch	TransCore	New York CV Pilot
Mark	Rindsberg	SiriusXM	Tampa CV Pilot
Mark	Robeson	Leidos	STOL
Randy	Roebuck	OmiAir	Certification
Kyle	Rush	Leidos	STOL
John	Sandlin	Brandmotion	Tampa CV Pilot
Igor	Savikhin	SiriusXM	Tampa CV Pilot
J.D.	Schneeberger	Noblis	CVDTA Contractor
Chris	Stanley	Leidos	STOL
Barbara	Staples	Noblis	CV Pilot Technical Support
Andras	Takas	Commsignia	New York CV Pilot / Tampa CV Pilot
Joel	Thompson	Leidos	STOL
Nayel	Urena Serulle	ICF	Wyoming CV Pilot
Govind	Vadakpat	FHWA	Tampa CV Pilot AOR
Meenakshy	Vasudevan	Noblis	CV Pilot Technical Support
Michael	Venus	Siemens	New York CV Pilot / Tampa CV Pilot
Judith	Villegas	THEA	Tampa CV Pilot
Harsh	Vipat	Savari	Tampa CV Pilot
Jonathan	Walker	FHWA	New York CV Pilot AOR
Peiwei	Wang	Noblis	CV Pilot Technical Support

First	Last	Organization	Site / Role
Lee	Whitman	BAH	Communications (Video)
Karl	Wunderlich	Noblis	CV Pilot Technical Support
James	Yeager	BAH	Communications (Video)

U.S. Department of Transportation
ITS Joint Program Office – HOIT
1200 New Jersey Avenue, SE
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