Connected Vehicle Deployment Technical Assistance

Onboard Unit (OBU) Lessons Learned and Best Practices

www.its.dot.gov/index.htm

Final Report – March 2020
FHWA-JPO-20-786

U.S. Department of Transportation

U.S. Department of Transportation

1. Report No. FHWA-JPO-20-786	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle Onboard Unit (OBU) Lessons Learned and Best Practices	5. Report Date May 2020 6. Performing Organization Code:
7. Author(s) J.D. Schneeberger (Noblis), Amy O'Hara (Noblis), Kathy Thompson (Noblis), David Benevelli (TransCore). Tony English (Neaera Consulting), Steve Johnson (HNTB), Steve Novosad (HNTB), and Bob Rausch (TransCore)	8. Performing Organization Report No.
9. Performing Organization Name and Address Noblis 500 L'Enfant Plaza, S.W., Suite 900 Washington, DC 20024	10. Work Unit No. 11. Contract or Grant No.
12. Sponsoring Agency Name and Address ITS Joint Program Office 1200 New Jersey Ave., SE Washington, DC 20590	13. Type of Report and Period Technical Primer 14. Sponsoring Agency code HOIT-1

15. Supplementary Notes
Michelle Noch (COR)

16. Abstract
This document captures lessons learned and best practices for onboard units (OBUs) as experienced by the United States Department of Transportation's (USDOT's) Connected Vehicle Pilot sites. The purpose of this document is to synthesize, at a high-level, key lessons learned, and best practices related to OBUs to assist other early deployers as they deploy connected vehicle technologies in their jurisdictions. OBU lessons learned and best practices were collected from documents and technical presentations produced by the CV Pilot sites, discussions from CV Pilot Technical Roundtables, and other sources. Content is captured for the acquisition/procurement, design, installation, and testing of OBUs.

17. Key Words	18. Distribution Statement
CV Pilots, Connected Vehicle, Onboard Unit (OBU), Lessons Learned, Best Practices	This document is available to the public through the ITS JPO PCB website.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	27	

Section 1: Introduction

This document captures lessons learned and best practices for onboard units[1] (OBUs) as experienced by the United States Department of Transportation's (USDOT's) Connected Vehicle Pilot sites. The USDOT awarded cooperative agreements collectively worth more than $45 million to three pilot sites in New York City; Wyoming; and Tampa, FL to implement a suite of connected vehicle applications and technologies tailored to meet their region's unique transportation needs. These pilot sites are helping connected vehicles make the final leap into real-world deployment so that they can deliver on their promises to increase safety, improve personal mobility, enhance economic productivity, reduce environmental impacts and transform public agency operations. Moreover, these sites are laying the groundwork for even more dramatic transformations as other areas follow in their footsteps.

The purpose of this document is to synthesize, at a high-level, key lessons learned, and best practices related to OBUs to assist other early deployers as they deploy connected vehicle technologies in their jurisdictions. Connected vehicle technologies are still an emerging technology. Before starting a connected vehicle project, it is important for deployers to understand the complexity and maturity of the technology. The intent of sharing these lessons learned is to assist future deployers in understanding some of the technical challenges related to deploying the technology so that they can more easily deploy consistent and interoperable systems.

OBU lessons learned and best practices were collected from documents and technical presentations produced by the CV Pilot sites, discussions from CV Pilot Technical Roundtables, and other sources. Content is captured for the acquisition/procurement, design, installation, and testing of OBUs.

OBUs are devices located in vehicles to collect data from the vehicle and/or provide an interface through which ITS services, e.g. travel information and warnings, can be provided to the driver. OBUs continuously broadcast data in the form of Basic Safety Messages (BSMs) to other vehicles, roadside units (RSUs), and other devices. OBUs also receive data transmitted by OBUs and RSUs. In-vehicle systems include software that runs vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) applications; a working human-machine interface (HMI) that issues audible and/or visual warnings or alerts to the driver; antennas, and possibly data internal storage capability. OBUs used in the CV Pilots are retrofitted to vehicles and were not provided by the vehicle's original manufacturer and integrated with the vehicle's onboard systems.

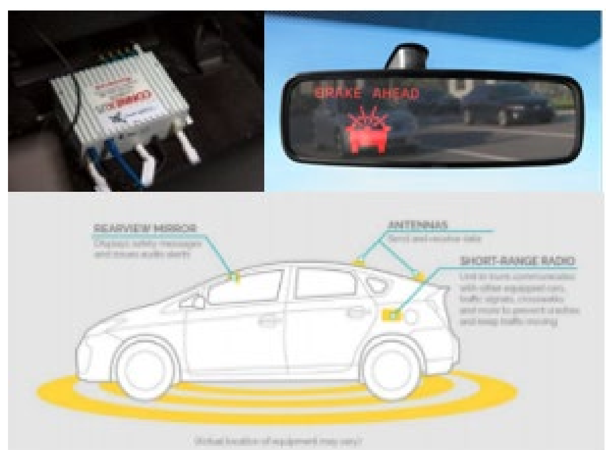

Figure 1. A Wyoming CV Pilot OBU installed in a vehicle (left) and a THEA Human Machine Interface (HMI) (right) (Source: Wyoming DOT (left) and THEA (right)

[1] Note that the New York Pilot project refers to the onboard units as *Aftermarket Safety Devices* (ASD); when referencing documents produced by the New York project, the onboard unit is referenced as an ASD.

Deploying a production-level end-to-end connected vehicle system takes more than transmitting signal phase and timing (SPaT), MAP and basic safety messages (BSMs). While "demos" are easy – especially without detailed performance measurements – deploying a complete connected vehicle ecosystem requires a significant amount of planning, engineering, and testing. The lessons learned and best practices, documented in this report, are intended to assist agencies as they deploy connected vehicle technologies. Just as a fully deployed traffic management system is a complex system of systems which extends from the intersection traffic controller to the central management and optimization of signal timing patterns and operation and maintenance management and data collection and analysis, the deployment of a connected vehicle eco system requires attention to large scale management of devices, tracking of performance data, detection of anomalies and dispatching of maintenance crews, monitoring of communications reliability, and overall monitoring of device health and operation.

Document Organization

This document is organized into five sections. Section 1 provides an introduction. Sections 2-5 include lessons learned organized by the following categories – Acquisition and Procurement, Design, Installation, and Testing. In total there are sixty-five (65) lessons learned and best practices. The following outline includes a summary of the lessons learned and includes hyperlinks to subsections within each section.

Section 1: Introduction

Section 2: OBU Acquisition and Procurement Lessons Learned and Best Practices

- Personnel and Stakeholder Engagement Considerations
    - Procurement 01: Obtain stakeholder feedback early for determining the details of the devices.
    - Procurement 02: Engage with procurement and contracting personnel early in the process.
    - Procurement 03: Procurement of "developmental" devices and evaluation of "prototypes" can present challenges to the procuring agency.
    - Procurement 04: Bring in Subject Matter Experts (SMEs) to support procurement efforts.
    - Procurement 05: Review preliminary contract specifications with the vendor community prior to releasing the procurement.
- Standards and Technology Maturity Considerations
    - Procurement 06: Conduct Technology Readiness Level (TRL) assessment for connected vehicle hardware elements and applications.
    - Procurement 07: Leverage standards and understand that standards and technology will evolve.
    - Procurement 08: Consider the maturity of connected vehicle devices and applications prior to procurement.
    - Procurement 09: Be cognizant that additional requirements may need to be considered when procuring devices.
    - Procurement 10: Reduce risk by selecting multiple suppliers.
- Vendor Capabilities and Support Services Considerations
    - Procurement 11: Procure vendor support for the entire project lifecycle.

  - Procurement 12: Documentation may be lacking from device vendors and needs to be kept up to date over the course of the project.
  - Procurement 13: Conduct multiple technical scans to better understand vendor capacity, depth, and resources.
- Phasing, Scheduling, and Timing Considerations
  - Procurement 14: Consider the time needed for large scale purchases.
  - Procurement 15: Consider splitting procurement into two phases to minimize risks.

Section 3: OBU Design Lessons Learned and Best Practices

- Standards Considerations
  - Design 01: Design systems using published U.S. Standards.
  - Design 02: Apply and update standards conformance where appropriate.
  - Design 03: Insist that your vendor's OBU be certified conformant by an independent laboratory.
- Large Fleet Vehicle Design Considerations
  - Design 04: It may be necessary to devise unique design requirements for large fleet vehicle antennas where necessary.
  - Design 05: Handle BSM vehicle length for tractor trailers and/or articulated buses carefully as they may pose challenges.
  - Design 06: Understand that obtaining CAN Bus data is difficult and should not be essential to design.
- Location Accuracy Design Considerations
  - Design 07: Assess GPS accuracy of OBUs in dense urban environments to determine whether a correction is needed.
  - Design 08: Embrace the challenge of establishing GNSS location accuracy (within 1.5m) in the urban canyon.
- Application Trigger and Alert Considerations
  - Design 09: Establish a clear protocol for warning priority for when multiple warnings are triggered to avoid driver confusion.
  - Design 10: Tune connected vehicle application alerts for factors impacting the system such as the roadway configuration, environment, and driver behavior.
  - Design 11: Tune the applications for the proper density and speed of the environment that you are deploying in.
- Other Design Considerations
  - Design 12: Augment connected vehicle solutions with more traditional ITS technologies where necessary.
  - Design 13: Align antenna types to vehicle needs.
  - Design 14: Leverage Over-the-Air (OTA) support networks for software/firmware updates.
  - Design 15: Secure a significant amount of time to review design documentation.

Section 4: OBU Installation Lessons Learned and Best Practices

- Personnel Resource Considerations for Installations
  - Installation 01: Ensure professional installations of OBUs in participant vehicles.

- Installation 02: Consider leveraging auto professionals to manage installations in private vehicles.
- Installation 03: Consider the time needed for coordination of device installations.

- Installation Timing/Scheduling Considerations
  - Installation 04: Conduct early, rudimentary installs early.
  - Installation 05: Fine-tune the installation by fleet vehicle type in the device prototype phase.
  - Installation 06: Conduct integration testing before private vehicle installs.
- Battery and Power Considerations for Installations
  - Installation 07: Ensure that the vehicle battery (not hybrid battery) is disconnected before OBU installation.
  - Installation 08: Be sensitive to the power drawn by in-vehicle devices to avoid vehicle power drain.
- Antenna Installation Considerations
  - Installation 09: Refine proper antenna placement to reduce communications interferences.
  - Installation 10: Check antennas for faulty sealing.
- Participant Engagement Considerations
  - Installation 11: Develop a structured process to engage with participants for installs on private vehicles.
  - Installation 12: Ensure that OBU and vehicle information from the asset management system is readily available on the OBU for device management and tracking.
- Other Installation Considerations
  - Installation 13: Consider using a cover over the OBU and existing connectors to protect them from water damage or liquid spill.
  - Installation 14: Pre-configure the OBU XYZ measurements prior to completion of the physical installation.
  - Installation 15: Perform appropriate calibration procedures for all onboard technologies.
  - Installation 16: Check vehicles for pre-existing safety systems that may interfere with an evaluator's ability to isolate impacts of the connected vehicle applications.
  - Installation 17: Permit special considerations for snowplows.

Section 5: OBU Testing Lessons Learned and Best Practices

- Overarching Testing Considerations
  - Testing 01: Perform detailed testing required for OBU and RSU software and hardware.
  - Testing 02: Ensure rigorous requirements verification and acceptance testing.
  - Testing 03: Conduct testing early with actual infrastructure.
  - Testing 04: Complete testing of individual components of the system prior to system-level testing.
  - Testing 05: Give a considerable amount of attention to testing prior to devices becoming operational.
  - Testing 06: Understand that testing for Pilot does not equal testing for scale.
  - Testing 07: Perform multiple/regression testing to verify that a previously tested system still performs the same way after changes were made in the field to another component.
  - Testing 08: Continually test systems and check their requirements.

  - Testing 09: Examine all possible root causes before power-cycle/reset/reboot of the device.
- Testing Location Considerations
  - Testing 10: Arrange a testing location that can accommodate the necessary test runs.
- Tools Considerations for Testing
  - Testing 11: Leverage Radio Frequency (RF) tools to support testing.
  - Testing 12: If using licensed spectrum, consider purchasing interference tracking equipment to detect potential interference from other users in the 5.9 GHz band that can compromise data exchange.
- Antenna Testing Considerations
  - Testing 13: Conduct extensive antenna testing on semis/trucks.
  - Testing 14: Conduct extensive OBU antenna durability test.
- Data Upload, Download, and Offloading Testing Considerations
  - Testing 15: Test the OTA download and upload mechanisms before extensive installation of the OBUs (and RSUs).
  - Testing 16: Test log offloading from OBU to TMC performance.
- Other Testing Considerations
  - Testing 17: Test for RSU Traveler Information Message (TIM) transmission range.
  - Testing 18: Test other connected vehicle hardware elements.

Section 2: OBU Acquisition and Procurement Lessons Learned and Best Practices

This section documents lessons learned and best practices for the procurement of OBUs.

Personnel and Stakeholder Engagement Considerations

- **Procurement 01: Obtain stakeholder feedback early for determining the details of the devices.** Meetings with stakeholders should be held early in the project to gain insight on the participants' needs (and expectations) in developing systems engineering deliverables – Concept of Operation (ConOps), System Requirements Specification (SyRS), System Architecture Document (SAD), and System Design Document (SDD). Based on stakeholder feedback, the CV Pilot Sites identified different needs for HMIs. For example, the THEA project decided to implement both visual and audio alerts to drivers. The NYC CV Pilot team chose to utilize an audio-only HMI for their OBUs instead of visual display as observed in other CV Pilot sites. The reason for this was to minimize visual distraction and accommodate space issues in taxis. The audio-only HMI provides words and tones associated with particular threats. In addition, the NYC CV Pilot project included spoken words, tones, and text to voice to support their applications.

- **Procurement 02: Engage with procurement and contracting personnel early in the process.** Ensure that contracting and procurement personnel are involved from the beginning of the project. Due to the challenges of using traditional procurement mechanisms, deployers found that involving contracting and procurement personnel from the beginning of the project can help prevent possible delays caused by miscommunication. Agencies need to work with their contracts office to ensure that the technical requirements are met when selecting a vendor/consultant. Traditional mechanisms for procurement that DOTs follow may not fit well with software/technology-heavy projects. In addition, some agencies may be required to use lowest bid contractors/equipment for their projects and may need to work with their contracts office to ensure that the technical requirements were met when selecting a vendor/consultant. For the THEA CV Pilot, THEA had the ability to sole source research projects. In addition, the THEA team was able to leverage existing contract vehicles to bring contractors onboard before award. Working with procurement and contracting personnel early in the process, may result in opportunities to streamline and simplify procurement and contracting efforts.

- **Procurement 03: Procurement of "developmental" devices and evaluation of "prototypes" can present challenges to the procuring agency.** In the case of the OBU procurements, there will likely be many custom features related to data collection, software updates, and security implementation that may be difficult to define in the procurement specification. The lack of maturity of the OBUs for deployment created issues for the projects requiring considerable design flexibility and negotiations on the final specifications and design. For traditional ITS procurements, agencies are used to publishing detailed device specifications and then choosing the low bidder. For OBU procurements, it may be necessary to modify the specifications in some cases to insure a practical and reliable implementation. It should be noted that even applications that have been deployed for other connected vehicle projects may be immature. As such, specifications and requirements may be moving targets. Agencies will need to partner with the vendor as part of the design process to ensure requirements are met and work with the vendor to resolve various practical design issues.

- **Procurement 04: Bring in Subject Matter Experts (SMEs) to support procurement efforts.** Consider bringing in System Engineers and connected vehicle experts to vet the project requirements prior to releasing the RFPs. Taking this approach enables deployers to contract with qualified consultants and ultimately receive a better final product. Consider a team of on-site and off-site connected vehicle experts. Having that expertise enables agencies to verify deliverable accuracy and ensure that they are meeting program goals and system requirements. For early deployers, SMEs may be difficult to identify as there have been a limited number of full deployments of the technology. Consideration should be given to engaging SMEs that have been engaged in connected vehicle standards activities and successful deployments from across the country, if possible. SMEs with proven systems project management and systems engineering capabilities should also be considered.
- **Procurement 05: Review preliminary contract specifications with the vendor community prior to releasing the procurement.** Consider reviewing the preliminary contract specifications with the vendor community through requests for expressions of information (RFEIs) and face-to-face technical reviews – prior to formal release – to ensure that the final specifications are practical, sustainable, saleable, and feasible within a reasonable budget for time and costs. This is especially important for emerging technologies – including connected vehicle technologies – which have not been deployed at a large scale.

Standards and Technology Maturity Considerations

- **Procurement 06: Conduct Technology Readiness Level (TRL) assessment for connected vehicle hardware elements and applications.** Use Technology Readiness Levels (TRL) to assess the development level for connected vehicle hardware and applications. TRLs are a method for estimating the maturity of technologies during the acquisition phase of a program, developed at NASA. The use of TRLs enables consistent, uniform discussions of technical maturity across different types of technology. TRLs are based on a scale from 1 to 9 with 9 being the most mature technology. The CV Pilot Sites noted that it would have been useful to accurately assess the connected vehicle hardware—primarily the OBUs and RSUs—as to where they were on the TRL scale. This assessment would have indicated the larger scope and cost of testing that they encountered. In hindsight, the initial TRL of the connected vehicle hardware was in the 5 to 7 range, while the required TRL for the hardware is 8 to 9. The general rule of thumb for development is that the development/test costs grow exponentially as you move up the scale and peak at TRL 8.
- **Procurement 07: Leverage standards and understand that standards and technology will evolve.** Leverage existing standards, specifications, and processes in procuring connected vehicle technologies, including but not limited to IEEE 1609.x, SAE J2735, SAE J2945/x, the USDOT's RSU 4.1 specification, etc. Agencies should understand that evolving standards and technology can cause the specifications to be a moving target. It usually requires at least some troubleshooting.
  Further, functionality such as probe data collection (e.g., collecting OBU logs), while included in the standards (J2735) is not supported by the OEMs and over-the-air (OTA) collection of such data is not part of the standards. Use of the service channels can support such data collection, but there are many aspects of an end-to-end deployment which are not included in the standards such as OTA firmware/software updates and OTA data collection from the devices.

- **Procurement 08: Consider the maturity of connected vehicle devices and applications prior to procurement.** Some deployers noted that the units they procured required substantial technical support from the vendor during their initial deployment. Connected vehicle technology and application maturity may be lower than initially anticipated and industry application performance requirements may not be available. Agencies should utilize the System Engineering process (needs, requirements, specifications, traceability) and leverage existing device vendor experience. To address the emerging nature of connected vehicle technology, some deployers have explicitly stated in their procurements that they were only interested in purchasing turn-key applications. In such cases, the vendor is responsible for any necessary application development. Turn-key V2I applications are difficult to implement as there is a vehicle (OBU) and infrastructure (RSU) component to the application. Simply implementing a standard is not enough. An interface control document (ICD) should be developed to better understand and document the interfaces.

- **Procurement 09: Be cognizant that additional requirements may need to be considered when procuring devices.** When developing requirements security, event recording, over-the-air (OTA) updates, radio frequency (RF) monitoring and other management applications need to be considered. These requirements may need to be further defined by the agency procuring the devices to ensure that security and other capabilities are considered.

- **Procurement 10: Reduce risk by selecting multiple suppliers.** To reduce risk, it is wise to select more than one supplier in the event that a supplier is unable to commit to previous agreements. With multiple selected vendors, an agency can disqualify any non-performing vendor(s) (if needed) and continue with the performing vendor(s) for the full complement of units. When awarding to multiple vendors, planning and testing for interoperability become even more important, and more costly. Keep in mind that until there is universal maturity, different devices can and often do behave differently. Such issues must be determined and addressed during the testing phase of the project and multiple vendors can and are likely increase the cost of integration. While selecting more than one vendor may be a good approach, agencies should not over commit to a particular vendor – including the vendor. If a particular vendor underperforms, it may be difficult to obtain additional units from other vendors because of manufacturing lead times.

Vendor Capabilities and Support Services Considerations

- **Procurement 11: Procure vendor support for the entire project lifecycle.** Due to the emerging nature of connected vehicle technology, many deployers emphasized the importance of considering the level of technical support needed from vendors during the procurement process. The level of technical support varies depending on the deployer and project phase. In addition, deployers have experienced varying levels of support were provided by different vendors. With any emerging technology, having the right vendor expertise on-site and on-call can expedite problem resolution and troubleshooting. Many vendors may be small companies with development staff overseas. Future deployers should inquire where the development staff resides to avoid 24-hour delays to respond to issues. Including clear requirements for vendor support can reduce additional needs for additional costs later in the project. While it might be expected that vendors will account for this level of support in the proposals, agencies should keep in mind that few vendors have deployed a large number of OBUs and may not account for the level of support needed to deploy a real-world deployment.

- **Procurement 12: Documentation may be lacking from device vendors and needs to be kept up to date over the course of the project.** The CV Pilot sites found a lack of user and admin documentation with some of their OBUs. This presented challenges and required the sites to require the vendor to conduct onsite training. Agencies should ensure that they procure services for training and technical support from vendors. It is also important to remember that some of this documentation may be evolving based on the changes (challenges) discovered during integration. Documentation should be kept up to date as project personnel can change over time. It is also important to document the configuration parameters and the rationale during incremental deployment – to serve as a future reference as the system expands. In summary, make sure you establish good configuration management practices for the project and make sure they are followed though all of the troubleshooting and change process.

- **Procurement 13: Conduct multiple technical scans to better understand vendor capacity, depth, and resources.** Consider conducting multiple technical scans to understand the vendors' technical depth and resources. This can be done by using a request for proposals (RFP) and on the road testing to identify promising suppliers who can meet the system, cost and project timing requirements. Prior to selection, obtain a better understanding of vendors' depth and resources to deliver. Some agencies experienced that OBU vendors did not have the capacity and staff to supply the required devices, which resulted in project delays. Vendors of RSUs and OBUs may not have the capacity and staff to supply the required devices for a project, which may result in delays. Technical scans are critical to scrutinize and select the best suppliers. Since this technology cannot be purchased off the shelf yet, the New York City CV Pilot Site did a Request for Expression of Interest (RFEI) demonstration/evaluation, where two vendors were eventually selected as their OBU suppliers. The THEA CV Pilot brought in multiple vendors to present and demonstrate their devices prior to award. The THEA CV Pilot team also traveled to vendor facilities for demonstrations. While demonstrations are useful, agencies should be cautioned that demonstrations are not real-world tests.

Phasing, Scheduling, and Timing Considerations

- **Procurement 14: Consider the time needed for large scale purchases.** One of the biggest challenges of the procurement process is the unexpected delays caused by lengthy negotiations and slow progress for issuing contracts with vendors. Deployers who have faced this challenge recommended forecasting possible delays in the process early in the project and to also allocate enough time for the procurement cycle. The time for an agency to issue a purchase order (PO) or contract for each vendor may be much more extensive than expected. It is also important to consider the practical schedule for the construction of electronic equipment; custom devices in small quantity (10-50) can occur quickly (8-12 weeks) but production quantities are more likely 16-20 weeks unless the device is “off the shelf” which has not been the case in the CV arena to date. Many vendors may sell agencies that they can deliver a certain number of devices in a given timeframe (e.g., XX number of devices in YY weeks). Vendors may or may not be able to meet those commitments due to several reasons including overseas manufacturing a well as the ability for the vendor to gear up and produce large numbers of devices.

- **Procurement 15: Consider splitting procurement into two phases to minimize risks.** Agencies may want to consider separating the procurement process into two phases with a prototype phase and production phase. Splitting the procurement process in this manner allows deployers to smooth out any kinks on a limited number of devices before scaling up to procure the complete set of devices for the deployment. It is important to perform extensive testing of these prototypes under field conditions and test and verify all of the features and interactions and attempt to expose the implementation to some of the "edge" conditions which often reveal areas where design changes may be required to support more extensive deployment.

Procurement-related Resources

The following are documents that provide additional information related to procurement lessons learned and best practices:

- New York CV Pilot: FHWA-JPO-17-455, Comprehensive Installation Plan - NYCDOT
- New York CV Pilot: Device Acquisition and Installation Experiences Webinar (July 30, 2018) Presentation Material, Recording and Q&A Notes
- THEA CV Pilot: FHWA-JPO-17-463, Comprehensive Installation Plan - Tampa (THEA)
- THEA CV Pilot: Device Acquisition and Installation Experiences Webinar (August 7, 2018) Presentation Material, Recording and Q&A Notes
- Wyoming CV Pilot: FHWA-JPO-17-471, Comprehensive Installation Plan - WYDOT
- Wyoming CV Pilot: Device Acquisition and Installation Experiences Webinar (July 23, 2018) Presentation Material, Recording and Q&A Notes

Section 3: OBU Design Lessons Learned and Best Practices

This section documents lessons learned and best practices for the design of OBUs.

Standards Considerations

- **Design 01: Design systems using published U.S. Standards.** Agencies considering connected vehicle deployments are highly recommended to use the most recently published ITS standards; any use of unpublished standards or standards in progress is discouraged. In addition, it is strongly encouraged that vendors should be participants in significant connected vehicle standards activities.
- **Design 02: Apply and update standards conformance where appropriate.** Though there is no USDOT OBU standard, all messages being used should conform to the latest versions of SAE J2735, SAE 2945/x, IEEE 802.11, IEEE 1609.x, and related standards. Vendors are expected to work with the deployer agency to determine the appropriate version for each standard/device specification that has been accepted for general use.
- **Design 03: Insist that your vendor's OBU be certified conformant by an independent laboratory.** Agencies should require their vendors to be certified conformant by an independent laboratory. It should be noted that J2945/1A now includes various test procedures for certification. Since virtually no agency has the laboratory facilities, test equipment, and expertise to perform conformance testing, requiring certification is a reasonable starting point – but does not guarantee interoperability.

Large Fleet Vehicle Design Considerations

- **Design 04: It may be necessary to devise unique design requirements for large fleet vehicle antennas where necessary.** Different vehicle sizes have different requirements for antennas. It is paramount to assess these early in the process and make sure the vendor can provide solutions for any gaps in their current products. Some vendors may lack experience in designing antenna for large vehicles. Agencies may need vendors – or specialists – to come to their site to look at their large vehicles (e.g., snowplows, trucks, etc.) to help design the antenna system. Likewise, agencies should be sure that antenna wiring uses low loss cables and that the cable runs are not damaged during installation. Another option is to engage a third-party aftermarket installer that has staff to deal with these types of issues.
- **Design 05: Handle BSM vehicle length for tractor trailers and/or articulated buses carefully as they may pose challenges.** There are several ways to interpret large vehicles (e.g., tractor trailers and/or articulated buses) – either as rigid bodies for trajectories or as articulated/with pivot points. BSM Part 1 includes the vehicle length, width, height, power. BSM Part 2 includes the pivot points for trailers. The BSM Part 2 has multiple extensions within the message (VehicleSafetyExtensions, SpecialVehicleExtensions, SupplementalVehicleExtensions), only one of which is currently required to be supported by the SAE standards. There is no requirement in any of the standards for vendors to support the SpecialVehicleExtensions of the BSM Part 2, which is where the Trailer Data can be found. SAE J2945/1 does require the implementation of the VehicleSafetyExtensions in the BSM Part 2 for certain V2V safety applications, such as Forward Collision Warning (FCW).

- **Design 06: Understand that obtaining CAN Bus data is difficult and should not be essential to design.** The CAN bus interface is a challenge for data definition. Most fleets are protective of CAN interface as making this information available could be dangerous to vehicle operation and security. For the Wyoming CV Pilot, the CAN interface was not essential to the Wyoming CV Pilot system design. However, the New York City CV Pilot required a CAN bus interface to obtain additional information used to improve the location accuracy in the urban canyons. Their solution included a passive CAN bus interface device which allowed the OBU to monitor the data on the CAN bus without interfering with the operations on the CAN bus. The issue then becomes learning the codes used for the various data elements, and the OEMs do not make this information readily available, so it often needs to be reverse engineered which can take time and varies by make, model, and year.

Location Accuracy Design Considerations

- **Design 07: Assess GPS accuracy of OBUs in dense urban environments to determine whether a correction is needed.** Urban areas are known for its "urban canyons" which provide a challenging environment for GPS technology; be aware that the OBU certification is for GPS using open sky and requires 1.5-meter accuracy at 1 sigma (reference J2945.1). Additional techniques were required in the OBUs positioning algorithms to provide the accuracy needed for many of the V2V and V2I safety applications to function properly in the urban canyons. In New York City, augmentation of vehicle positioning was needed to provide continuous access to positioning data so that the safety applications could continue operating while the connected vehicles passed under bridges, elevated roadways, and while navigating the typical Manhattan streetscapes and traffic environment. The NYC Pilot vendors introduced a combination of supporting techniques to improve location accuracy, including RSU triangulation, dead reckoning, CAN bus integration for speed information, Inertial Measurement Unit (IMU) integration, and RSU time-of-flight feature.
- **Design 08: Embrace the challenge of establishing GNSS location accuracy (within 1.5m) in the urban canyon.** Limited open-sky conditions from high-rise buildings, bridges, roadway decks, and short tunnels hinder location accuracy of the GNSS chipset in the OBU. Test the location accuracy with GNSS and location augmentation mechanism(s) (i.e. dead reckoning, CAN bus integration for speed information, inertial management unit (IMU) integration, RSU triangulation, RTCM) on roadways closed to the public. Without location accuracy, many V2V safety applications (e.g., forward collision warning) will not work. While RTCM was considered and explored, the NYC CV Pilot site chose RSU triangulation as the method for improving the location accuracy for their system.

Application Trigger and Alert Considerations

- **Design 09: Establish a clear protocol for warning priority for when multiple warnings are triggered to avoid driver confusion.** The number of applications on an OBU can cause priority confusion to the driver, such as forward collision warning (FCW), electronic emergency brake light (EEBL) and end of ramp deceleration warning (ERDW) alerts. A clear protocol for warning priority is needed to avoid driver confusion. In addition, there may also be time constraints where words are used. For example, when issuing a warning, does a forward collision audio warning interrupt an EEBL audio warning? Do higher priority alerts stop the current message and immediately start the higher priority warning?

- **Design 10: Tune connected vehicle application alerts for factors impacting the system such as the roadway configuration, environment, and driver behavior.** Connected vehicle application alerts will generate different experiences for different drivers. Tune the applications for urban density and speeds to balance the number of alerts while reducing number of false alarms. Stage open-sky testing and urban-canyon testing separately. To account for differences between vehicles, operating environments and end user needs, all three CV Pilot Deployments have made the warning trigger points for the V2V safety applications a configuration setting that can be set via an over-the-air (OTA) update process. All three deployments evaluated the performance of these applications during their pre-acceptance and acceptance testing, which allows them to tweak these configurable thresholds to better suit the performance of their specific vehicles, environment and users. As an example, NYC is very concerned about triggering too many warnings that become a nuisance for drivers. They are conducting a silent period, where operational vehicles will record when warnings would be triggered, but do not actually present the warning to the drivers. This will allow them to identify if warnings are triggered too often and allow them to recalibrate the trigger points, so the drivers (or owners) do not disable or ignore the safety warnings.

- **Design 11: Tune the applications for the proper density and speed of the environment that you are deploying in.** In the absence of standard performance requirements for applications, it became evident that each CV Pilot vendor had their own interpretation and tuning of applications deployed. For NYC, it was key that the applications be tuned for urban density and speeds to balance proper alerts versus false alarms. In Wyoming, applications needed to be tuned for trucks and larger commercial vehicles. This required: (i) consistent expectations for the drivers about the sensitivity of the applications across all vendors, (ii) Performance tradeoffs, and (iii) Staging open sky testing (for baseline) and urban canyon testing. The THEA CV Pilot tuned their applications to balance between false positives and missing actual warnings. Agencies deploying connected vehicle applications should ensure that this level of fine-tuning is considered as part of their deployment efforts. It should be noted that tuning an aftermarket device is very different that the OEM's embedded device. The external device does not have access to all of the parameters available to the embedded device and hence the performance may be different than some of the demonstrations where the OEM device is used.

Other Design Considerations

- **Design 12: Augment connected vehicle solutions with more traditional ITS technologies where necessary.** For some use cases and specific applications, traditional ITS devices can be highly useful in supporting connected vehicle applications. For example, in the case of pedestrian detection for including the pedestrian in crosswalk warning in the SPaT message – the NYC CV Pilot used traditional ITS video technology to detect pedestrians in the cross walk. The THEA CV Pilot also deployed traditional ITS devices as part of their project – including cameras to determine queue length, thermal cameras for detecting wrong way drivers, and lidar to detect pedestrians. These devices were deployment to augment the connected vehicle technologies.

- **Design 13: Align antenna types to vehicle needs.** Two types of antennas may need to be considered and should be based on the feasibility and any limitations on vehicle types/makes/models and any other aftermarket equipment currently installed such as other radios, GPS, emergency light bars, etc.). Some deployments may require 2 DSRC, 1 GNSS antenna that may require either: (i) roof drilling/access or (ii) through the glass stub antenna.

- **Design 14: Leverage Over-the-Air (OTA) support networks for software/firmware updates.** Over-the-air (OTA) technology allows software and firmware updates to be rolled out to a connected vehicle remotely and eliminates the need to require a technician to physically install them in the vehicle. Such implementation is expected to be a game-changer for future CV deployers' vehicle fleet management. Enabling OTA updates was particularly critical for all three CV Pilot sites' deployment concepts due to: (i) the number of vehicles involved in the projects and (ii) the need to update software and application parameters during the operational phase. Many of the Pilot participant vehicles (e.g., taxis, buses, semi-trucks) have schedule and operational constraints that restrict them from coming into the maintenance shop for manual software updates. The sites thus performed extensive research, design and testing of their individual OTA mechanisms to accommodate these needs. While OTA provides opportunities, it is not without challenges. For example, it may be difficult for a vehicle OBU to download 100 megabytes of data over a 1.5-megabyte channel where the vehicle is only within a range of the RSU for a few seconds. For more information, visit: https://www.its.dot.gov/pilots/cvp_over_the_air.htm
- **Design 15: Secure a significant amount of time to review design documentation.** Reviews, updates, and discussion with vendors on System Design Documents (SDDs) and System Architecture Documents (SADs) take a significant amount of time. Time and effort are needed to nail down details about algorithms and integration points for wireless communication, OBUs, and RSUs. Since emerging technologies may not be well defined or tested, documentation is critical to fall back on to ensure vendors deliver products that meet user needs.

Design-related Resources

The following are documents that provide additional information related to design lessons learned and best practices:

- New York CV Pilot: Application Design Stage Webinar (June 26, 2018): Presentation Material and Recording
- New York CV Pilot: System Design Document: Document Forthcoming
- THEA CV Pilot: Application Design Stage Webinar (January 19, 2018): Presentation Material and Recording
- THEA CV Pilot: System Design Document: Document Forthcoming
- Wyoming CV Pilot: FHWA-JPO-17-468: System Design Document - WYDOT
- Wyoming CV Pilot: System Design Webinar (September 13, 2017): Presentation Material and Recording

Section 4: OBU Installation Lessons Learned and Best Practices

This section documents lessons learned and best practices for the installation of OBUs.

Personnel Resource Considerations for Installations

- **Installation 01: Ensure professional installations of OBUs in participant vehicles.** OBU installations should be done in a professional setting to prevent unintentional modifications or damage to vehicles. In particular, deployments with a large number of vehicles should utilize standardized installation and checkout procedures to ensure efficiency.
    - NYC used the City's mechanical installers for the installations of the OBUs on the NYCDOT fleet vehicles. NYC planned on contracting out the installation of their onboard devices for the nearly 8,000 vehicles to outside professionals after concluding that the City's mechanical installers had insufficient resources to address the fleet size within the time constraints.
    - The THEA team partnered with nearby Hillsborough Community College (HCC) to use their Master Mechanic Program facility and staff to install the OBUs, giving the students real-world experience and helping reduce labor costs.
    - WYDOT and their partner were each responsible for installing the OBUs in their own vehicles, though the team contracted with a local audio installer for the installations. WYDOT staff were used to install the OBUs in the WYDOT fleet vehicles.
- **Installation 02: Consider leveraging auto professionals to manage installations in private vehicles.** It is important to manage and perform installations of equipment in private vehicles in a professional manner and ensure that the installers have a good understanding of the in-vehicle needs. Technical staff may not be concerned with ensuring clean installations in private vehicles. When installing devices in private vehicles, a lot of attention is required because participants do not want sloppy installations in their vehicles.

Installation Timing/Scheduling Considerations

- **Installation 03: Consider the time needed for coordination of device installations.** The time for installation contract execution between the lead public agency and each OBU installation contractor can be more extensive than expected. Consider any forecasted delays in the contract process early in the project. It is also important to understand the vehicle availability logistics. If the size of the fleet is large, the installer needs to be assured of the uniform flow of vehicles for installation, testing, calibration, etc. as well as the availability of the installation "kits" and OBUs.
- **Installation 04: Conduct early, rudimentary installs early.** Conducting rudimentary installs early allows for quick basic testing. For the Wyoming CV Pilot, simple installations allowed the team to find problems early in the process including connections in OBU units, antenna issues, HMI placement issues, and interference with other devices. The THEA CV Pilot utilized their Friends of the Pilot (FOP) to work through installation issues/kinks. However, because the team did not know the make and model of a private vehicle that was coming in for installation, having a standard approach for consistent installs was difficult.

- **Installation 05: Fine-tune the installation by fleet vehicle type in the device prototype phase.** Each fleet vehicle class (light-duty sedan, light-duty truck, bus, truck, etc.) is different in size, configuration, use, etc. Different versions of the installation manuals/procedures should be generated for each fleet vehicle type. It should be noted that this may not be practical for private fleet installs since agencies may not know the make and model of a private vehicle that is coming in for and installation.
- **Installation 06: Conduct integration testing before private vehicle installs.** Complete integration testing before private vehicle installs begin. Once installations are completed in private vehicles, it is difficult to make any changes once deployed.

Battery and Power Considerations for Installations

- **Installation 07: Ensure that the vehicle battery (not hybrid battery) is disconnected before OBU installation.** After OBU installation and initial testing, the New York City team experienced the hybrid vehicle not starting. Several errors were issued by the vehicle including an error message to "Check the Hybrid System". After discussions with the vehicle OEM, it was discovered that the problem was caused by interruptions on the CAN bus – even though the ignition was off, some of the vehicle processors were still “active” in sleep mode and became corrupted. Before OBU installation, it is recommended that installers disconnect the vehicle battery. In addition, it is recommended that before starting any installation that the installer should clear all diagnostic trouble codes (DTC), and address any technical service bulletins (TSB). The Installers should consider avoiding OBU installation into any vehicle displaying a “check engine” or unresolved error codes to avoid any apparent relationship between the OBU and vehicle problems.
- **Installation 08: Be sensitive to the power drawn by in-vehicle devices to avoid vehicle power drain.** Fleet vehicle owners involved in the CV Pilots originally desired a zero quiescent current draw – but this was not feasible with the selected devices. As a result, the pilots restricted the current draw of their OBU vendors, with NYCDOT restricting their OBU vendors to a current draw of 25 micro-amps as noted in the SAE standards. To prevent subsequent maintenance issues, it was standard operating procedure for the installers to first check the vehicle’s electrical system (including battery and alternator/charger) before installing any connected vehicle equipment and installers would not proceed if any issues were found. Additionally, crews would not proceed with any installation when any vehicle’s indicator lights (e.g. check engine) were activated.

Antenna Installation Considerations

- **Installation 09: Refine proper antenna placement to reduce communications interferences.** The location of the antenna is critical to ensure continuous wireless communication without loss of signal strength. The New York City and Tampa teams found that for light-vehicles, antennas mounted near the rear-center of the rooftop was most ideal. However, large vehicles, such as the semi-trucks that the WYDOT pilot installed onboard units on, often have “self-blocking” physical elements that obstruct the vehicle’s own DSRC antennas from direct line of sight with other vehicles. This resulted in “shadows” for the Wyoming vehicles that prevented remote vehicles from properly communicating with the trucks. To alleviate this effect, the Wyoming team worked with USDOT’s communication experts to perform numerous tests in Wyoming and at the Aberdeen

Proving Grounds. The testing concluded that the effect of the DSRC shadows could be best alleviated by mounting the antennas on the side mirrors of the semi-trucks.

- **Installation 10: Check antennas for faulty sealing.** Some CV Pilot sites found a seal missing for the shark fin antennae that allowed water to leak inside the vehicle. They adopted a routine pressure test to confirm the seal problem and thereafter all antennas were tested to make sure the seal was properly installed. Failure to ensure a tight seal could cause damage to the antenna, or if mounted on roof, may leak inside vehicle.

Participant Engagement Considerations

- **Installation 11: Develop a structured process to engage with participants for installs on private vehicles.** The THEA CV Pilot developed a structured process for engaging with participants for installs. This process is summarized below:
    - Prior to installation. Potential participants sign up online and fill out a survey that provides installers with details about their vehicle. This information is used to determine if the vehicle can participate in the pilot. Some disqualifying features include removable roofs, all-glass roofs, safety systems implemented in the rear-view mirror, etc. Once the vehicle is approved, the participant is able to come in for an installation.
    - Participant appointments. A two-hour appointment block is required for: (i) Inspection of the vehicle, (ii) installation of antennas, on-board units, and rear-view mirrors to the participant's approved vehicle, (iii) training session for the participant on the usage and intended reactions regarding the equipment and safety messages they will receive, and (iv) Receipt and signature by the participant of an informed consent document regarding their participation in this human use study.

- **Installation 12: Ensure that OBU and vehicle information from the asset management system is readily available on the OBU for device management and tracking.** To ensure information is included in the asset management system, the installer needs to enter inventory information including vehicle registration, ownership (DOT property), type, model, year, DOT vehicle #, VIN, and contact information for returning the OBU in case it is lost. The installer should be required to enter device information into the asset management system, print out the label, and put it on the OBU.

Other Installation Considerations

- **Installation 13: Consider using a cover over the OBU and existing connectors to protect them from water damage or liquid spill.** The OBU in the vehicle may be placed underneath the car seat which makes it susceptible to damage from getting wet. Consider adding a cover over the OBU and existing connectors to protect them from water damage or liquid spill.

- **Installation 14: Pre-configure the OBU XYZ measurements prior to completion of the physical installation.** Consult vendors to pre-configure the XYZ values in the OBU and request that the vendor preset the XYZ measurements to ensure that the OBU is ready for installation by the technicians. Otherwise, the technician will need to log into the OBU to configure the XYZ values using the device's command lines. OBUs will come with a configuration program which runs on a laptop that allows the installer to configure all of the parameters including antenna location, vehicle make/model/year, group identification, etc. Installers will need to establish a configuration database for each vehicle make/model/year and antenna mounting that they can invoke at configuration time – and we continue to increase the available vehicle selection. It is important that this information be double checked.

- **Installation 15: Perform appropriate calibration procedures for all onboard technologies.** Following the installation of the devices in private vehicles, the Tampa installation crews drove the vehicles in "figure 8's" to calibrate the accelerators in the OBUs. However, this method was not a practical approach for the NYC vehicles, especially with their MTA buses. NYC later proposed mounting an OBU on a gimbal with a known orientation for proper calibration. Additionally, NYC had their vendors provide a calibration indication to their device's system logs at each start-up. It is recommended that a location calibration "location" be established at the installer that can be used to confirm the accuracy of the vehicle location sensors and algorithms. The vehicle then needs to be calibrated and checked by positioning it at the "location" and monitoring the BSM.

- **Installation 16: Check vehicles for pre-existing safety systems that may interfere with an evaluator's ability to isolate impacts of the connected vehicle applications.** If an evaluation is being performed, it is strongly recommended that aftermarket connected vehicle technologies not be installed on vehicles that have existing safety system since many of the warning types will be redundant with the connected vehicle safety applications. Having redundant technologies that serve the same purpose on the connected vehicle-equipped vehicles will interfere with an evaluator's ability to isolate impacts of the connected vehicle applications. NYCDOT confirmed that their partners Metropolitan Transportation Authority (MTA) and the Taxi and Limousine Commission (TLC) had some vehicles fit with preexisting safety systems. The NYC Pilot requested that MTA vehicles with these systems be excluded from the Pilot. However, the same blanket-ban was not able to be made for the TLC vehicles as the taxis have different owners. To address the issue of redundant safety systems in the TLC vehicles, the NYC team provided installers with a pre-install checklist that included a check item for pre-existing safety systems. If such pre-existing safety system were found during installation, an OBU was not installed on the vehicle.

- **Installation 17: Permit special considerations for snowplows.** Installing OBUs in snowplows have unique challenges and require additional configuration. For example, not all snowplows have metal roofs, which created challenges for the WYDOT CV Pilot since the antenna base was magnetic. In addition, the plow cab is not the high point of the vehicle. This causes challenges since the antenna had to have clear line of sight when mounted directly on the roof. As a result, the Wyoming CV Pilot team had to raise the antenna high. Roof installations also required the installs to be placed in roof ribs for plows.

Installation-related Resources

The following are documents that provide additional information related to installation lessons learned and best practices:

- New York CV Pilot: FHWA-JPO-17-455, Comprehensive Installation Plan - NYCDOT
- New York CV Pilot: Device Acquisition and Installation Experiences Webinar (July 30, 2018): Presentation Material, Recording and Q&A Notes

- THEA CV Pilot: FHWA-JPO-17-463, Comprehensive Installation Plan - Tampa (THEA)
- THEA CV Pilot: Device Acquisition and Installation Experiences Webinar (August 7, 2018): Presentation Material, Recording and Q&A Notes
- Wyoming CV Pilot: FHWA-JPO-17-471, Comprehensive Installation Plan - WYDOT
- Wyoming CV Pilot: Device Acquisition and Installation Experiences Webinar (July 23, 2018): Presentation Material, Recording and Q&A Notes

Section 5: OBU Testing Lessons Learned and Best Practices

This section documents lessons learned and best practices for the testing of OBUs.

Overarching Testing Considerations

- **Testing 01: Perform detailed testing required for OBU and RSU software and hardware.** Connected vehicle software from vendors may be immature. As such, it is important to account for detailed testing of all software, and even the hardware. For mature, existing applications, agencies should consider purchasing proof of concept devices to begin testing early in the process and notify and work with vendors to address shortcomings. If new applications are being developed, it will be difficult to prototype and test.
  As with any similar device, it is important that the testing include the "edge" conditions and "corner cases" – to make sure that the device does not take inappropriate action when confronted with such situations. The device must always recover without any operator interaction. It is also recommended that various types of power interruption testing be performed on a larger sample of units to ensure that regardless of the repetition rate, time between outages, and battery disconnection and reconnection, the unit always recovers and proceeds once power is stable.
- **Testing 02: Ensure rigorous requirements verification and acceptance testing.** Systematic acceptance testing and requirements verifications should be performed throughout development, integration, installation, and deployment. Systems readiness (at each level of development and integration) is measured by completion and internal approval of:
  - Test cases and procedures
  - Requirements verification
  - Passing of acceptance test
  - Test results report
- **Testing 03: Conduct testing early with actual infrastructure.** Conduct testing early with real-life, actual infrastructure to verify end-to-end system/application performance (over-the-air updates, data management, security, etc.). New development efforts such as over-the-air updates and connected vehicle security need to be piloted/tested early in the program.
- **Testing 04: Complete testing of individual components of the system prior to system-level testing.** Testing the individual components and verifying the messages coming in and out of each unit provides a better understanding of the failures in the system, if any arise during use case testing. Define procedures for testing individual components prior to those for system-level testing.
- **Testing 05: Give a considerable amount of attention to testing prior to devices becoming operational.** To ensure the safe operation of connected vehicle technologies, the CV Pilot sites conducted rigorous testing – including an Operational Readiness Test – prior to the technologies becoming operational. The purpose of this rigorous testing was to ensure that devices operated safely and performed in accordance to the requirements. For Example, New York City testing included:
  - Functional V2V Tests

  - Functional V2I Tests
  - OTA – Uploading Tests
  - OTA – Downloading Tests
  - Radio Frequency (RF) Receiver and Transmitter Tests
  - Tests to Validate Data Collected
  - Operational Stability Tests
  - Security Support Test
  - Power Consumption Tests
  - Startup-shutdown - Power Interruption Tests
  - Routine Environmental, Shock, and Vibration Tests

- **Testing 06: Understand that testing for Pilot does not equal testing for scale.** There can be gaps between testing and operating at scale. Examples are summarized below:
  - If a device works on cars it should not be assumed that it will operate properly on trucks. In addition, many standards and solutions may not fully apply—e.g., antenna location.
  - As data volumes increase (e.g., more BSMs are sent to devices), devices may not operate properly or as expected.
  - Agencies need to consider OBU's failing at scale (e.g., numerous deployed devices requiring updates) as this may require a large number of either hardware or firmware updates.
  - Technical challenges exist in ensuring a secure network—e.g., SCMS integration and firewall compatibility.
  - There are likely to be stability challenges with software/code (e.g., crashes, GPS not coming online, HMI disconnecting, offloading random, etc.).
  - Consider that having a few RSUs and a few vehicles is very different than seeing 20-30 RSUs all broadcasting various WSAs and SPaT and MAP messages along with 100 vehicles within range. Several issues of overloading the OBU were discovered as the data logging and number of messages arriving for processing caused problems for the OBU.
- **Testing 07: Perform multiple/regression testing to verify that a previously tested system still performs the same way after changes were made in the field to another component.** Some fine tuning may make one part (one OBU type) of the system work, but this can result in other elements (other OBU types) failing. Make sure to test other parts of the system again after changes are made. Conduct multiple tests to show system stability.
- **Testing 08: Continually test systems and check their requirements.** Software and hardware might not be fully compliant with the requirements at the beginning of the development process. It is important to track closely their improvement, and make sure to test any updates against requirements. The NYC CV Pilot established a field testing environment around the City offices in Queens and the City staff check the operation of all of the applications on a continuous basis to determine if any changes made in the firmware have had an impact on the apparent reliability or operation of the various applications. Since the NYC CV Pilot had 13 applications, testing was been extensive.

- **Testing 09: Examine all possible root causes before power-cycle/reset/reboot of the device.** As part of device and network troubleshooting, devices were power cycled/reset/rebooted in order to minimize the down time. However, the determination of root causes and resolution/mitigation measures were not immediately considered. Log and monitor all possible root causes and resolution/mitigation measures for each device in the system. In some cases, if the vendor debug log is not downloaded before the next time the vehicle is used, it will be lost.

Testing Location Considerations

- **Testing 10: Arrange a testing location that can accommodate the necessary test runs.** Testing should occur in a closed environment that is sufficiently large. A large, closed environment is needed to support safe testing of V2V and V2I safety applications. NYCDOT made available a test location within the Aqueduct Racetrack parking lot to demonstrate their connected vehicle applications. Through partnerships, WYDOT was able to perform testing on tracks owned by the Office of Emergency Management. THEA was able to close its Reversible Express Lanes for the testing and demonstration of their connected vehicle technology.

Tools Considerations for Testing

- **Testing 11: Leverage Radio Frequency (RF) tools to support testing.** It is important to obtain RF tools (interference detection, protocol analyzers, GPS repeaters, etc.) early for testing. Test Tools should be required from each vendor. Agencies should work with the vendors to leverage tools they may have that allow you to collect and visualize the data; all of the pilot project purchased a “sniffer” which allowed them to monitor the transmissions from both the OBU and the RSU.

- **Testing 12: If using licensed spectrum, consider purchasing interference tracking equipment to detect potential interference from other users in the 5.9 GHz band that can compromise data exchange.** Though the FCC originally allocated the 5.9 GHz band for DSRC-based ITS applications, in 2013 the FCC proposed allowing unlicensed devices to share the spectrum with primary users as long as they were not found to be interfering with the primary DSRC users. During the deployment period, THEA detected and tracked down an interference on their DSRC communication channels coming from a local amateur radio operator. While the ham radio could not receive DSRC radio messages due to the far lesser range of DSRC, THEA’s DSRC radio would receive the ham radio messages, causing the DSRC radio to consider the channel “busy” and not “clear to send”. The additional signal on THEA’s channels impacted the performance of their equipment in terms of data exchange and back haul speed, with testing indicating a degradation in data uploads by up to 50%. Upon review of these findings, Florida Department of Transportation (acting as the enforcement agency) ordered the amateur radio operator to vacate the channel. Due to the scale of the NYC deployment, the NYC team invested in the purchase of sophisticated interference checking and RF spectrum analysis equipment. This equipment will allow them to locate and quantify field interference with GNSS and DSRC and to confirm the failures of the OBU and RSUs in the event of a suspected failure.

Antenna Testing Considerations

- **Testing 13: Conduct extensive antenna testing on semis/trucks.** The Wyoming CV Pilot team conducted extensive testing of their antennas by testing all available antennas on all configurations of vehicles. This included testing both pole and shark fin antennas on semis out to 300 meters and ensuring that cables and antennas were reliable.

- **Testing 14: Conduct extensive OBU antenna durability test.** In New York, the deployment team worked closely with the Metropolitan Transportation Authority (MTA) and the OBU vendor to improve the reliability of the through the glass antenna mounting used on the MTA buses. The buses go through a “brutal” bus-wash which was breaking or tearing off. Eventually, design improvements – including improved adhesives, better cleaning, and protection on the springs and mounting – resolved the issue so that the antenna is now mounted through the glass on the center front of the bus.

Data Upload, Download, and Offloading Testing Considerations

- **Testing 15: Test the OTA download and upload mechanisms before extensive installation of the OBUs (and RSUs).** OTA download and upload were tested through several scenarios including stationary vehicles, moving vehicles in contact with single or multiple RSUs, and interrupted data connection. File sizes were varied to evaluate the expected application/media performance in consideration of the contact time between OBU and RSU that will vary by location. It was concluded that the NYC CV Pilot project's objectives for managing the vehicle fleet's firmware, configuration files, and data logs can be met at the proposed RSU support locations in the pilot area. The NYC CV Pilot team worked with the OBU and RSU vendors to conduct the OTA testing in Atlanta's test environment. They will use the test results for RSU installations under various operating scenarios for deployment throughout the NYC pilot area.

- **Testing 16: Test log offloading from OBU to TMC performance.** It is important to test the speed of log file offloading at highway speed, as this can be unreliable. Agencies should work with their vendor to test the successful offloading of data.

Other Testing Considerations

- **Testing 17: Test for RSU Traveler Information Message (TIM) transmission range.** During testing, the CV Pilots encountered some range issues with sending TIMs to vehicles. It is important to test the range of RSU to OBU communication. It is recommended that agencies work with their vendor to test and verify configuration to ensure successful transmission range.

- **Testing 18: Test other connected vehicle hardware elements.** Exposure to weather conditions can also impact connected vehicle technology and hardware. For example, one deployer found that other connected vehicle hardware elements, such as the seal for antennas, should also be tested to ensure the hardware is equipped to withstand weather conditions. Missing elements can expose the equipment to water damage. For devices that required drilling through the glass or vehicle. Water was found to be leaking into the vehicle interior from the antenna. If this type of configuration is used, the team should ensure that the antenna dome seal to the base plate is properly sealed.

Testing-related Resources

- New York CV Pilot: Update at the Operational Readiness Milestone (March 11, 2019)
- THEA CV Pilot: Update at the Operational Readiness Milestone (March 11, 2019): Presentation Material and Recording
- Wyoming CV Pilot: Update at the Operational Readiness Milestone (July 18, 2019): Presentation Material and Recording

U.S. Department of Transportation
ITS Joint Program Office – HOIT
1200 New Jersey Avenue, SE
Washington, DC 20590

Toll-Free "Help Line" 866-367-7487

www.its.dot.gov

FHWA-JPO-20-786

U.S. Department of Transportation