5.9 GHz Dedicated Short Range Communication Vehicle-based Road and Weather Condition Application

Project Documents:
- Final Report
- Concept of Operations
- Messaging Requirements
- Test Plan
- Installation Guide

August 2015

Prepared For:
Connected Vehicle Pooled Fund Study

By:
Synesis Partners LLC
5.9 GHz Dedicated Short Range Communication Vehicle-based Road and Weather Condition Application

Final Report

Version 1.0

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REVISION HISTORY

<table>
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EXECUTIVE SUMMARY

The objective of this Connected Vehicle Pooled Fund Study (CVPFS) project is to develop and test the acquisition of road and weather condition information on public agency vehicles and transmit it to roadside equipment over 5.9 GHz Dedicated Short-Range Communications (DSRC). The project consisted of four tasks that included activities needed for this and any other similar CV application development initiatives:

**Task 1 – Requirements Development** described the data elements and data sets desired for the road weather applications; determined what weather-related data are actually available on each of the vehicles; and identified what additional sensors and equipment would be needed to provide the desired data sets. The output of this task is documented in a *Messaging Requirements* specification.

**Task 2 – Concept of Operations** developed a *Concept of Operations* (ConOps) for collecting and processing the data on the DSRC on-board equipment (OBE) and sending the data to the roadside equipment (RSE). The ConOps includes use cases, a description of the system architecture, and high-level system requirements.

**Task 3 – Application Development** specified the DSRC equipment, developed the OBE, RSE and data transmission components, and determined any adaptations needed to support integration with existing New York State DOT DSRC deployments on the Long Island Expressway.

**Task 4 – Application Installation and Testing** procured equipment, selected deployment sites, assembled and tested the system hardware and software in preparation for New York State DOT deployment. Testing parameters are documented in a *Test Plan*, and the deployment process is described in an *Installation Guide*.

Hardware procured for the project included six DSRC OBEs from Cohda Wireless, three DSRC RSEs from Savari, and two High Sierra IceSight mobile road weather sensor units to provide additional on-board data gathering. The software developed in the project for the OBE can be configured to collect data from the vehicle’s Controller Area Network (CAN) bus, the aftermarket IceSight device, and Dickey John road treatment equipment (if present), in addition to the Global Positioning System (GPS). Data are transmitted to the DSRC RSE using IPv6 messaging, and are stored as files on the RSE. Data can be retrieved from the RSE by agency network administrators and systems over a backhaul connection.

Several development and deployment challenges were raised and overcome. In particular, agencies deploying the DSRC-based road weather system and similar CV
applications will want to assure that DSRC components are fully standards-compliant and meet the application functional requirements, and that sufficient IPv6 knowledge and skills are available to support deployment and operations.
1 INTRODUCTION

1.1 Purpose

The purpose of this document is to provide a summary report of project findings and experience for the 5.9 GHz Dedicated Short Range Communication (DSRC) Vehicle Based Road and Weather Condition Application developed for the Connected Vehicle (CV) Pooled Fund Study (PFS). The report summarizes project activities and work products created throughout the project, including: the Concept of Operations; Messaging Requirements; the system software, hardware, and communications interfaces for the vehicle on-board and roadside equipment; an Installation Guide; backhaul communications networking experience; and a Test Plan for a future deployment.

1.2 Background and Scope

Significant effort has been and continues to be expended in the Federal Highway Administration’s (FHWA) Road Weather Management Program and in various federal and state connected vehicle programs to identify opportunities to acquire data from vehicles acting as mobile sensor platforms. Federal, state and local transportation agencies have also been working with automakers and communications technology providers to develop and standardize information exchange between vehicles and the transportation infrastructure, enabling a variety of applications that could improve transportation safety, mobility and environmental performance. This 5.9 GHz DSRC Vehicle-based Road and Weather Condition Application project is a synergistic result of those converging opportunities.

Accurate, timely and route-specific weather information allows traffic and maintenance managers to better operate and maintain roads under adverse conditions. The research system developed by this project enables collection of vehicle-based probe and observation data from mobile sensors on transportation agency vehicles and transmission of the data over DSRC to roadside units from where it can be accessed by agency systems such as the New York State DOT INFORM. In this way, information from mobile platforms will eventually enable traffic managers and maintenance personnel to implement operational strategies that optimize the performance of the transportation system by mitigating the effects of weather on the roadways.

Potential use case scenarios for the system are well known from previous connected vehicle and road weather research. All connected vehicle applications make use of and depend on probe data, but six high-priority connected vehicle road weather
applications were specifically identified in the Concept of Operations for Road Weather Connected Vehicle Applications\(^1\). Many of these applications/use cases recognize agency vehicles, including snow plow and maintenance trucks, as key sources of connected vehicle road-weather data, particularly since they are logical candidates for the installation of specialized sensors that will generate data sets that will be unavailable from vehicles in the general public fleet. Other use cases/applications are focused on delivering data to agency vehicles, especially for winter maintenance decision support and for maintenance management systems. The six road weather applications are:

- Enhanced Maintenance Decision Support System
- Information for Maintenance and Fleet Management Systems
- Variable Speed Limits for Weather-Responsive Traffic Management
- Motorist Advisories and Warnings
- Information for Freight Carriers
- Information and Routing Support for Emergency Responders

Within the greater connected vehicle context, the scope of this project is to develop, test, and prepare to deploy in-vehicle and roadside components with 5.9 GHz DSRC capabilities for road and weather condition data in maintenance and highway emergency local patrol (HELP) vehicles. The system is capable of obtaining vehicle data from SAE J1939 and J1979 diagnostic buses and various peripheral devices on maintenance vehicles; transmitting this data from 5.9 GHz DSRC on-board equipment (OBE) to compliant roadside equipment (RSE)\(^2\); and providing the data on the roadside equipment to agency systems when requested. It is envisioned that this application could be deployed on agency maintenance vehicles of the members of the CV PFS along connected vehicle test beds.


\(^2\) The DSRC community vernacular refers to the on-board radio unit as an “OBE” and the roadside radio unit as an “RSE”. This is somewhat confusing since there are other on-board equipment and roadside equipment components other than the DSRC radios. “OBE” and “RSE” will be used in this report to refer specifically to the DSRC units, and “on-board equipment” and “roadside equipment” will be used to refer to the equipment more generally deployed in those locations.
1.3 Definitions, Acronyms, and Abbreviations

This document may contain terms, acronyms, and abbreviations that are unfamiliar to the reader. A description of these terms, acronyms, and abbreviations is provided in Appendix A.

1.4 References

The following documents contain additional information pertaining to this project and the requirements for the system,

5.9 GHz Dedicated Short Range Communication Vehicle Based Road and Weather Condition Application Concept of Operations, May 2013, Synesis Partners LLC.

5.9 GHz Dedicated Short Range Communication Vehicle Based Road and Weather Condition Application Messaging Requirements, May 2013, Synesis Partners LLC.

5.9 GHz Dedicated Short Range Communication Vehicle Based Road and Weather Condition Application Test Plan, December 2013, Synesis Partners LLC.

5.9 GHz Dedicated Short Range Communication Vehicle Based Road and Weather Condition Application Installation Guide, August 2015, Synesis Partners LLC.


1.5 Overview

The remaining sections of the document describe each of the three major system interfaces and their potential use in connected vehicle.

Section 2 – Application Planning and Specification summarizes the basis for and content of the system Concept of Operations and the Messaging Requirements. These documents were generated early in the project and have been published as independent work products.

Section 3 – System Implementation describes the system OBE and RSE implementations in terms of its hardware, software, and interfaces.

Section 4 – Deployment summarizes the system in-vehicle and roadside installation (for which an Installation Manual is provided as a separate work product), describes the supporting backhaul network, and summarizes the system Test Plan (also available as a separate work product).
Section 5 – Analysis and Recommendations discusses key project findings and suggests topics for further investigation.
2 APPLICATION PLANNING AND SPECIFICATION

Development of the 5.9 GHz DSRC vehicle-based data acquisition system in this project began with a Concept of Operations and an analysis of Messaging Requirements. The purpose of these tasks was to identify existing and applicable CV research and standards, and then describe the means of applying the research and standards to acquiring the data over DSRC for CV applications. The gaps between the existing needed capabilities would define the particulars for new development.

2.1 Concept of Operations

The Concept of Operations developed for this project describes concepts for a system to support road weather operations using 5.9 GHz DSRC for mobile data gathering. It is based largely on descriptions of the current situation and justifications for change detailed in the Concept of Operations for Road Weather Connected Vehicle Applications mentioned in the Introduction to this report. That document describes six road weather-related application concepts and scenarios in which data from vehicles might be used to improve safety, agency operations and traveler information. The concepts and operational scenarios for this project’s DSRC-based application more specifically describe a 5.9 GHz DSRC implementation for New York State DOT (NYSDOT) snow plow trucks and HELP vehicles operating along and near the Long Island Expressway from which data might be used in agency operations and traveler information systems.

As is often the case with research of this type, the scope and particulars of the demonstration application changed over the course of the project. It became clear that demonstrating particular applications of the gathered data was less useful than a more complete and flexible implementation of the ability to obtain data from various vehicle data sources, assemble the appropriate data messages for DSRC transmission, and store the data on the RSE for later retrieval. For example, it was decided during the conduct of the project to add an additional data source—an IceSight mobile weather data sensor—to the vehicle configuration and on-board data acquisition, exercising different device connection, protocols and data formats for the OBE. By contrast, the back-end network acquisition of the data from the RSE and its use in potential CV applications—by NYSDOT’s INformation FOR Motorists (INFORM) system, for example—does not differ significantly from use cases for more traditional road weather information systems. As such, the overall implementation scope of the application was pared back, with a corresponding increased focus on generalizing the on-board data collection, the

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data transmission over DSRC, and the staging of data on the RSE for use by others. The final implementation concept as illustrated in Figure 1 emphasizes the DSRC components and communications, and defers the application to the particular agency deployments. Data collected on the RSU can be retrieved over a network connection by distributor(s) and applications as the need arises, but there is no data “push” from the RSU.

![Symbols Key](Labels: Implemented, Deferred)

![Diagram: DSRC Components and Communications](RSU to Connected Vehicle, RSU to Distributor(s), Distributor(s) to Weather Data Users, INFORM, NYS DOT Maintenance Management)

**Figure 1 - System Concept Interactions (Source: Synesis Partners LLC)**

This refocus and deferment is reflected in the application scenario as well as in the system concept. Whereas the more extensive scenario in the ConOps includes steps describing data flowing out to NYS DOT’s INFORM system, the application scenario as implemented is focused on the DSRC interaction:

1. Vehicles equipped for connected vehicle data gathering operate on the roadways
2. Sensors on the vehicle measure and record data, in some instances reporting data to the vehicle’s data bus (typically a Controller Area Network (CAN) bus)
3. The vehicle’s OBE obtains weather-related data from sensor systems and the data bus, when available
4. OBE formats data snapshots into probe data message(s)
5. OBE stores probe data message(s) for transmittal
6. Vehicle comes in range of RSE; OBE receives service announcement from RSE
7. OBE broadcasts probe data message(s) to RSE
8. RSE stores probe data message(s)
Data can then be retrieved from the RSE by any system with appropriate access permissions through the data interface described later in this report.

2.2 **Messaging Standards**

The Messaging Requirements developed for this project addressed application of the DSRC standards, device interfaces and data element definitions for data acquisition and communications. As was the case for the ConOps, the purpose was to identify the relevant standards and describe their application in the context of this project, rather than to develop any new standard(s) unique to the project. Lists and descriptions of applicable data standards and data elements were included in the document. Table 1 summarizes the applicable standards and their relevance.

**Table 1 - Applicable Messaging Standards (Source: Synesis Partners LLC)**

<table>
<thead>
<tr>
<th>Standard</th>
<th>Title</th>
<th>Relevance</th>
</tr>
</thead>
<tbody>
<tr>
<td>IEEE 802.11p</td>
<td>Wireless Access in Vehicular Environments</td>
<td>Specifies the extensions to IEEE Std 802.11 for wireless local area networks (WLANs) — the radio standard—providing wireless communications while in a vehicular environment</td>
</tr>
<tr>
<td>IEEE 1609.x</td>
<td>Wireless Access in Vehicular Environments (WAVE)</td>
<td>Set of standards describing protocols for WAVE messaging</td>
</tr>
<tr>
<td>IEEE 1609.3</td>
<td>Wireless Access in Vehicular Environments (WAVE) – Networking Services</td>
<td>The 1609 standard describing the use of Internet Protocol (IP), User Datagram Protocol (UDP), and Transmission Control Protocol (TCP) in WAVE</td>
</tr>
<tr>
<td>SAE J1939</td>
<td>Serial Control and Communications Heavy Duty Vehicle Network (Top Level Document)</td>
<td>Describes the vehicle data network, layer structure, documentation, and pre-assigned data elements for heavy vehicles</td>
</tr>
<tr>
<td>SAE J1979</td>
<td>E/E Diagnostic Test Modes [Ed. Note: E/E in this context is Electrical/Electronic]</td>
<td>Describes light vehicle On-Board Diagnostics (OBD) services, messaging and data availability</td>
</tr>
<tr>
<td>SAE J2735</td>
<td>Dedicated Short Range Communications (DSRC) Message Set Dictionary™</td>
<td>Specifies a message set, data frames and elements for applications using 5.9 GHz DSRC/WAVE</td>
</tr>
</tbody>
</table>

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Exhaustive lists of the road weather-related data elements described in these standards were provided in the appendices to the Messaging Requirements document. Analysis revealed three potential gaps in the specifications: data elements defined by the J1939 and J1979 vehicle standards missing from the J2735 DSRC messaging standard; data elements defined in J2735 but missing from J1939/1979; and elements available from third-party equipment that is not explicitly specified in J1939, J1979, or J2735. The messaging requirements stated that all available data elements would be accommodated in the outgoing OBE messages and specified the use of the DSRC Basic Safety Message (BSM), with its optional free-form “local” content field for non-standard data.

Using the BSM in this manner did not, however, prove to be feasible with the available DSRC OBEs and RSEs. As shown in Table 2, Versions of the DSRC components available during the course of the project supported only the BSM Part 1 and not the extended BSM Part 2 capabilities. (Even if they were supported, BSM Part 2 did not support all of the potential or desirable data elements.) Forwarding of BSM messages from the RSE to back office systems was supported in the Ann Arbor Safety Pilot demonstration, but not guaranteed to be available on future generations of RSEs. The availability of other potential DSRC messaging services—the Probe Vehicle Data Message (PVDM) and the A la Cart Message—was similarly questionable on current and future equipment.

The best option for fulfilling the project intent to acquire and send the available weather-related data was determined to be compiling the data on the OBE into records in a simple comma-separated variable file for transmission over the DSRC Internet Protocol (IP) service to the RSE. Although this approach did not take advantage of any of the particular DSRC messaging services, it does have the advantage of being somewhat portable—that is, independent of the availability of any particular DSRC service other than IP—between and among OBEs and RSEs.

Using the DSRC IP services and a simple comma-separated value (CSV) file has an additional advantage of providing flexibility to use the data payload for whatever vehicle data may be available and desired. The utility of the application is thereby extended beyond the original specified purpose of collecting road weather data and becomes a generalized tool for other potential CV applications. The system implementation that enables the data payload to be configured for gathering generalized vehicle probe data, including road weather-related data, is described in Section 3.
### Table 2 - Messaging Requirements Options (Source: Synesis Partners LLC)

<table>
<thead>
<tr>
<th>Message/Function</th>
<th>This Project</th>
<th>Future Deployments</th>
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<tbody>
<tr>
<td></td>
<td>J2735 2009</td>
<td>Cohda OBE MK2</td>
</tr>
<tr>
<td>BSM Part 1</td>
<td>●</td>
<td>○^5</td>
</tr>
<tr>
<td>BSM Part 2</td>
<td>●</td>
<td>○</td>
</tr>
<tr>
<td>PVDM</td>
<td>●</td>
<td>○</td>
</tr>
<tr>
<td>IP [Secure Shell (SSH)]</td>
<td>n/a</td>
<td>●</td>
</tr>
<tr>
<td>WAVE Message Forwarding</td>
<td>n/a</td>
<td>n/a</td>
</tr>
</tbody>
</table>

**Table Key:** ● - supports the message type/function; ○ - does not support the message type/function; ○ - partially supports the message type/function; n/a – message/function not applicable to this standard/component

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5 The Cohda Mark2 OBU natively supports the “Here I Am” implementation of the BSM Part 1 (i.e., without the optional J2735 optional elements; the BSM Part 2 is not supported.

6 The Savari RSU 3.x provides non-standard BSM validation as implemented for the Safety Pilot Demonstration.

7 Per the RSU 4.x specification, the Savari RSU 4.x forwards the BSM and all other WAVE message types according to its configuration settings.

8 The Savari RSE 3.x supported a non-standard BSM forwarding for the Safety Pilot Demonstration; it did not support the standard forwarding of other WAVE messages as specified in the 4.x specification.
3 SYSTEM IMPLEMENTATION

As discussed in the Concept of Operations, the deployment concept for the system consists of on-board equipment capable of acquiring, caching, formatting and sending data from the vehicle over DSRC to roadside equipment from which other agency systems can in turn acquire the data for use in connected vehicle applications. This section of the report describes the implementation of the vehicle on-board and roadside component hardware, software, and interfaces. All implemented hardware and software has been delivered to New York State DOT.

Figure 2 - Conceptual System Deployment (Source: Synesis Partners LLC)

3.1 Vehicle On-board Components

The vehicle on-board components are illustrated in Figure 3 for the light commercial vehicle (in this case, a Ford F250 or F350) and the heavy vehicle (a Mack truck). Connections to the DSRC OBE provide power, access to communication antennas, and data connections to on-board sensors. Sensor connections are made to the vehicle data buses (J1979 OBD-II on commercial light vehicles and J1939 on heavy vehicles); to the Dickey John plow and treatment equipment; and to the IceSight road weather sensors. The on-board equipment consists of the DSRC OBE, with the application software; the OBE’s associated DSRC/Global Positioning System (GPS) antenna; the ChargeGuard vehicle power interface; a cable to connect the OBE to the vehicle data bus; a serial DE9 cable to connect the OBE to a Dickey John road treatment system (if present); and an
Ethernet serial cable to connect the OBE to an aftermarket IceSight sensor unit (if present).

Functionally, the OBE reads the desired data as specified in the application configuration file\(^9\) from the CAN bus and other devices on the connected vehicle. The software formats those data into a CSV file that includes header information defining the tabular data. If the OBE is not within range of an RSE, as determined by the absence of a WAVE Service Announcement, the data are stored for transmission at a later time. When an OBE detects the presence of a WAVE Service Announcement, vehicle-derived data are transmitted in last-in-first-out order so that the most recent data are sent to the RSE first. Data files stored on the OBE are deleted upon successful transmission to an RSE. If storage on the OBE becomes scarce because of lack of contact with an RSE, the oldest data files are deleted to make room for newer data.

Figure 3 - Vehicle On-board Components (Source: Synesis Partners LLC)

3.1.1 OBE Hardware

The OBE hardware collectively consists of the components that together integrate DSRC radios to vehicle data sources. The core of OBE is the OBU itself. This device is an embedded computer with the processor, memory, storage, and application software in an aluminum enclosure that also contains interface hardware for DSRC radio, GPS, CAN bus, Ethernet, and serial data. DSRC and GPS radios are connected to a combined external antenna with quick-connect automotive standard terminations. Serial data sources are connected using common DE9 serial cables and Ethernet network connections use readily available RJ45 CAT5 (or higher) cabling.

\(^9\) The desired data and sampling frequency are configurable by the system manager using the specification described in Section 3.1.4 of this document.
The OBU is connected to the vehicle CAN bus with cables assembled as described in the installation guide. There are two types of CAN bus cables: one for light vehicles that are terminated with an OBD-II style low profile connector, and the other with a heavy vehicle J1979 connector. The OBU side of the CAN bus cable is similar to the serial data connection, except that it is a DE9 male termination.

Power is wired directly to a ChargeGuard power management module through the exposed power supply wires from the CAN bus cable. The OBU input power is terminated via a 4-pin Molex connector directly wired to the power management module output.

Figure 4 - Heavy Vehicle OBE, Antenna and Cables (Source: Synesis Partners LLC)
3.1.2 IceSight

The High Sierra Electronics IceSight (Model 2020S) mobile road weather sensor device (Figure 6) procured for this project provides data to supplement those available from a vehicle’s on-board sensors. The device is intended by NYSDOT for deployment on one of their heavy snow plow trucks and will provide road surface temperature, air temperature, relative humidity, surface state (dry, damp, etc.) and surface grip data. The IceSight device is connected to the OBU with an Ethernet cable.
3.1.3 OBE Software

The OBE software includes modules provided by the manufacturer and those developed specifically for this project. As shown in Figure 7, these software modules are the operating system; the WAVE Basic Service Set (WBSS) that supports the DSRC messaging; the Startup script that identifies and initiates the system modules; the Upload module that manages interactions with the RSE through the WBSS; and the Road Weather (RdWx) application that manages the data processing for the connected data sources.

The Cohda RSU procured for this project use an embedded GNU/Linux operating system for the firmware based on the version 2.6 kernel that includes BusyBox (combined set of standard command-line utilities for embedded systems) and Dropbear (small-memory footprint Secure Sockets Layer (SSL) utility that supports Secure Shell (SSH) server, client, and Secure Copy (SCP) functions).

The WBSS is supplied by the OBU vendor as part of the native OBU software package. It is also started and runs in the background when the device is powered on. Once running, the WBSS listens for RSE radio signals advertising the IP version 6 (IPv6) WAVE service and creates an IP network connection when an RSU is in range, and also initiates the upload component.

The OBU is powered on by the ChargeGuard power monitor a few minutes after the host vehicle is started. The OBU operating system executes the RdWx startup script that
first checks for a newer version of the RdWx being present and installs it if present. It then initiates the RdWx application followed by the WBSS application.

The Upload component’s primary purpose is to connect to the RSU and upload collected data files, with the most recent data being sent first. The upload component also checks for application updates and downloads them when available. This check occurs a maximum of once per day so as to not interfere with data transmission but still enabling remote software updating to occur at reasonable intervals.

The Road Weather application itself consists of four independent modules that each independently manages data processing for the connected data sources: GPS, CAN, Dickey John, and IceSight. The startup script initiates the main RdWx application when the OBU is first powered on, first checking for and applying updated software. The main RdWx application continues to run in the background after startup is complete, collecting data from its configured data sources, aggregating the data into snapshots, managing the storage space on the OBU, and formatting the data into CSV files for upload.

Additional information on the OBE application data processing is provided in Appendix B.
3.1.4 OBE Interfaces

This section describes the OBE interface for the IP messaging application in terms of its configuration settings on the OBE. The OBU configuration settings are contained in a single configuration file consisting of six sections. The six sections each specify how the OBE should process data from particular connected sources:

- [RdWx] configures data selection, sampling frequency, and storage options for the main Road Weather application
- [GPS] sets the names associated with global positioning data
- [Dickie John] configures the reading of Dickie John Control Point® data
- [IceSight] configures weather measurements reported by the mobile pavement condition sensor
- [J1979] configures the weather-related data to be captured from the light vehicle CAN bus (using the OBD-II parameter identifiers [PIDs]) according to the SAE J1979 standard
- [J1939] configures the weather-related data to be captured from the heavy vehicle CAN bus according to the SAE J1939 standard

The order of the sections within the file is not constrained. The example configuration in Figure 8 suggests the order [RdWx], [GPS], [J1979], [J1939], [Dickie John], and [IceSight], reflecting a presumed likelihood that a particular device is available. The application and GPS are always present; otherwise no data would be captured. Only one of the CAN bus devices will be present at any given time. The SAE J1979 standard applies when the system is deployed on a light vehicle, and SAE J1939 when the system is deployed on a heavy vehicle. The Dickey John and IceSight equipment are completely optional. They provide additional data beyond those available from the CAN bus, but do not have to be present for the application to function properly.

Each of the configuration sections includes a parameter that indicates whether that component is active in this configuration. “Active” can be either “0” for an inactive component or “1” for an active component. Its purpose is to switch off individual components for testing purposes. While completely removing a section accomplishes the same goal—the component module won’t be initialized—the “active” parameter setting enables retaining a standard configuration file while testing individual components. The RdWx and GPS components default to active, and the others default to inactive since they represent optional sensors as in the case of DICKEY-john or IceSight, or are deployment dependent as with J1939 for a heavy vehicle and J1979 for a light vehicle.
The component activation logic is straightforward: if the section is present, load the software; if the “active” parameter is “0” then stop; otherwise, continue and try to connect to the specified data device. Each device has a built-in timeout period so the
software won’t get stuck trying to collect data from a device that isn’t configured properly or isn’t connected.

The configuration file data specifications are shown in Table 3. The low-level configuration options for each section, such as device driver name or network address, have reasonable default values. The majority of the configuration effort is determining what data to capture and what label to give it. The “params” option is a comma-separated list of labels used to identify each piece of data being collected from a data capture device.

Some of the application devices report similar weather information. For example, air temperature is a common weather observation and is reported by the CAN bus as well as multiple times from an IceSight. Consequently, the data labels should be unique across the entire configuration file to distinguish among the data types and values. If two or more labels are the same, then the “last man wins”; if the IceSight section is configured to use “airtemp” as a label and the CAN bus also uses “airtemp” as a label, then the most recently polled device will determine the value associated with that label.

The RdWx “params” is the list of parameters identified in the other (for example, [GPS] and [J1979]) sections to be saved and transmitted in the data file. The data labels used in the RdWx “params” option must match the labels identified in the other sections. The order of “params” in the [RdWx] section defines the order of parameters in the header and each record of the data file. While “airtemp, airtemp, airtemp” is a valid configuration, it will report the same value three times and isn’t an especially useful feature.

For these reasons, it is recommended that data labels be prefixed with the device section. For example, three air temperatures values from three IceSight sensors could be labeled “icesight.airtemp1, icesight.airtemp2, icesight.airtemp3” and another air temperature from the CAN bus could be labeled “CAN.airtemp”. This pattern distinguishes between data provided by particular devices and better describes the source of the data in the transmitted data file.
<table>
<thead>
<tr>
<th>Configuration Parameter</th>
<th>Description</th>
<th>Valid Values/ Default Value</th>
<th>Notes/Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>[RdWx]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>active</td>
<td>Enables or disables the component configured by the section. In the case of RdWx, it is an easy way for a user to disable the entire application without making OBU operating system changes.</td>
<td>0 for inactive, or 1 for active. Default value is 1.</td>
<td>active=1</td>
</tr>
<tr>
<td>params</td>
<td>The comma-separated list of labels to be included in the application output files. Labels must correspond to the labels specified in other modules.</td>
<td>Any text label that matches labels defined by the data capture components. Default value is nothing, so output files will be empty.</td>
<td>params=gps.time,gps.lat,gps.lon,gps.alt,gps.sat,j1979.airtemp,dj.all,icesight.airtemp1</td>
</tr>
<tr>
<td>delay</td>
<td>The number of milliseconds to wait between recording data in the output.</td>
<td>A reasonable number of milliseconds. Default is 1000, which is 1 second.</td>
<td>delay=10000 will record one set of data every ten seconds delay=100 will record 10 sets of data every second</td>
</tr>
<tr>
<td>records</td>
<td>The number of data records to include in each output file.</td>
<td>Default is 600.</td>
<td>This is related to the delay. If delay is set to 1000, then 600 records will record ten minutes (600 seconds) of data in each file. A very low number will result in many files being recorded, but few transmitted because the overhead of connecting wirelessly is much greater than the time to</td>
</tr>
</tbody>
</table>
| prefix | Optional alphanumeric string prepended to the data file name to simplify identification. | Default value is blank; maximum length is 16 characters. | This can be any readable text that represents useful information to the operating agency. It could be a vehicle identification number, for example. The data file name without the prefix will be the OBU media access control (MAC) address with a UTC date and 24-hour time, for example, “0A22C10B751D-20150630-1425.csv”. With a “prefix=TRUCK64”, the same file name would be “TRUCK64-0A22C10B751D-20150630-1425.csv”.
 |
| work | OBU local storage location for work-in-progress. | Default value is /dev/shm. | work=/dev/shm specifies a shared memory location where data can be rapidly accumulated and then written all at one time to the save directory for later transmission. |
| save | OBU local storage location for completed data files to be stored and from where to be transmitted. | Default value is /mnt/ubi/dbg/data | save=/mnt/ubi/dbg/data specifies onboard flash memory storage. A micro SD card can also be inserted into the OBU and then this configuration item can be changed to point there for potentially greater storage capacity. |
| maxspace | The total storage space, | Default value is 30 for 30 | The default delay and record values will exchange the actual data file. A very large number creates few files but likely won’t successfully transmit because the exchange takes longer than a vehicle is within range of a RSU. |
measures in megabytes, that the locally saved data files may occupy before the application begins deleting the oldest files.

megabytes.

generate six files per hour with an estimated size of 100 kilobytes. A 30 megabyte local storage limit allows for 50 continuous hours of vehicle and OBU operation before needing to eliminate old files to free storage space. This should be sufficient time for the OBU to encounter an RSU to offload data files.

<table>
<thead>
<tr>
<th>[GPS]</th>
<th>active</th>
<th>Enables or disables the GPS.</th>
<th>0 for inactive, or 1 for active. Default value is 1.</th>
<th>active=1</th>
</tr>
</thead>
<tbody>
<tr>
<td>params</td>
<td></td>
<td>The comma separated list of labels that uniquely identifies the data captured by this component.</td>
<td>There is no default value. The GPS component produces these seven data in order: timestamp, latitude, longitude, altitude, fix, satellite count, and calculated speed.</td>
<td>params=gps.ts,gps.lat,gps.long,gps.alt,gps.fix,gps.sat,gps.spd</td>
</tr>
<tr>
<td>device</td>
<td></td>
<td>The logical name of the GPS operating system device.</td>
<td>Default value is /dev/ttygps</td>
<td>device=/dev/ttygps corresponds to the serial port that reads GPS coordinates in National Marine Electronics Association (NMEA) strings.</td>
</tr>
<tr>
<td>[Dickey-John]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------------------</td>
<td>-----------------------------------------------------------------</td>
<td>-----------------------------------------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>active</td>
<td>Enables or disables the DICKEY-john data capture component.</td>
<td>0 for inactive, or 1 for active. Default value is 0.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>params</td>
<td>The comma separated list of labels that uniquely identifies the data captured by this component.</td>
<td>Default value is dj.all.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>device</td>
<td>The logical name of the operating system device from which data are gathered.</td>
<td>Default value is /dev/ttymxc1. Default value is /dev/ttymxc1 corresponds to the external OBU serial port.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>[IceSight]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>active</td>
<td>Enables or disables the IceSight external sensor data capture.</td>
<td>0 for inactive, or 1 for active. Default value is 0.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>params</td>
<td>The comma separated list of labels that uniquely identifies the data captured by the IceSight sensor.</td>
<td>There is no default value. The IceSight sensor records eighteen parameters: y voltage, x voltage, ratio of the voltages (y/x), air temperature 2, surface temperature, displayed condition code, Measured condition code, mnemonic for displayed condition, mnemonic for measured condition, displayed friction code number, measured friction code number,</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>params=is.airtemp1,is.airtemp2,is.rh Refer to Appendix C for the complete description of each parameter and its interpretation in the case of a lookup value.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------</td>
<td>-----------------------------------------------------------------</td>
<td>-----------------------------------------------------------------</td>
<td>-----------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td></td>
<td>displayed friction code value, measured friction code value, dirty</td>
<td>The IceSight sends its data via TCP on address 192.168.1.180 and</td>
<td>The IceSight sends its data via TCP on address 192.168.1.180 and</td>
<td></td>
</tr>
<tr>
<td></td>
<td>lens value, grip value, relative humidity, air temperature 3, air</td>
<td>the OBU is configured to be on the same network 192.168.1.x.</td>
<td>the OBU is configured to be on the same network 192.168.1.x.</td>
<td></td>
</tr>
<tr>
<td>address</td>
<td>The IP address to listen on for capturing data from a connected</td>
<td>Default value is 192.168.1.180</td>
<td>Default value is 192.168.1.180</td>
<td></td>
</tr>
<tr>
<td></td>
<td>IceSight sensor.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>port</td>
<td>The network port to listen on used in conjunction with the</td>
<td>Default value is 1776</td>
<td>Port 1776 is the logical port where the IceSight sensor sends its data.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>address configuration item.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>[J1979]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>active</td>
<td>Enables or disables the light vehicle CAN bus data capture</td>
<td>0 for inactive, or 1 for active. Default value is 0.</td>
<td>active=0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>component.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>params</td>
<td>The comma separated list of labels that uniquely identifies the</td>
<td>Default value is blank.</td>
<td>The text labels in this list correspond to the labels defined by the CAN bus data capture configuration items contained within the same J1979 section. If a label is in this list, then there is a CAN bus configuration of the same name. For example, “params=can.airtemp,can.airpressure” should have a corresponding “can.airtemp=” and “can.airpressure=” configuration items. Refer to the &lt;name&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>the CAN bus data captured by this component.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>device</strong></td>
<td>The logical name of the operating system device from which data are gathered.</td>
<td>Default value is can0</td>
<td>device=can0 corresponds to the high-speed CAN bus port that includes a termination resistor and is configured for the light vehicle bus speed of 500 kbps.</td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td><strong>&lt;name&gt;</strong></td>
<td>A changeable configuration item that maps the “params” labels to the CAN bus data capture configuration.</td>
<td>There is no default value as these items only exist if they are included by the params configuration item.</td>
<td>This is a complex configuration item with its own embedded formatting. Refer to Figure 8 for an example. There should be one of these for each of the labels included in the params list. The CAN configuration is a comma-separated list in the order of CAN id, filter, start bit, bit count, and conversion. CAN data consist of an 11- or 29-bit identifier and 8 bytes of data. CAN id is the decimal representation of the desired CAN identifier. Filter is a variable length hexadecimal representation of a number that the CAN data must match before being accepted. There are 64 bits in the 8-byte value and the start bit references where the desired data starts. The bit count is the number of bits to extract from the data starting from the start bit position. The conversion configuration is a space-separated list of mathematical operations. Once the desired bits have been read from the data portion of the CAN message, the operations are evaluated on the resulting number from left to right. Each operation</td>
<td></td>
</tr>
<tr>
<td>[J1939]</td>
<td>active</td>
<td>params</td>
<td>device</td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>active</td>
<td>Enables or disables the light vehicle CAN bus data capture component.</td>
<td>0 for inactive, or 1 for active. Default value is 0.</td>
<td>The logical name of the operating system device from which data are gathered.</td>
<td>The comma separated list of labels that uniquely identifies the CAN bus data captured by this component.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Default value is blank.</td>
</tr>
<tr>
<td></td>
<td>active=0</td>
<td></td>
<td></td>
<td>Default value is can1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>device=can1 corresponds to the CAN bus port that is unterminated and configured for the heavy vehicle bus speed of 250 kbps.</td>
</tr>
<tr>
<td>&lt;name&gt;</td>
<td>A changeable configuration item that maps the “params” labels to the CAN bus data capture configuration.</td>
<td>There is no default value as these items only exist if they are included by the params configuration item.</td>
<td>This is a complex configuration item with its own embedded formatting. Refer to Figure 8 for an example. There should be one of these for each of the labels included in the params list. The CAN configuration is a comma-separated list in the order of CAN id, filter, start bit, bit count, and conversion. Heavy vehicle CAN data consist of a 29-bit identifier and 8 bytes of data. CAN id is the decimal representation of the desired PGN. Filter is a variable length hexadecimal representation of a number that the CAN data must match before being accepted. There are 64 bits in the 8-byte value and the start bit references where the desired data starts, together with the PGN, is known as the SPN. The bit count is the number of bits to extract from the data starting from the start bit position. The conversion configuration is a space-separated list of mathematical operations. Once the desired bits have been read from the data portion of the CAN message, the operations are evaluated on the resulting number from left to right. Each operation consists of a mathematical operator symbol immediately followed by an integer number. Decimal numbers are not allowed. Fractional conversions are achieved by multiplying and dividing, i.e.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>*5/9. Refer to the published OBD-II parameter identifiers for more detail.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3.2 Roadside Components

The roadside equipment procured, configured, tested, and deployed in this project is shown in Figure 9 and consists of the DSRC RSU, GPS antenna, DSRC antennae, antennae surge protectors, RSU mounting bracket, 48VDC power supply, power-over-Ethernet (PoE) switch, and PoE Ethernet cable surge protector. Functionally, the RSE advertises IPv6 service over the DSRC broadcast, routes IPv6 traffic, receives data files from OBEs, sends data files when requested by backhaul network servers, and sends updated software on-demand to OBEs over DSRC.

Figure 9 - RSE Schematic (Source: Synesis Partners LLC)

3.2.1 RSE Hardware

The roadside equipment includes the DSRC radio roadside unit and the infrastructure support components providing structural and power. The DSRC-enabling components consist of the DSRC RSU with its GPS and DSRC antennae. The DSRC RSU consists of a weather-proof enclosure that houses the processing, memory, storage, DSRC radio, and power electronics, with protruding connectors for antennae, power, and the local wired network. There are four external DSRC antennae mounts to support various antennae configurations—two paired antennae on the top or bottom of the enclosure are most common, with unused antenna connectors capped. There is one GPS antenna connector at the top of the enclosure. RSUs can be powered either through the Ethernet cable connected to a PoE switch or wired directly to line voltage. The Ethernet port is also used to connect the RSU to the agency network or local network equipment for stand-alone operation. Infrastructure support equipment consists of the mounting brackets, electrical surge suppressors (both antennae and Ethernet), and power supply with PoE network switch.
3.2.2 RSE Software

At its core, the RSU is a single-board computer interfaced to dual DSRC radios with network software based on an open-source Linux operating system. The Linux OS is configured to provide network hardware (wired Ethernet and DSRC radios) with IPv6 addresses, default routing information, and firewall rule enforcement. The OS also includes widely-available secure shell (SSH) and secure copy (SCP) applications that enable remote interaction and file transfer with each RSU.

Most of the software functions used by the road weather application are provided by the built-in Linux capabilities. The RSU IPv6 application enables OBU s within range of an RSU to use IPv6 network features. The IPv6 application broadcasts the radio-side IPv6 address and network. Nearby OBU s receive the IPv6 network information and

Figure 10 - RSE, Ethernet Switch, and Bracket/Surge Suppressor (Source: Synesis Partners LLC)
dynamically set their network address and routing information. The IPv6 application also monitors radio data and repackages the DSRC data for non-DSRC (back-office) network transport.

From the perspective of the OBU, the RSU advertises the availability of the IPv6 service, routes network traffic, receives collected data files, and supplies updated road weather application software. The IPv6 application enables the network connection, but file transfer between the OBU and RSU is handled by the SSH and SCP applications provided by the operating system on both devices.

From the perspective of a RSE managing organization, each RSU is a router that can be contacted through the wired network to modify configuration parameters, retrieve accumulated data files and move them to other servers, and send new road weather application software for distribution to roaming OBUs.

3.2.3 RSE Interfaces

The RSE interfaces provide access to the data received by the RSE from vehicles and monitor the state of operations (“health”) of the RSE. Health monitoring on the RSEs is provided by three applications built over the IPv6 services that send information to the back office: file upload, heartbeat, and alarm.

The road weather application software includes two complementary scripts that reside on each RSU and are configured to manage the collected data files.

The first script is enabled by default and scheduled to run once daily. It accepts the source data directory and threshold file count as inputs. The executing script reads the data file storage directory and, when there are more files than the specified threshold, removes excess files in oldest first order to prevent overrunning the limited storage space. The default threshold file count limit is 300, which is about 30 MB and imitates similar OBE local storage limits.

The second related script pushes collected data files to another network destination and cleans them up once successfully transmitted, but is not enabled by default. To enable this function, the script accepts the destination network address and source data directory as input. The operating system scheduler must then be configured to run the script at regular intervals—every five or ten minutes is reasonable timing. The receiving server also needs the RdWx user added with the appropriate public key from the RSU RdWx user.

Each RSU records a system log file and a network traffic log file which are regularly offloaded to a defined network address through the file upload application. This allows the detailed log files to be recorded continuously and analyzed as needed while minimizing RSU storage space. The RSU 4.x firmware disables the log files by default so an operating agency can opt-in to collect them rather than cause RSU storage problems
when the agency is unaware that the RSU storage needs to be freed regularly. As such, the log file gathering should be enabled if detailed monitoring is desired.

The heartbeat application transmits a simple device status message that consists of the RSU identifier, time stamp, and a coded status number that indicates potential problems such as low storage. The heartbeat message is sent once per minute using UDP. Although UDP does not guarantee delivery, its messages are easy to process and rarely get dropped, making it an excellent choice for heartbeat monitoring. There are a variety of open-source monitoring applications for the back office that can be configured to listen for these messages and send email alerts to appropriate personnel when problems arise and need correction. For this project, a simple web server was configured to listen for the heartbeat messages and put them on a web page to be viewed regularly. This was sufficient for the two-unit RSE deployment. Table 4 is an example of the received data from project deployed RSU.

![Table 4 - Example Heartbeat Message Records](source: Synesis Partners LLC)

<table>
<thead>
<tr>
<th>RSEUnitID</th>
<th>MessageTimestamp</th>
<th>RSEStatus Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Savari-SN0003</td>
<td>&lt;06/25/2015,16:36:20&gt;</td>
<td>0</td>
</tr>
<tr>
<td>Savari-SN0005</td>
<td>&lt;06/25/2015,16:35:50&gt;</td>
<td>0</td>
</tr>
<tr>
<td>Savari-SN0006</td>
<td>&lt;06/25/2015,16:36:37&gt;</td>
<td>0</td>
</tr>
</tbody>
</table>

The alarm application is similar to the heartbeat application in that it sends short messages via UDP. The alarm message includes the status of installed applications, and if they are configured to run, disabled, or report a failure condition. The Savari RSU manufacturer provides an alarm monitoring application based on Java with configuration documentation.

### 3.3 Back Office Services

The back office services play a passive role in the system as deployed in this project. Back office services receive the data and the health monitoring heartbeat and alarm messages pushed from the RSEs. Server locations to which the messages are delivered are configured on the RSEs.

A script or application similar to the RSE push script could be created to gather the distributed data files by pulling them from the RSEs. This application would be configured with the list of RSEs to contact and also should clean up the remote files when successfully received. In this case, the username and public key used by this application would need to be applied to the originating RSEs.
**5.9 GHz DSRC Vehicle-based Road and Weather Condition Application**

**Final Report**

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**Figure 11 - Data File List on Savari Monitoring Server Application** (Source: Savari Inc.; Synesis Partners LLC)

---

![Savari Monitoring Server Application](image_url)

<table>
<thead>
<tr>
<th>S. No.</th>
<th>RSE</th>
<th>Connection Status</th>
<th>Last Reported Application Status</th>
<th>Last Reported Timestamp</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Savari-910003</td>
<td></td>
<td></td>
<td>2015-07-03 15:40:59</td>
</tr>
<tr>
<td>2</td>
<td>Savari-910005</td>
<td></td>
<td></td>
<td>2015-07-03 15:40:48</td>
</tr>
<tr>
<td>3</td>
<td>Savari-910006</td>
<td></td>
<td></td>
<td>2015-07-03 15:41:06</td>
</tr>
</tbody>
</table>

---

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4 DEPLOYMENT

Deployment of the DSRC-based system for collecting road weather data for this project consisted of three related sets of activities: installing the roadside and vehicle on-board equipment, configuring the supporting IPv6 backhaul network connections, and testing the connections, data transport, and interfaces. As discussed earlier, however, the actual scope of deployment was somewhat modified from the original plan to place the focus more squarely on the DSRC capability rather than on any application-specific back office data exchange. This section describes the deployment insofar as it was completed to demonstrate the system capabilities, with the installation guidance and test plans as will be needed when an agency might complete the deployment.

4.1 Testing

The objective of system testing is to demonstrate that the system performs its intended functions as described in its concept of operations and specified by the user needs and requirements. Testing will assess both nonconformance with the stated requirements and any unexpected or undesired side effects of system operation. Just as the functional requirements specify behaviors of particular system components, testing will need to be performed on particular components as well as the fully integrated system. The behaviors of even moderately complex systems are nearly impossible to adequately test when fully assembled.

The system Test Plan\textsuperscript{10} describes the overall approach to testing the application. It is based on the user need and requirements and is complemented by test scripts that reflect the specific testing needs based on implemented system features. The Test Plan first identifies system elements—i.e., the components and processes to be tested—and the testing methods. It then describes the test cases and test scripts at a high-level, relates the test cases to requirements, and relates the test cases to project tasks during which particular tests are to be performed. The Test Plan also identifies activities needed to configure test environments, if any. Eight test cases are described in the Test Plan. Of these, five have been completed as unit and integration tests during the system development; three will need to be completed as part of the eventual field deployments.

Test Case 1 confirms that the OBE acquires weather-related data according to the OBE application configuration settings from the various connected vehicle data sources. This testing has been competed for the GPS, the light vehicle CAN bus, and the IceSight unit. Installation testing will be needed for heavy vehicle and Dickey John data connections. When executing the test procedures for this test case, the completed OBE data files are

\textsuperscript{10} 5.9 GHz Dedicated Short Range Communication Vehicle Based Road and Weather Condition Application Test Plan, December 2013, Synesis Partners LLC.
inspected to assure that the anticipated values are present. Values are then compared to the vendor sensor specifications, where available, to verify that weather-related data values are within the range of a sensor and make sense given the local environmental circumstances. An air temperature of 140°F would, for example, indicate a problem.

Test Case 2 evaluates the transport mechanisms of the vehicle weather-related data over DSRC. Data files generated on an OBE and transmitted to an RSE are retrieved from RSE. Analyzing the RSE log file against the data files confirms that DSRC transmission was successful since that is the only means for the OBE to deliver the data to the RSE. This testing was performed during development and in the initial RSE and OBE configuration and test operations.

Test Case 3 assures that the data collected on vehicles is sent to RSEs and retains the ability to associate individual data records with the source OBE according to the specification encoded in the OBE’s configuration file. This testing was performed during development.

Test Case 4 uses the inspection testing method to verify that OBE-provided data are available on and can be retrieved from the RSE. Files on the RSE are pushed to a remote server as configured on the RSE; the contents of the files are inspected to ensure that they are uncorrupted and complete. This testing was performed during development.

Test Case 5 verifies that monitoring software correctly identifies system problems and notifies administrators to fix the problems. Malfunctions are simulated by moving processed data files and heartbeat logs from their expected locations. System monitoring results are then compared to the malfunction characteristics to verify that the error condition was correctly identified. This testing was performed after development of the Heartbeat Monitor software.

Test Case 6 verifies the field installation and operation of OBEs. Its activities are similar to Test Cases 1 and 2 in that they verify OBE operation, but the testing environment is moved to the field. The Test Case 6 testing environment includes light (HELP) vehicles and heavy (snow plow) vehicles with Dickey John equipment and IceSight units. This OBE field installation test case also evaluates independent power control hardware (the Charge Guard unit) that protects the OBEs from noisy vehicle power supplies and prevents OBEs from discharging vehicle batteries when vehicles are not operating. This testing should be performed in conclusion of the OBE field installation and is described in the OBE installation guidance.

Test Case 7 verifies the field installation and operation of RSEs. Just as Test Case 6 shares common activities with previous test cases, Test Case 7 shares some aspects of Test Case 3. The RSE field testing environment consists of the RSEs deployed to the LIE sites, relying on power supplied from PoE switches installed in cabinets, and using the
NYSDOT INFORM network. This testing should be performed in conclusion of the OBE and RSE field installation and is described in the RSE installation guidance.

Test Case 8 verifies the end-to-end system deployment. At this stage, it is important to verify that the remote power cycling capability (used to reboot RSEs when necessary) is functional, reducing the need for on-site maintenance. This test case evaluates OBEs continuously collecting sensor data from operating vehicles and successfully detecting RSEs under moving conditions. Test Case 8 also evaluates each component’s ability within the system to store and forward information when some components are unavailable. This testing should be performed in conclusion of the OBE and RSE field installation and is described in the installation guidance. Successful performance of Test Case 8 will fundamentally confirm that data originating on a particular vehicle are retrievable from the RSEs, and secondarily demonstrate system coverage and capabilities. For example, Figure 12 depicts the path travelled by a test vehicle (blue line) when in range of a deployed RSE (red dot), and implicitly illustrates the coverage provided by that RSE.

![Figure 12 - Typical RSE Deployment Validation Result (Source: Synesis Partners LLC)](image)

### 4.2 Backhaul Network and IPv6

The purpose of this section is to describe the implementation of the IPv6 network for this 5.9 GHz DSRC Vehicle Based Road and Weather Condition Application and for similar projects. The section summarizes the networking needs for connected vehicle applications and the case for using IPv6 instead of the more established IPv4 standards and describes the project experience with deployment of IPv6 support for the CV application.

#### 4.2.1 CV Application Needs and the IPv6 Network Challenge

CV application performance requirements particular to vehicle-based networking with DSRC have resulted in the network implementation decision to use IPv6 rather than the more established IPv4. The major concerns, driven largely by the brief intermittent
connections needed between vehicles, are to support large numbers of connections, minimize network connection time, assure security of transactions, and protect privacy. Some CV may require connections from vehicles to infrastructure, then through an agency network to external servers, and then back to the vehicle, necessitating an IPv6 connection through the network from end to end.

A synopsis of Internet Protocol history is helpful in providing some context for the discussion. IPv4 dates to the 1970s and became the basis for the existing Internet deployment during the rapid growth of the Internet in the 1990s. The IPv4 addressing scheme uses 4-byte network addresses to yield approximately $4.2 \times 10^9$ directly addressable network nodes—fewer than the number of humans on Earth. As such, schemes such as network address translation were used to extend the number of nodes available for addressing, with the consequence of increasingly elaborate network management and routing. The network management standard practice has become “switch where you can, route where you must”—meaning to stay whenever possible within trusted local networks. Hardware and software advances have alleviated some of the pain of growth, but have largely maxed out network performance within the inherent constraints of IPv4.

IPv6 was developed in the 1990s primarily to expand the available Internet address space, and also to simplify network routing configuration, enable multi-cast data streams (the IPv4 mechanism was not interoperable), and to support improved security algorithms. Network address lengths were increased from the four bytes in IPv4 to sixteen bytes in IPv6, yielding a network capacity of approximately $3.4 \times 10^{18}$ addressable nodes. This increase in the address space could create significant changes in the way networks are managed and operated, with a corresponding variety of mechanisms for transitioning from IPv4 to IPv6.

With this context, it becomes clearer why IPv6 is a better fit than IPv4 for CV applications. IPv6 accommodates larger numbers of vehicles more easily because of the larger number of addresses available on the network and within any particular subnet. It furthermore simplifies addressability by enabling connections between more network nodes without having to translate addresses between subnets. IPv6 enables faster connections because each node (radio/vehicle) is individually addressable (using the nearby RSE router portion of its IPv6 address combined with the device radio hardware identifier) and does not rely on subnetwork address assignments as with IPv4.

IPv6 nonetheless has its own deployment and operations challenges. As described earlier, IPv6 network domains are bigger than ITS IPv4 networks, with associated more complex management needs. IPv6 addressability creates more opportunities for unauthorized access; IPv4 created multiple subnetworks to manage, but protected us from ourselves (through dynamic host configuration protocol (DHCP) and network
address translation (NAT)). The so-called “Internet of Things” depends on enabling IPv6 devices to communicate directly with other IPv6 devices. Consequently, IPv6 requires diligent network planning and policies. Typical considerations include determining what type of network traffic is allowed from which sources and to which destinations, and establishing proactive security management and monitoring to protect devices from potentially harmful interactions (rather than depending at least in part on DHCP and NAT to obscure the network for IPv4). These considerations may present new challenges for network managers not yet trained or familiar with IPv6 deployments.

The operational challenges virtually assure that IPv4 and IPv6 networks will coexist thru a transition period. Agency networks for ITS do not have to have to be converted to IPv6 before CV technologies are deployed. Most recent networking equipment is capable of dual-stacked IPv4 and IPv6 protocol support, providing flexibility for network managers to use the most appropriate protocol for each purpose and device. The new operations mantra is “dual-stack IPv4 and IPv6 where you can, tunnel IPv6 where you must, avoid translation between the two.”

4.2.2 IPv6 Network Deployment Planning and Project Experience

Setting up the IPv6 network for supporting CV applications starts with obtaining the external address for the network from an IPv6 service provider (ISP). Up to 65,000 subnetworks would typically be made available to enable IPv6 applications, and ISPs may provide more or fewer to meet the particular need. In cases of unusually large network needs, multiple independent IPv6 addresses could be requested with each one representing 65,000 subnetworks. Each DSRC RSU acts as a router for one of the assigned subnetworks with its own connections to nearby OBUs. The RSU’s routing capabilities enable connected OBUs to contact remote applications and services.

Deployment of the IPv6 network does not necessarily mean a complete redeployment of all network equipment. Most networking equipment manufactured within the last ten years supports both IPv4 and IPv6 addressing, and it will be beneficial to dual-stack wherever possible. This strategy enables both current IPv4 ITS equipment and potentially new IPv6 CV equipment to connect to the same routers and switches; a DSRC RSE along a freeway, for example, could be connected to a switch originally deployed to support a message sign or vehicle detection station. The RSE inside-network-interface is itself dual-stacked.

IPv6 connections between network nodes similarly need not depend on dedicated IPv6 infrastructure. Not all ISPs currently supply native IPv6 connection, and may themselves be using tunnels through IPv4 connections to provide IPv6 service. Tunneling wraps IPv6 data packets with an IPv4 header for transmission through the IPv4 network. The header is stripped off at the end of the tunnel for routing to its
eventual IPv6 destination. The process requires configuring the tunnel at its IPv4 ends, but generally does not any significant transmission delays.

An alternative means of supporting IPv6 data traffic through an IPv4 network is to translate or rewrite the IPv6 packets as IPv4 and then to retranslate the packets at their destination. Although technically feasible, translation of this type is complex to configure and support, can degrade performance, and should general be avoided.

Deploying RSEs on the IPv6 network is similar to deploying a Wi-Fi connection on an IPv4 network, and will require similar security provisions to protect the network from potentially misbehaving end-user/vehicle and network applications. Figure 13 illustrates the general concepts. As with any existing Internet connection, the IPv6 connection should be protected by an appropriately configured firewall. The firewall on the RSE enables and disables routing of messages to and from particular destinations that could include an agency’s own CV services or those of third-party providers on the far side of the agency IPv6 Internet connection. The four connection paths (IPv4 in and out, IPv6 in and out) on each RSE firewall necessitate multiple configuration sets to be managed. Anti-lockout rules on the firewall are used to keep network administrators from inadvertently disabling access.

On the other end, CV application services are likely to need connections into and through an agency IPv6 network. Externally hosted services such as a Security Certificate Management System (SCMS), for example, may need to be able to send messages to vehicle OBEs connected to RSEs on the network. This will generally be managed by configuring the network edge router for specific IPv6 addresses. This will necessitate one route table entry per RSU, manually or script generated, and may in the near term present management challenges. Internally hosted services would avoid the need to configure the edge router for all RSEs. Every RSE network interface will need to be configured to accept traffic from application services whether inside or external to the agency network.

A few notes on distinctions between and use of networking components...

A router connects an organization’s inside network to the Internet. IPv6 tunneling is typically configured here.

A firewall enforces an organization’s network traffic policies. Its configuration settings define which addresses and protocols are allowed access to the network.

A switch physically connects network devices within a subnetwork. It tracks hardware addresses by physical ports for fast packet movement. RSUs in a CV network can be isolated using a virtual local area network (VLAN) or dedicated switches.
The IPv6 network deployment and configuration experience for this project reflects and amplifies the general planning considerations. The Long Island Expressway (INFORM) network infrastructure is operated by Hinck Electric for New York State DOT. Hinck Electric personnel were very familiar with the network components, their configuration, and IPv6 concepts. This made the deployment of IPv6 needs for RSE support relatively seamless.

The provider of the public IP address to INFORM did not currently provide IPv6 addresses, so a tunneling solution was chosen. Hurricane Electric (tunnelbroker.net) provides free IPv6 over IPv4 tunneling, as well as configuration guides for a wide variety of common network routers. An IPv6 tunnel was configured to operate between the back-office servers and the INFORM network using the Hurricane Electric web portal. The necessary configuration settings for the INFORM side of the IPv6 tunnel were sent to Hinck Electric personnel for implementation on the Internet router.

The tunnel was then tested using the ping utility for the tunnel end-points since RSEs had not been deployed at the time. The initial tests revealed that the tunnel was configured correctly, but that a firewall configuration needed to be updated to allow the traffic at the back-office server side. Once the firewall modification was completed, all the tunnel communication tests passed.

In addition to the IPv6 tunnel configuration, an access control list (ACL) was also put in place on the INFORM router to only allow traffic between their network and the back-office network. Related to this basic network security precaution, the RSUs to be...
deployed were configured to send their data only to the back-office server IPv6 address, and their individual firewalls were set to allow only secure traffic.

Since an IPv6 tunneling solution was chosen, each RSE inside-network interface was configured to have a maximum transmission unit (MTU) size of 1280. This ensures that data packets easily traverse the IPv6 tunnel without the need for intermediate routers to split single packets into two or more packets for transmission. The smaller MTU originating from an RSE also helps reduce unexpected network behavior such as secure connections being dropped or appearing to hang.

Enterprise-class network equipment can have complex configuration characteristics, some of which may affect IPv6 tunneling. In the INFORM case, RSEs worked flawlessly with an MTU of 1500 until the ACL was applied at the Internet edge router. It was then necessary to use an MTU of 1280 with the ACL—which was modifying the original data packets in unexpected ways when verifying them against the allowed IPv6 addresses.

The INFORM network switches were capable of dual-stacking to simultaneously support IPv4 and IPv6 hosts. This greatly facilitated deploying the RSEs. Each RSE was assigned both an IPv4 address and an IPv6 address. The IPv6 addresses were only reachable between the back-office and INFORM networks, and the IPv4 addresses were only accessible from within the INFORM network.

Setting both IPv4 and IPv6 addresses is an important consideration for the RSE. Externally connected equipment, such as signal controllers, may only support IPv4, and having an IPv4 address on the RSE facilitates retrieving data from that external equipment. Having an IPv4 address can also be beneficial during RSE firmware upgrades. Firmware updates frequently modify network settings, and the IPv4 address provided another mechanism to connect with the RSE should there be unexpected results.

### 4.3 In-Vehicle and Roadside Installation

Installation of the in-vehicle and roadside components of the road weather application is described in the Installation Guide\(^\text{11}\). The Guide provides a description and list of the system parts; identifies the immediate tools and resources needed for installation; describes the step-by-step on-board equipment installation; describes the step-by-step roadside equipment installation; and provides system installation testing instructions. Appendices to the Guide provide instructions for installation tasks that might be needed for deployment of units beyond those procured and provided for the NYSDOT

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deployment: construction of OBU-to-OBD-II cables for light vehicle installation; construction of OBU-to-J1939 cables for heavy vehicle installation; the ChargeGuard configuration; and OBU software installation.
5  ANALYSIS AND RECOMMENDATIONS

This project has successfully developed and demonstrated a capability for aggregating weather-related data from a variety of original and aftermarket vehicle on-board sensors, sending the data over a DSRC connection from the vehicle to the roadside, and making the data available to other agency systems. This section describes some of the challenges and opportunities encountered in the project, and offers recommendations for future consideration.

5.1  Messaging Standards

DSRC messaging standards offer three options for getting probe data from vehicles to the roadside, from where they can be provided to other applications and data services: probe vehicle data messages, Part II of the basic safety messages (BSMs), and IP datagrams. Although any of these options could presumably be used to meet the data messaging objectives of the application, each option has its challenges.

There is generally a lack of J2735 probe vehicle data message support on current generation RSEs, including the Savari RSU 3.2 procured for this project. The most recent April 2015 version of the J2735 DSRC Message Set Dictionary identifies but does not provide any specific message formatting for the probe vehicle data message.

BSMs are broadcast continuously by the OBE and would require an OBE store-and-forward application in order to provide continuous operational coverage. If that capability were developed, accessing BSMs received by an RSE would require a store-and-forward capability as well. The store component could be accommodated by the log file, but requires processing of the log file to extract only the BSM probe data content. Alternatively, a BSM forwarding application on the RSE could be used to specifically store and forward only the BSMs. BSM forwarding on the Savari 3.x RSE was specific to Safety Pilot and not necessarily supported on other RSUs.

IP messaging is supported by the RSE 3.x and 4.x standards, but requires an OBU application as developed in this project to originate messages, rather than using native DSRC J2735 messages. This is a practical solution to the project objectives and constraints, but somewhat misses the point of having the DSRC standards for probe data.

Recommendation: Agencies wanting to deploy DSRC-based applications should monitor ongoing standards development and deployment to assure that viable probe message capabilities are included. Probe message capability and support (in one of the three forms described above) can be included in DSRC equipment procurements, even if applications for the data are not fully developed.
5.2 **OBU and RSU Software Portability**

Although the road weather application developed for this project has been deployed and tested on specific manufacturer versions of OBEs and RSEs, it may become desirable to deploy the application on devices from other manufacturers as well. The Portable Operating System Interface (POSIX) is a group of standards maintained by the IEEE Computer Society that specifies consistent application programming interfaces between operating systems in order to maintain compatibility. It appears that both OBE and RSE vendors have consistently used variants of open source GNU/Linux operating systems as the basis for their device software and GNU/Linux is POSIX-certified.

The road weather application itself is implemented through a combination of operating system scripts and compiled standard C++ instructions. Because the application is simple, and both it and the operating system adhere to POSIX standards, it should be possible to recompile the source code to run on a different OBE, under the condition that the vendor of the different OBE provides the necessary cross-compiler software. Cross-compiling (using a computer with one type of central processing unit (CPU) to create software for a computer with a different CPU) is a fairly common practice. If a vendor won’t supply the cross-compiling software, they should be able to cross-compile the RdWx application if requested.

The most critical questions for porting the road weather application to another OBE are whether the target OBE (1) contains a component that detects RSE IPv6 application announcements, (2) can configure the OBU IPv6 network settings, and (3) can be adapted through a script to notify the RdWx upload script to perform its function. Beyond this, every vendor that bases its device software on a POSIX-compliant GNU/Linux variant should be able to support the functions needed for the RdWx application.

**Recommendation:** Agencies considering deployment of the road weather application developed in this study should, at a minimum, assure that the OBEs and RSEs to be used are POSIX-compatible and that the OBE meet the three configuration conditions.

5.3 **IPv6 Network Support for CV Applications**

Deployments of DSRC RSEs have numbered generally in the tens of devices. This deployment is relatively small given that three version 3.2 RSUs were procured—two for deployment and one as a drop-in spare or for additional deployment. OBU numbers are similar small with six devices being procured—five for deployment and one as a spare. The limited number of devices greatly reduces the burden of configuring the devices and the network. However, upcoming pilot deployments could include hundreds of devices, and repetitive one-off manual configurations will not be practical or recommended.
RSUs are network routers. The IPv6 Internet of Things (IoT) has made the managing agencies (or their contractors) responsible for expanding network access and administration beyond the traditional roadside cabinet. The management entity must ensure that critical network systems are protected while providing unprecedented public access to and across its network.

Ideally, installers should be able to hang it up, plug it in, and walk away. If planned correctly, RSEs should be able to be deployed in a shoot-then-aim fashion—deploy it to the field and, as long as it has power and is connected to the network, test and configure it remotely.

In addition to being a network router, each RSU maintains a firewall on both the inside network and outside radio interfaces; it transmits wave service advertisements; broadcasts active messages; and receives and forwards field data. Managing a network of RSUs with this diversity of functions will necessarily be complex. To facilitate RSE management, the RSU 4.0 specification describes in detail the management information base (MIB) for Simple Network Management Protocol (SNMPv3), which enables COTS network management systems to monitor RSU hardware and configure its functions.

One item that the RSU 4.0 Specification does not define is the use of DHCPv6 with prefix delegation. Each RSU has at least one IPv6 address on the inside network interface and, depending on application needs, may also have up to two more IPv6 addresses—one for each of the radios. If the RSU vendor supports DHCPv6 with prefix delegation, it is possible to configure the agency router so that the RSU automatically acquires all the needed addresses and the agency routing tables are updated accordingly. For this road weather application study, routing information was updated manually as there were potentially only three RSU in total and the 3.2 firmware did not support DHCPv6 with prefix delegation.

If the procured RSU hardware does not support DHCPv6, one possible alternative is to deploy software that acts as a surrogate on behalf of both agency routers and RSE. Every IPv6-enabled device generates a link-local IPv6 address based on the manufacturer-assigned Ethernet Media Access Control (MAC) identifier. By definition, the agency router and RSE must be connected to the same virtual LAN (VLAN) and associated set of network switches. Therefore, surrogate software is able to request IPv6 addresses from the router, provide those addresses to RSE, and inform the router to update its routing table information.

Once the RSE has a routable IPv6 address, COTS network management software can be used to manage and configure the remaining RSE configuration items depending on managing agency application requirements. It is also possible to use COTS network management software to configure both RSE and routers through the same link-local network address mechanism without the need for DHCPv6. However, the COTS
network management software should be carefully specified so that it can automatically assign IPv6 network addresses and update routing tables. Without attention to these functions, network management software tends to degenerate into simply a display for manually updating thousands of network entries.

Experience updating firmware suggests that it is best to deploy first on a spare device at the agency to avoid unworkable surprises, like the needed IPv6 address being masked by a new tunnel configuration thereby cutting off contact with the unit.

The only equipment failures during the initial field deployments have been the PoE switches and fiber transceivers—the RSE has been more robust than the COTS equipment.

**Recommendation:** An agency planning for deployment of an IPv6 network to support DSRC devices should have in-house and/or contract network administrators with IPv6-specific training and experience. The agency should also consider the use of SNMP and/or related network management tools to assist in the configuration, management and operations of the deployed network and devices.
APPENDIX A - DEFINITIONS

The following table provides the definitions of all terms, acronyms, and abbreviations required to properly interpret this System Test Plan.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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<tbody>
<tr>
<td>ACL</td>
<td>Access Control List</td>
</tr>
<tr>
<td>BSM</td>
<td>Basic Safety Message</td>
</tr>
<tr>
<td>CAN</td>
<td>Controller Area Network. An electrical specification and signaling protocol developed by Bosch to facilitate simple data communication between connected equipment control units.</td>
</tr>
<tr>
<td>ConOps</td>
<td>Concept of Operations</td>
</tr>
<tr>
<td>COTS</td>
<td>Commercial off-the-Shelf</td>
</tr>
<tr>
<td>CPU</td>
<td>Central Processing Unit</td>
</tr>
<tr>
<td>CSV</td>
<td>Comma-separated Value</td>
</tr>
<tr>
<td>CV</td>
<td>Connected Vehicles</td>
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<tr>
<td>DHCP</td>
<td>Dynamic Host Configuration Protocol</td>
</tr>
<tr>
<td>DHCPv6</td>
<td>DHCP for IPv6</td>
</tr>
<tr>
<td>DOT</td>
<td>Department of Transportation</td>
</tr>
<tr>
<td>DSRC</td>
<td>Dedicated Short Range Communication. A low-latency, line-of-sight wireless data transmission standard designed for interactions between vehicles and infrastructure in a dynamic transportation environment.</td>
</tr>
<tr>
<td>FHWA</td>
<td>Federal Highway Administration</td>
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<tr>
<td>FTP</td>
<td>File Transfer Protocol</td>
</tr>
<tr>
<td>GHz</td>
<td>Gigahertz</td>
</tr>
<tr>
<td>GPS</td>
<td>Global Positioning System</td>
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<tr>
<td>HCI</td>
<td>Hardware Configuration Item</td>
</tr>
<tr>
<td>HELP</td>
<td>Highway Emergency Local Patrol</td>
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<tr>
<td>HTTP</td>
<td>Hyper-Text Transfer Protocol</td>
</tr>
<tr>
<td>IEEE</td>
<td>Institute of Electrical and Electronics Engineers</td>
</tr>
<tr>
<td>IoT</td>
<td>Internet of Things</td>
</tr>
<tr>
<td>IP</td>
<td>Internet Protocol</td>
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<tr>
<td>IPv4</td>
<td>Internet Protocol version 4</td>
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<tr>
<td>Term</td>
<td>Definition</td>
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<td>---------------------------------------------------------------------------</td>
</tr>
<tr>
<td>IPv6</td>
<td>Internet Protocol version 6</td>
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<tr>
<td>LAN</td>
<td>Local Area Network</td>
</tr>
<tr>
<td>MAC</td>
<td>Media Access Control</td>
</tr>
<tr>
<td>MTU</td>
<td>Maximum Transmission Unit</td>
</tr>
<tr>
<td>NMEA</td>
<td>National Marine Electronics Association</td>
</tr>
<tr>
<td>NY</td>
<td>New York</td>
</tr>
<tr>
<td>NYSDOT</td>
<td>New York State Department of Transportation</td>
</tr>
<tr>
<td>OBD-II</td>
<td>On-board Diagnostics II. A standard for a light vehicle diagnostics port.</td>
</tr>
<tr>
<td>OBE</td>
<td>On-board equipment</td>
</tr>
<tr>
<td>OBU</td>
<td>On-board unit. In this context, more specifically the DSRC equipment</td>
</tr>
<tr>
<td></td>
<td>connected directly to a vehicle data bus.</td>
</tr>
<tr>
<td>OS</td>
<td>Operating System</td>
</tr>
<tr>
<td>PFS</td>
<td>Pooled Fund Study</td>
</tr>
<tr>
<td>PGN</td>
<td>Parameter Group Number. A unique identifier used as a network address in</td>
</tr>
<tr>
<td></td>
<td>the SAE J1939 data standard to group similar data parameters.</td>
</tr>
<tr>
<td>PID</td>
<td>Parameter identifier. A unique code used in a controller area network</td>
</tr>
<tr>
<td></td>
<td>to request specific equipment operational and state data.</td>
</tr>
<tr>
<td>PoE</td>
<td>Power over Ethernet</td>
</tr>
<tr>
<td>POSIX</td>
<td>Portable Operating System Interface</td>
</tr>
<tr>
<td>PSID</td>
<td>Provider service identifier</td>
</tr>
<tr>
<td>PVDM</td>
<td>Probe Vehicle Data Message</td>
</tr>
<tr>
<td>RSE</td>
<td>Roadside equipment. DSRC-related equipment deployed near a roadway or</td>
</tr>
<tr>
<td></td>
<td>intersection.</td>
</tr>
<tr>
<td>RSU</td>
<td>Roadside unit. In this context, more specifically the DSRC equipment</td>
</tr>
<tr>
<td></td>
<td>(radio and processor) at the roadside connected to a backhaul connection.</td>
</tr>
<tr>
<td>SAE</td>
<td>Society of Automotive Engineers</td>
</tr>
<tr>
<td>SCMS</td>
<td>Security Certificate Management System</td>
</tr>
<tr>
<td>SCP</td>
<td>Secure Copy</td>
</tr>
<tr>
<td>SNMP</td>
<td>Simple Network Management Protocol</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
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<td>-------</td>
<td>---------------------------------------------------------------------------</td>
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<tr>
<td>SP</td>
<td>Synesis Partners</td>
</tr>
<tr>
<td>SPN</td>
<td>Suspect Parameter Number. A lower-level identifier within a PGN that describes what a particular data value represents, its update frequency, and its unit of measure.</td>
</tr>
<tr>
<td>SSH</td>
<td>Secure Shell</td>
</tr>
<tr>
<td>SSL</td>
<td>Secure Sockets Layer</td>
</tr>
<tr>
<td>STP</td>
<td>System Test Plan</td>
</tr>
<tr>
<td>UDP</td>
<td>User Datagram Protocol</td>
</tr>
<tr>
<td>UML</td>
<td>Unified Modeling Language</td>
</tr>
<tr>
<td>U.S. DOT</td>
<td>United States Department of Transportation</td>
</tr>
<tr>
<td>UTC</td>
<td>Coordinated Universal Time. The primary time standard by which clocks can be regulated. Daylight savings time changes are ignored.</td>
</tr>
<tr>
<td>VLAN</td>
<td>Virtual Local Area Network</td>
</tr>
<tr>
<td>WAVE</td>
<td>Wireless Access in Vehicular Environments</td>
</tr>
<tr>
<td>WBSS</td>
<td>WAVE Basic Service Set</td>
</tr>
</tbody>
</table>
APPENDIX B - ADDITIONAL APPLICATION SOFTWARE DESCRIPTION

This appendix provides additional information about the functions of the OBU application software. Unified Modeling Language (UML) sequence diagrams are provided herein as a way of amplifying the broader description in Section 3 of the main report.

**Startup** The Startup sequence, as shown in Figure 14, begins with the OS initiating the startup module, which first checks for updates on the OBU, updates application modules as appropriate from local storage, and then starts the main RdWx application module. The RdWx module then reads the configuration file and initiates each of the submodules. Each submodule then reads its own configuration and schedules its continuous data collection.

![Figure 14 - Startup Sequence Diagram (Source: Synesis Partners LLC)](image)

**Collect**

The Collect sequence, as shown in Figure 15, begins with the RdWx module determining that the collection interval has passed and asking for the most recent data from each of the device-specific submodules. Each submodule has been continuously monitoring its sensing devices for new data and provides the most recent data to the
RdWx module. The RdWx module then checks the available storage space on the OBU and, if necessary, deletes the oldest data file to make room for the newest data. The RdWx module then opens the current data file and saves the most recent data.

![Sequence Diagram](image)

**Figure 15 - Collect Sequence Diagram (Source: Synesis Partners LLC)**

**Upload**

The Upload sequence, as shown in Figure 16, begins with the WBSS monitoring the OBU for detection of an available IPv6 network connection over DSRC. When a network connection is made, the Upload module checks the remote server over the network connection for OBU software updates and downloads any appropriate updates. The Upload module then starts uploading data files from local OBU storage, starting with the most recent file and working back through the older files. The Upload module verifies with the remote server that each file has been received. Data files received on the remote server are then deleted from local OBU storage.
Figure 16 - Upload Sequence Diagram (Source: Synesis Partners LLC)
APPENDIX C - ICESIGHT INTERFACE

The IceSight sensor package procured in this project for deployment on a New York State DOT maintenance vehicle provides road condition data to supplement the data obtained directly from the vehicle CAN bus. The IceSight device is connected to the OBU by an Ethernet cable and provides data once per second (1 Hz). As detailed below, the data include instantaneous and interval-averaged parameter values.

Data Definitions

Each record (line) of the data stream from the IceSight contains thirteen or more values, each separated by at least one space, as demonstrated by the following example:

1321 1210 1.091 32.1 35.4 3 3 WET WET 7 7 0.86 0.86 0 FAIR 32.22 33.55 33.55 -102

The sequence and values appearing in the data record are defined in Table 5 and Table 6, respectively.

Table 5 - IceSight Data Record Definitions (Source: High Sierra Electronics)

<table>
<thead>
<tr>
<th>Position</th>
<th>Example</th>
<th>Format</th>
<th>Data Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1321</td>
<td>YYYY</td>
<td>Floating point</td>
<td>Reported Y voltage (0-5,000 mV)</td>
</tr>
<tr>
<td>2</td>
<td>1210</td>
<td>XXXX</td>
<td>Floating point</td>
<td>Reported X voltage (0-5,000 mV)</td>
</tr>
<tr>
<td>3</td>
<td>1.091</td>
<td>R.RRR</td>
<td>Floating point</td>
<td>Ratio of the voltages (y/x)</td>
</tr>
<tr>
<td>4</td>
<td>32.1</td>
<td>AAA.A</td>
<td>Floating point</td>
<td>Air temperature (Celsius), secondary, (100.1 signifies an error condition)</td>
</tr>
<tr>
<td>5</td>
<td>35.4</td>
<td>BBB.B</td>
<td>Floating point</td>
<td>Surface temperature (Celsius), (100.1 signifies an error condition)</td>
</tr>
<tr>
<td>6</td>
<td>3</td>
<td>C</td>
<td>Integer</td>
<td>Displayed condition code number (0-15)</td>
</tr>
<tr>
<td>7</td>
<td>3</td>
<td>D</td>
<td>Integer</td>
<td>Measured condition code number (0-15)</td>
</tr>
<tr>
<td>8</td>
<td>WET</td>
<td>EEE</td>
<td>Text</td>
<td>Mnemonic for displayed condition</td>
</tr>
<tr>
<td>9</td>
<td>WET</td>
<td>FFF</td>
<td>Text</td>
<td>Mnemonic for measured condition</td>
</tr>
<tr>
<td>10</td>
<td>7</td>
<td>G</td>
<td>Integer</td>
<td>Displayed friction code number (0-31)</td>
</tr>
<tr>
<td>11</td>
<td>7</td>
<td>H</td>
<td>Integer</td>
<td>Measured friction code number (0-31)</td>
</tr>
<tr>
<td>12</td>
<td>0.86</td>
<td>I.II</td>
<td>Floating point</td>
<td>Displayed friction code value</td>
</tr>
<tr>
<td>13</td>
<td>0.86</td>
<td>J.JJ</td>
<td>Floating point</td>
<td>Measured friction code value</td>
</tr>
<tr>
<td>14</td>
<td>0</td>
<td>K</td>
<td>Integer</td>
<td>&quot;dirty lens&quot; value3 (0-10)</td>
</tr>
<tr>
<td>15</td>
<td>FAIR</td>
<td>LLLL</td>
<td>Text</td>
<td>&quot;grip&quot; value (GOOD, FAIR, POOR)</td>
</tr>
<tr>
<td>16</td>
<td>32.22</td>
<td>MMM.MM</td>
<td>Floating point</td>
<td>Relative humidity (%)</td>
</tr>
<tr>
<td>17</td>
<td>33.55</td>
<td>NNN.NN</td>
<td>Floating point</td>
<td>Air temperature (Celsius), tertiary, (100.1 signifies an error condition)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>-----------</td>
<td>-----</td>
<td>------------</td>
<td>------------------------------------------------------------------</td>
</tr>
<tr>
<td>18</td>
<td>33.55</td>
<td>OOO.OO</td>
<td>Floating point</td>
<td>Air temperature (Celsius), primary, (100.1 signifies an error condition)</td>
</tr>
<tr>
<td>19</td>
<td>-102</td>
<td>PPP.PP</td>
<td>Floating point</td>
<td>Currently not used</td>
</tr>
</tbody>
</table>

1 Measured condition, measured friction code, measured mnemonic, and measured friction are instantaneous values. Displayed condition, displayed friction code, displayed mnemonic, and displayed friction are averaged values.

2 Condition Codes:
- 0 UNK Unknown
- 1 DRY Dry
- 2 DMP Damp
- 3 WET Wet
- 4 SNO Snow
- 5 ICE Ice
- 6 SLH Slush
- 10 ERR Error Condition

3 “Dirty lens” value: Note that values of 2, 6 and 8 would indicate lens cleaning is necessary.
- 0 Not “Soiled” in any way.
- 1 Within “Soiled” zone, but not for very long.
- 2 Within “Soiled” zone for long enough to be of concern.
- 3 Not Used.
- 4 Received optical signal is low enough that lens could be “Soiled” if condition continues for a long time. Note that a 4 reading is normal in adverse weather conditions.
- 5 Low enough that lens could be “Soiled”, and also within of “Soiled” zone for a short time.
- 6 Low enough that lens could be “Soiled”, and also has been inside of “Soiled” polygon long enough to be of concern.
- 8 Low for long enough that lens should be considered “Soiled”.
- 9 Low for a long time and also within the “Soiled” zone for a short time.
- 10 Low for a long time and also within the “Soiled” zone for a long time.
5.9 GHz Dedicated Short Range Communication Vehicle-based Road and Weather Condition Application

Concept of Operations

Final
Version 1.0

August 2013

Prepared For:
Cooperative Transportation Systems Pooled Fund Study

By:
Synesis Partners LLC
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<table>
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<th>Version</th>
<th>Description</th>
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<tr>
<td>1</td>
<td>submitted to CTS PFS for review, May 29, 2013</td>
</tr>
<tr>
<td>2</td>
<td>Incorporates changes in response to comments received on v0.1</td>
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</table>
1 Scope

1.1 Identification

This document is the “Concept of Operations for the “5.9 GHz Dedicated Short Range Communication Vehicle-based Road and Weather Condition Application,” Final Version 1.0, dated August 2013.”

1.2 Document Overview

The structure of this document is generally consistent with the outline of a Concept of Operations document defined in IEEE Standard 1362-1998. Some sections herein have been somewhat enhanced to accommodate more detailed content than are described in the standard, and titles of some sections may have been edited to more specifically capture that enhancement.

Section 2 describes the current situation with respect to processes and systems to be affected by the concept of operations.

Section 3 identifies the need for changes from the current situation.

Section 4 describes the concept for the new system capabilities and their operations.

Section 5 presents operational scenarios.

Section 6 summarizes operational and organizational impacts that may results from the development of the selected applications.

Section 7 provides an analysis of the expected improvements and disadvantages or limitations that may occur following deployment.

Section 8 provides lists of reference documents and acronyms and abbreviations.

1.3 System Overview

Significant effort has been expended in the Federal Highway Administration’s (FHWA) Road Weather Management Program and in various federal and state connected vehicle programs to identify opportunities to acquire data from vehicles acting as mobile sensor platforms. Federal, state and local transportation agencies have also been working with automakers and communications technology providers to develop and standardize information exchange between vehicles and the transportation infrastructure, enabling a variety of applications that could improve transportation safety, mobility and environmental performance. This 5.9 GHz Dedicated Short Range Communication (DSRC)
Vehicle-based Road and Weather Condition Application project is a synergistic result of those converging opportunities. Accurate, timely and route-specific weather information allows traffic and maintenance managers to better operate and maintain roads under adverse conditions. The research system developed by this project will collect weather observation data from mobile sensors on transportation agency vehicles; transmit the data by way of DSRC roadside units (RSE) to one or more collection systems; and ultimately make the data available to other information systems such as the New York State DOT INFORM system and the U.S. DOT’s Weather Data Environment. In this way, the additional weather information from mobile platforms will eventually enable traffic managers and maintenance personnel to implement operational strategies that optimize the performance of the transportation system by mitigating the effects of weather on the roadways.

Potential use case scenarios for the system are drawn largely from previous road weather and connected vehicle research. Six high-priority connected vehicle road weather applications were identified in the *Concept of Operations for Road Weather Connected Vehicle Applications*. Many of these applications/use cases recognize agency vehicles, including plows and dump trucks, as key sources of connected vehicle road-weather data, particularly since they are logical candidates for the installation of specialized sensors that will generate data sets that will be unavailable from vehicles in the general public fleet. Others of these use cases are focused on delivering data to agency vehicles, especially for winter maintenance decision support and for maintenance management systems. The applications are:

- Enhanced Maintenance Decision Support System
- Information for Maintenance and Fleet Management Systems
- Variable Speed Limits for Weather-Responsive Traffic Management
- Motorist Advisories and Warnings
- Information for Freight Carriers
- Information and Routing Support for Emergency Responders
2 CURRENT SITUATION

2.1 Background and Objectives

The Concept of Operations for Road Weather Connected Vehicle Applications describes in thorough detail the current situation with respect to the convergence of connected vehicle technologies, road weather information, and transportation operations:

Weather has a significant impact on the operations of the nation’s roadway system year round. Rain reduces pavement friction. Winter weather can leave pavements snow-covered or icy. Fog, smoke, blowing dust, heavy precipitation, and vehicle spray can restrict visibility. Flooding, snow accumulation, and wind-blown debris can cause or obscure lane obstructions. These weather events translate into changes in traffic conditions, roadway safety, travel reliability, operational effectiveness, and productivity.

Traffic conditions may change in a variety of ways. Weather events may prompt travelers to change departure times, cancel trips, choose an alternative route, or select a different mode. Slick pavements, low visibility, and lane obstructions lead to driving at lower speeds or with increased following distances. These changes in driver behavior can impact the operation of signalized roadways, where traffic signals are timed for clear, dry conditions, through reduced traffic throughputs, increased delays, and increased travel times.

Weather affects roadway safety by increasing exposure to hazards and crash risk. Travel reliability for motorists and commercial vehicle operators is affected by a variety of weather conditions. Weather also impacts the operational effectiveness and productivity of traffic management agencies and road maintenance agencies through increased costs and lost time.

It is, therefore, an important responsibility of traffic managers and maintenance personnel to implement operational strategies that optimize system performance by mitigating the effects of weather on the roadways. The operational approaches used by these personnel dictate their needs for weather and road condition information. Accurate, timely, route-specific weather information, allows traffic and maintenance managers to better operate and maintain roads under adverse conditions.

The U.S. Department of Transportation (USDOT), Federal Highway Administration (FHWA) has defined three types of road weather management
strategies that may be employed in response to rain, snow, ice, fog, high winds, flooding, tornadoes, hurricanes, and avalanches. These comprise:

- **Advisory strategies** that provide information on prevailing and predicted conditions and impacts to motorists;
- **Control strategies** that alter the state of roadway devices to permit or restrict traffic flow and regulate roadway capacity; and
- **Treatment strategies** that supply resources to roadways to minimize or eliminate weather impacts.

There are a variety of approaches available to traffic managers to advise travelers of road weather conditions and weather-related travel restrictions (such as road closures due to fog or flooding). Strategies include posting warnings on dynamic message signs (DMS), broadcasting messages via highway advisory radio (HAR), and providing road condition reports through interactive traveler information systems such as web sites and 511 phone systems.

To control traffic flow during adverse weather, traffic managers may regulate lane use (such as lane reversals for evacuations), close hazardous roads and bridges, restrict access on particular roadways to designated vehicle types (e.g., tractor-trailers during high winds), implement variable speed limits, adjust freeway ramp metering rates, or modify traffic signal timings.

Maintenance managers utilize road weather information and decision support tools to assess the nature and magnitude of winter storms, determine the level of staffing required during a weather event, plan road treatment strategies (e.g., plowing, sanding, chemical applications), and activate anti-icing/deicing systems. Beyond winter weather, maintenance managers are also concerned about the impacts of other events such as sand storms and wildfires that may reduce visibility and create hazardous driving conditions.

Access to high quality road weather information helps managers improve safety, enhance traffic flow and travel reliability, and increase agency productivity. Weather mitigation strategies enhance roadway safety by reducing crash frequency and severity, restricting access to hazardous roads, and encouraging safer driver behavior. Road weather management strategies enhance traffic flow and mobility by allowing the public to make more informed travel decisions, promoting more uniform traffic flow, reducing traffic congestion and delay, and minimizing the time to clear roads of snow and ice. Productivity is increased through better interagency communication and data sharing, and by reduced labor, material and equipment costs for snow and ice control operations.
Underneath these broad operational objectives is a common need for actionable weather information based on high-quality weather data relevant to the transportation facilities to be managed. As described in more detail below, transportation operations managers have long depended on traditional weather data from the National Weather Service, commercial weather service providers, and more recently from their own road weather information systems (RWIS). These sources are limiting, however, in that they describe weather conditions in the atmosphere rather than on the ground—as with traditional weather reports and forecasts—or are insufficiently distributed to characterize conditions across the entire road network—as when obtained from fixed roadside environmental sensor stations (ESS). Connected vehicle technologies under development have the potential to address both of these challenges by distributing weather sensors everywhere across the road network at ground level.

2.2 Operational Policies and Constraints

The Concept of Operations for Road Weather Connected Vehicle Applications again provides an overview of the operational policies and constraints on acquisition and use of road weather condition information.

Operational policies for road weather management activities vary from state-to-state, both in terms of their detail and formality. Although they vary significantly in terms of scope and level of detail, many state transportation agencies have documented policies and procedures that describe strategies for conducting winter and non-winter maintenance activities under various adverse weather conditions. Similar guidelines for the management of traffic operations under adverse weather conditions appear to be less widespread but are gaining ground due to the efforts of the FHWA Weather-Responsive Traffic Management initiative. In many instances, the documented policies and procedures appear to be derived from personnel experience and informal rules of practice. It also appears that documented operational policies are supplemented with undocumented practices.

According to the American Association of State Highway and Transportation Officials (AASHTO), state transportation agencies are increasingly adopting the use of performance-based management approaches. All state departments of transportation track asset condition and safety data. The majority of states provide comprehensive performance data to decision makers to both increase accountability to customers, and achieve the best possible transportation system performance under current levels of investment. The definition of the performance measures and the formality of reporting again appear to vary from state to state,
but weather-related metrics, particularly relating to snow removal during winter storms, are not uncommon.

Overall, there are no operational policies related to road weather management that are common across the United States. In addition, there do not appear to be any policies that will specifically constrain the development of connected vehicle road weather applications.

2.3 Description of Current Situation

2.3.1 Road Weather Systems

Traffic and maintenance managers use a variety of environmental monitoring systems and other data sources to gather information on weather and related road conditions to make their decisions on how best to mitigate weather impacts. These managers typically use four types of road weather information: atmospheric data (e.g., precipitation type and rate, wind speed and direction), roadway surface data (e.g., surface status and temperature), roadway subsurface data (e.g., subsurface temperature and moisture content), and hydrologic data (e.g., stream levels near roads). These data are generally obtained from various observing system technologies, including fixed sensor stations, transportable sensor stations, mobile sensing devices, and remote sensors.

Additionally, predictions of environmental conditions can be obtained by traffic and maintenance managers from public sources, such as the National Weather Service (NWS) and the Tropical Prediction Center, and from private meteorological service providers. Environmental data may also be obtained from mesoscale environmental monitoring networks, or mesonets, which integrate and disseminate data from many observing systems (including agricultural, flood monitoring and aviation networks).

An environmental sensor station (ESS) is the field component of an overall Road-Weather Information System (RWIS). An ESS comprises one or more sensors measuring atmospheric, surface, subsurface, and water level conditions, while centralized RWIS hardware and software are used to collect and process observation data from numerous ESS. Environmental observation data from the field are then used to develop route-specific forecasts and provide decision support for various operational actions by the traffic and maintenance managers. There are more than 2,400 ESS owned by state transportation agencies. Most of these stations - over 2,000 - are part of an RWIS used to support winter road maintenance activities. The other stations are deployed for various applications, including traffic management, flood monitoring, and aviation.
Atmospheric data from ESS can include air temperature and humidity, visibility distance, wind speed and direction, precipitation type and rate, as well as air quality. Roadway surface data include pavement temperature, pavement freeze point, pavement condition (e.g., wet, icy, flooded), pavement chemical concentration, and subsurface conditions (e.g., soil temperature). Water level data include tide levels (e.g., hurricane storm surge), stream, river, and lake levels near roads, and the conditions in areas known to flood during heavy rains or as a result of runoff.

Mobile sensing involves the integration of sensors and other systems onto vehicle platforms. In combination with vehicle location and data communications technologies, mobile sensor systems can be used to sense both pavement conditions (e.g., temperature, friction) and atmospheric conditions (e.g., air temperature). While less widespread than fixed sensors, several state transportation agencies have deployed maintenance vehicles equipped with mobile environmental sensors. These environmental sensors will complement other data collected on vehicles for maintenance purposes, such as snow plow status and material usage. In addition to these efforts by state agencies, the Connected Vehicle program that could be widely deployed on light and heavy vehicles has the potential to dramatically increase the number of mobile sensor systems across the United States.

The value of obtaining data from heavy vehicles needs to be noted here. Trucks and public transit vehicles operated as part of public fleets offer two particular advantages over privately-owned light vehicles: their data buses generally offer more data that is more easily accessible than that on light vehicles, and there are fewer privacy restrictions associated with their location data. These factors together facilitate gathering a wider range of data types with better correlation to roadway and vehicular conditions than are generally available from privately-owned light vehicles.

The Concept of Operations for Road Weather Connected Vehicle Applications continues.

The FHWA Road Weather Management Program (RWMP) is currently demonstrating how weather, road condition, and related vehicle data can be collected, transmitted, processed, and used for decision making through the Integrated Mobile Observations (IMO) project. In this project, the National Center for Atmospheric Research (NCAR) is partnering with the Minnesota and Nevada Departments of Transportation to obtain vehicle data from heavy
vehicles, including snow plows, and light-duty vehicles as they carry on routine maintenance functions across their states.

Additionally, the NWS has sponsored the development of the Mobile Platform Environmental Data (MoPED) system, a mobile sensing system deployed on buses and commercial trucks. Current MoPED data elements comprise road and air temperature, rain intensity, light level, relative humidity, and atmospheric pressure, plus derived values of dew point and sea level pressure.

Remote sensors are located at a significant distance from their target. Examples are satellites and radar systems that can be used for surveillance of meteorological conditions. Images and observations from remote sensors are used for weather monitoring and forecasting from local to global scales. Remote sensing is used to quantitatively measure atmospheric temperature and wind patterns, monitor advancing fronts and storms, and image water in all three of its states (e.g., vapor in the air, clouds, snow cover).

Beyond the deployment of the various environmental data collection systems, other initiatives have been undertaken to make the information usable to the transportation community and others. In 2004, USDOT established the Clarus Initiative with a broad goal to reduce the impact of adverse weather conditions on surface transportation users. The Clarus Initiative is based on the premise that the integration of a wide variety of weather observing, forecasting, and data management systems, combined with robust and continuous data quality checking, could serve as the basis for timely, accurate, and reliable weather and road condition information.

A core component of the Clarus Initiative is the Clarus System. The Clarus System is an integrated observation and data management system that collects near-real time information from state and local government-owned ESS, together with comprehensive metadata on these systems. The Clarus System conducts a variety of quality checks on the data, and makes the data available to public and private sector end-users, and researchers.

The Clarus System is, however, nearing the end of its effective life and its functions are being migrated to next-generation systems. Its operations support functions will be moved to the NOAA Meteorological Assimilation Data Ingest System (MADIS)\(^1\). Like the Clarus System, MADIS collects data from surface surveillance systems, but its sources also include hydrological monitoring networks, balloon-borne instruments, Doppler radars, and aircraft sensors. This

\(^1\) madis.noaa.gov
multimodal data collection providing a broader range of meteorological data in one system can offer significant advantages for road weather operations. The research functions of *Clarus* will be transitioned to the U.S. DOT’s Real-Time Data Capture and Management (RTDCM) program and a new Weather Data Environment (WxDE) that will capture data from both the existing *Clarus* sources and from new mobile sources in the IMO and other connected vehicle deployments. The WxDE will support both near real-time applications and long-term archiving of road weather data.

The RWMP has also invested significantly in connected vehicle technologies through its development of the Vehicle Data Translator (VDT) at NCAR. The VDT ingests and processes mobile data from sensors on vehicle and combines this with ancillary weather data sources. The earliest versions of the VDT were developed around data from connected vehicles in a development test environment in the Detroit area during the winter and spring of 2009 and 2010. For this data to be useful to the broad community of stakeholders, it must be acquired and then processed into meaningful, actionable information. The VDT inputs two types of data:

- Mobile data are all data originating from a vehicle, whether native to the Controller Access Network (CAN) bus or as an add-on sensor (e.g., pavement temperature sensor mounted to a vehicle).
- Ancillary data represent all other data, such as surface weather stations, model output, satellite data, and radar data.

Vehicle data of interest in the VDT include external air temperature, wiper status, headlight status, antilock braking system and traction control system status, rate of change of steering wheel, vehicle velocity, date, time, location, vehicle heading, and pavement temperature; ancillary data elements used in VDT algorithms include radar, satellite, and surface station data from fixed data sources. Algorithms in development through VDT Version 3.0 include:

- A precipitation algorithm that will provide an assessment of the type and intensity (amount/hour) or accumulation rate of precipitation that is falling to the road surface by road segment.
- A pavement condition algorithm is being developed to derive the pavement condition on a segment of roadway from the vehicle observations.
• A visibility algorithm is being designed to provide additional information by road segment on both a general decrease in visibility, and more specific visibility issues.

2.3.2 Connected Vehicle Programs

Connected vehicle programs as a whole represent an interconnected set of cooperative efforts among many constituencies: the U.S. DOT, state and local agencies, vehicle manufacturers, academic and research organizations, commercial vehicle operators, and communications equipment providers. These programs aim to enable interoperable networked wireless communications among vehicles, the infrastructure, and other wireless devices. Connected vehicle applications have the potential to affect all dimensions of surface transportation system operations.

• Connected vehicle safety applications are intended to increase situational awareness and reduce or eliminate crashes through vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) data transmission that will support driver advisories, driver warnings, and vehicle and infrastructure controls.

• Connected vehicle mobility applications will provide a connected, data-rich travel environment. The connected vehicle network will capture real-time data from equipment located on-board vehicles and within the infrastructure.

• Connected vehicle environmental applications will both generate and capture environmentally-relevant real-time transportation data and use this data to create actionable information to facilitate "green" transportation choices.

The development and applications of wireless communications in vehicular environments has been a major focus of development within and in support of connected vehicle applications. In particular, 5.9 GHz DSRC technologies have been specified and developed specifically to support V2V and V2I interactions with low wireless communications latency and high bandwidth. Although it is possible to implement many connected vehicle applications with other wireless technologies—cellular data networks or Wi-Fi, for example—DSRC has been developed from its beginnings to meet the specific needs of connected vehicles.

Within this broader context, connected vehicle technologies hold the promise to transform road-weather management. Road weather connected vehicle applications will dramatically expand the amount of data that can be used to assess, forecast, and address the impacts that weather has on roads, vehicles, and
travelers; fundamentally changing the manner in which weather-sensitive transportation system management and operations are conducted. The availability of road weather data from an extended set of mobile sources will vastly improve the ability to detect and forecast road weather and pavement conditions, and will provide the capability to manage road-weather response on specific roadway links.

The potential for improvements in road weather information availability through deployment of connected vehicle technologies is already being demonstrated in the U.S. DOT RWMP IMO projects mentioned earlier. The Nevada DOT IMO demonstration gathered data from sensors on agency vehicles and sent it to a data aggregation system over the state’s 915 MHz wireless data network. Minnesota DOT gathered data from snowplow trucks with an existing automated vehicle location (AVL) system and sent it to a data aggregation system over a commercial cellular network. Data from both of these demonstrations was sent to the VDT and the Clarus System and will be migrated to the WxDE for future studies. The RWMP and Michigan DOT have started a project demonstrating collection of data from vehicles using cell phones connected directly to a vehicle’s CAN bus through the OBD-II port, again sending the observations to data aggregation systems over the cellular network, to be processed by the VDT and ultimately to be archived in the WxDE.

2.4 Users and Other Involved Personnel

The Concept of Operations for Road Weather Connected Vehicle Applications describes the key constituencies for road weather information use within transportation operations.

2.4.1 Use of Road Weather Information in Maintenance Operations

Maintenance managers obtain and make extensive use of road weather information. This information help managers make decisions for a variety of winter and non-winter maintenance activities, including decisions about staffing levels, the selection and timing of maintenance activities, and resource management (such as personnel, equipment, and materials), as well as road treatment strategies during winter storms.

Winter road maintenance activities are especially sensitive to weather conditions. During this period of the year, maintenance tasks can often involve snow and ice treatment strategies, including plowing snow, spreading abrasives to improve vehicle traction, and dispensing anti-icing/deicing chemicals to lower the freezing point of precipitation on the pavement. In regions with heavy snowfall,
maintenance managers may erect snow fences adjacent to roads to reduce blowing and drifting snow. Another mitigation strategy involves the use of slope sensors and avalanche forecasts to minimize landslide and avalanche risks. When a slope becomes unstable due to snow accumulation or soil saturation, roads in the slide path may be closed to allow the controlled release of an avalanche or landslide. Snow, mud and debris are cleared and damaged infrastructure is repaired before the affected route can be reopened to traffic.

Many non-winter maintenance activities are also impacted by weather conditions. Mowing is conducted on a cycle throughout the summer months but will be suspended during heavy rain and thunderstorms. The spraying of herbicides is not conducted during rain storms or high winds. Striping requires a dry roadway, no high winds, a minimum ambient air temperature, and no immediate likelihood of rain. Surface repairs (such as pothole and seam repairs) using hot mix asphalt need dry pavement with a minimum ambient air temperature and no risk of rain in the short-term. Many maintenance activities will also be suspended for lightning storms, tornado forecasts, and periods of low visibility to protect the safety of both maintenance personnel and travelers who may unexpectedly encounter maintenance equipment on or near the roadway.

2.4.2 Use of Road Weather Information in Traffic Operations

The FHWA RWMP is encouraging state and local transportation agencies to be more proactive in the way that they manage traffic operations during weather events. Weather Responsive Traffic Management (WRTM) is the central component of the program’s efforts. WRTM involves the implementation of traffic advisory, control, and treatment strategies in direct response to or in anticipation of developing roadway and visibility issues that result from deteriorating or forecast weather conditions.

Over the past 10 years, transportation agencies have implemented various strategies to mitigate the impacts of adverse weather on their operations. These strategies range from simple flashing signs to coordinated traffic control strategies and regional traveler information. More recently, various new approaches, technologies, and strategies have emerged that hold potential for WRTM, including Active Traffic and Demand Management (ATDM) and Integrated Corridor Management (ICM). Operational strategies that are currently used by traffic managers include the following:

- Motorist advisories, alerts and warnings intended to increase the awareness of the traveler to current and impending weather and pavement conditions. Approaches include active warning systems that
warn drivers of unsafe travel conditions through a particular section of roadway, often in remote or isolated locations; pre-trip road condition information and forecast systems; and en-route weather alerts and pavement condition information;

- Speed management strategies designed to manage speed during inclement weather events. This includes both advisory, which usually involves posting an advisory travel speed that is deemed safe by the operating agency for the current travel conditions, and regulatory speed management techniques, which include speed limits that change based on road, traffic, or weather conditions;

- Vehicle restriction strategies involve placing restrictions on the types or characteristics of vehicles using a facility during inclement weather events. These strategies might include size, height, weight, or profile restrictions;

- Road restriction strategies restrict the use of a facility during inclement weather to help travelers avoid sections of roadway that are dangerous or would cause substantial delay. Approaches include lane use restrictions, such as requiring trucks to use a specific lane during inclement weather conditions; parking restrictions including special parking rules that are implemented during significant snow events that restrict when and where on-street parking is permitted; access control and facility closures; and reversible lane operations, particularly during evacuations;

- Traffic signal control strategies involve making modifications or influencing the way traffic signals operate during inclement weather. Approaches in this category include changes to vehicle detector configuration, vehicle clearance intervals, interval and phase duration settings, and implementation of special signal coordination plans designed for inclement weather.

### 2.4.3 Use of Road Weather Information by Emergency Managers and Emergency Responders

Emergency managers, who are responsible the safe movement or evacuation of people during natural or man-made disasters rely on comprehensive weather and road condition data. Current and predicted weather and road condition information is obtained through RWIS (often through collaboration with transportation agencies or airport operators), water level monitoring systems, federal government sources such as the Tropical Prediction Center, commercial weather information providers, and the media. Emergency managers use decision
support systems that present weather data integrated with population data, topographic data, road and bridge locations, and traffic flow data.

Emergency managers gather weather observations and forecasts to identify hazards, their associated threatened areas, and select a response or mitigation strategy. In response to flooding, tornadoes, hurricanes, wild fires or hazardous material incidents, emergency managers can evacuate vulnerable residents, close threatened roadways and bridges, operate outflow devices to lower water levels, and disseminate information to the public. Many emergency management practices require coordination with traffic managers. Emergency managers may use several control strategies to manage traffic on designated evacuation routes. These strategies include opening shoulder lanes to traffic, contraflow operations to reverse traffic flow in selected freeway lanes, and modified traffic signal timing on arterial routes.

Emergency responders, including fire trucks, ambulances, and paramedics, must routinely operate on roadways affected by adverse weather events. With no option to defer their trips, emergency responders must reach their destinations irrespective of conditions or road closures. Emergency responders rely on routing systems or must make dispatching decisions to hand-off an emergency call to another responder often in the absence of accurate, up-to-date road-weather information.

2.4.4 Use of Road Weather Information by Motorists and Commercial Vehicle Operators

Traffic managers disseminate road weather information to road users of all types to influence their travel decisions. Different types of road users have varying information needs. In the event of a road closure, recreational travelers may need alternative route information, while commuters familiar with their route may not. Passenger vehicle drivers are interested in road surface conditions. Commercial vehicle operators, who are especially sensitive to time delays and routing, may also need information about road restrictions due to high winds, height and weight limits, or subsurface freeze/thaw conditions. Overall, road weather information allows travelers to make decisions about travel mode, departure and travel time, route selection, vehicle type and equipment, and driving behavior.

Road weather information may be disseminated via roadway infrastructure, telephone systems, web sites, and other broadcast media. Roadway systems that are typically controlled by traffic managers utilize highway advisory radio, dynamic message signs, and flashing beacons atop static signs to alert motorists to hazards. Interactive telephone systems and applications on smart phones allow
motorists to access road weather information both pre-trip and en-route. Many state transportation agencies provide general road condition data through toll-free or 511 telephone numbers, web sites, and, increasingly, through social media.

It is also significant in this context that messages can be tailored to particular types of vehicles. For example, high profile vehicles could subscribe to wind advisories and be routed around segments and bridges subject to those advisories.
3 Justification For and Nature of Changes

This section of the Concept of Operations describes the challenges in the current situation and the opportunities for improvement.

3.1 Justification for Changes

The Concept of Operations for Road Weather Connected Vehicle Applications provides a thorough description of the impacts of weather and the case for proactive measures to mitigate its impacts on roadways.

The influence and impacts of weather conditions on the operation of the transportation system have been well analyzed\(^2\). Adverse weather conditions have been shown to have significant impacts on the safety, mobility, and productivity of transportation system users and roadway operators.

On average, there are over 6,301,000 vehicle crashes in the United States each year\(^3\). Twenty-four percent of these crashes, or approximately 1,511,000, are identified as weather-related. Weather-related crashes are defined as those crashes that occur in adverse weather (such as, rain, sleet, snow, high winds, or fog) or on slick pavement (i.e., wet, snowy/slushy, or icy).

Weather has similarly dramatic effects on transportation system mobility. Significant roadway capacity reductions can be caused by flooding or by lane obstruction due to snow accumulation and wind-blown debris. Road closures and access restrictions due to hazardous conditions (such as large trucks in high winds) also decrease roadway capacity. Weather events can also reduce mobility and reduce the effectiveness of traffic signal timing plans on arterials. On freeways, light rain or snow can reduce average speed by three to thirteen percent, while heavy rain can decrease average speed by three to sixteen percent, and in heavy snow, average freeway speeds can decline by five to forty percent. Low visibility can cause speed reductions of ten to twelve percent. Freeway capacity reductions can also be significant: from four to eleven percent in light rain; ten to thirty percent in heavy rain; twelve to twenty-seven percent in heavy snow; and by twelve percent in low visibility.

Overall, it has been estimated that twenty-three percent of the non-recurrent delay on highways across the nation is due to the impacts associated with snow,

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\(^2\) [http://ops.fhwa.dot.gov/weather/q1_roadimpact.htm](http://ops.fhwa.dot.gov/weather/q1_roadimpact.htm), Retrieved March 31, 2012

\(^3\) Fourteen-year averages from 1995 to 2008 analyzed by Noblis, based on NHTSA data
ice, and fog. This amounts to an estimated 544 million vehicle-hours of delay per year.

Adverse weather increases the operating and maintenance costs of road maintenance agencies, traffic management agencies, emergency management agencies, law enforcement agencies, and commercial vehicle operators. Winter road maintenance activities account for roughly twenty percent of state transportation agency maintenance budgets. Each year, state and local agencies spend more than $2.3 billion on snow and ice control operations.

Each year trucking companies lose an estimated 32.6 billion vehicle-hours due to weather-related congestion in the nation’s top 281 metropolitan areas. The estimated cost of weather-related delay to trucking companies is $3.1 billion annually in the nation's 50 largest cities.

The availability of accurate, up-to-date road weather observations that are tailored to the needs of roadway operators, together with the decision support tools that place the observation data in a transportation system operations and management context, can play a significant role in helping better prepare roadway operators and users of the transportation system for adverse weather conditions. In turn, this approach has the potential to improve safety, mobility, and productivity. The FHWA Road Weather Management Program has already undertaken significant work to acquire, quality check, and make available road weather observations from fixed, mobile, and remote sensing systems.

### 3.2 Description of Opportunities and Desired Changes

The convergence of rapid advances in CV technology with similar advances in processing of mobile weather data has created a unique opportunity to develop and demonstrate collection of weather observations from probe data in standardized DSRC transmissions. This project will bring developments in connected vehicle and road weather research together into an end-to-end prototype of deployable connected vehicle technology for road weather applications. It will:

- Collect data according to latest data standards from embedded vehicle sensors through the vehicle’s CAN bus;
- Use interoperable DSRC equipment to send data from the vehicle to roadside units;
- Deploy the newest generation (3.0) of roadside units in locations along the Long Island Expressway where the previous generation equipment was deployed and supported by power and backhaul services;
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- Forward data from RSEs to a data aggregation service;
- Provide data from the aggregation service to
  - The VDT, for synthesis of road weather condition data from vehicle-based observations, and
  - The WxDE, where it becomes available for connected vehicle researchers and real-time applications.

3.3 Preliminary System Requirements

A Concept of Operations typically identifies priorities among the changes being proposed as a means of clarifying and providing some bounds to the potential for system development. For this project, that intent is being met by specification of a set of preliminary system requirements.

Table 1 - Preliminary System Requirements

<table>
<thead>
<tr>
<th>ID</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>The system shall acquire weather-related data from vehicles.</td>
</tr>
<tr>
<td>110</td>
<td>The system shall be able to acquire weather-related data from a heavy vehicle J1939 data bus.</td>
</tr>
<tr>
<td>120</td>
<td>The system shall be able to acquire weather-related data from a vehicle J1979 data bus.</td>
</tr>
<tr>
<td>130</td>
<td>The system shall be able to acquire weather-related data from a RS-232 serial data bus.</td>
</tr>
<tr>
<td>200</td>
<td>The system shall assemble weather-related data acquired from vehicles into messages.</td>
</tr>
<tr>
<td>210</td>
<td>The system shall encode weather-related data elements defined in the SAE J2735 DF_VehicleStatus data frame into a message conforming to the MSG_BasicSafetyMessage specification.</td>
</tr>
<tr>
<td>220</td>
<td>The system shall encode weather-related data elements not defined in the SAE J2735 DF_VehicleStatus data frame into free-form local content within a message conforming to the SAE J2735 MSG_BasicSafetyMessage specification.</td>
</tr>
<tr>
<td>300</td>
<td>The system shall transmit messages containing weather data from vehicles to roadside units over 5.9 GHz DSRC.</td>
</tr>
<tr>
<td>350</td>
<td>The system shall encode digital signatures according to the ToBeSigned message format defined by IEEE 1609.2.</td>
</tr>
</tbody>
</table>
The system shall aggregate probe data from RSEs.

The system shall associate probe data with its vehicular sources.

The system shall make weather and road condition data available to other systems.

The system shall make weather and road condition data available to other systems in the form of subscriptions.

The system shall make weather and road condition data available to the WxDE.

The system shall make weather and road condition data available to the VDT.

The system shall monitor the state of its operations.

The system shall monitor the state of its RSE operations.

The system shall monitor the state of its aggregator operations.

3.4 Changes Considered But Not Included

The nature of this opportunity and the defined scope of work are sufficiently specific that there are few alternatives to the changes described above to be considered outside the detailed design.

This is especially true with respect to the available DSRC-based messaging schemes. Many of the connected vehicle references, including the Concept of Operations for Road Weather Connected Vehicle Applications describe the use of the Basic Safety Message (BSM) Part 2 as a means of structuring data obtained from vehicles for DSRC transmission. Although this is an alternative under the SAE J2735 standard, it presents limitations to ensuring effective probe data collection.

The BSM represents a single snapshot in time to be broadcast at a regular interval. There is no provision within the BSM itself for recording or rebroadcast of data that was not received by an RSE. As such, only the BSM data captured and broadcast within range of another DSRC receiver would generally be passed on to a data aggregator. Probe data transmitted in a BSM would effectively cover only the range of the receiving RSE.

Because of the BSM limitations on geographical and temporal range, it would be preferable to use the J2735 Probe Vehicle Data Message (PVDM) as the basis for
weather and road condition data exchange. The PVDM accumulates snapshots into a message that can be stored and sent when an RSE is in range. The management of the PVDM allows some flexibility in how frequently and how many snapshots are written into any particular message. Multiple PVDMs can be accumulated for transmission when in range of a receiving RSE. These characteristics of the PVDM make it preferable to the BSM Part 2 for probe data gathering.

Unfortunately, the current generation of available RSEs does not fully support nor has been tested for implementation of the PVDM. The only alternative supported by RSEs available at this time is to use the BSM Part 2 to transmit the data from the OBE on the vehicle to the RSE and provide the data from the RSE to an aggregator. A work-around solution, described in Section 4.1, will be needed to extend the probe data availability beyond the context of the RSE.
4 CONCEPTS FOR THE PROPOSED APPLICATION

The DSRC-based Mobile Road and Weather Condition application (MRdWxS-D) is described in this section in terms of its system architecture, expressed in two views; its potential operational policies and constraints; modes of operation; user classes; and support environment.

4.1 System Architecture

The system’s proposed architecture can be described from various viewpoints, depending on the range of perspectives needed to appropriately detail its design and operation. For the MRdWxS-D, a functional view and a deployment view are offered here.

4.1.1 Functional View

A functional view of the system describes the system and its components in terms of what its major components do—its functions—and in the flow of data among those components.

![Figure 1 - Functional Data Flows](image-url)
Figure 1 presents a functional view of the system. Components inside the system boundary are those to be developed in this project; those outside the boundary represent existing systems and users that will (or could) interact with the new MRdWxS-D. The major components of the system in this view are the OBE, the RSE, the system monitor, and the weather data aggregator. Interfacing systems outside the system are the vehicle’s sensors, through its data logger, the WxDE, the VDT, and NY State systems that may use the data.

The OBE obtains data from the vehicle data logger through a set of data message standards, each one of which is specific to a particular type of vehicle. As described in the *Messaging Requirements* document, the SAE J1939 standard specifies the data that may be available from heavy vehicles such as snowplow trucks. The SAE J1979 standard describes data that may be available from “light” vehicles including passenger cars and the HELP vehicles that will be used in this project. Each of these standards applies only to those vehicle types for which it is intended, and there is no particular overlap or consistency between the data specifications or standards.
Furthermore, these standards describe the data that may be available from those vehicle types. The actual data available from the vehicle will depend on which sensors are installed on the vehicle and connected to its data bus and on the manufacturer’s implementation of the standard. Determination of what data have been made available through this interface will come through either manufacturer-specific documentation or through polling and discovery on that interface.

The OBE itself captures the data from the interface, caches it locally, repackages the data for transmission, and transmits the data. Functionally, the OBE watches the stream of data on the data logger interface (the vehicle data bus) for parameters of interest and captures them for further processing. Caching the data enables the system to create snapshots of data from the higher-frequency flow of data provided by the vehicle data logger. The repackaged snapshots are then ready for off-board DSRC transmission.

The snapshot message broadcast from the OBE to the RSE conforms to the MSG_BasicSafetyMessage in the SAE J2735 standard as described by the Messaging Requirements document.

The RSE records all network traffic, both input and output, for each physical interface in a separate messaging log file. For this deployment there will be a NYSDOT backhaul network interface and the wireless DSRC interface. There will therefore be four log files: DSRC input, DSRC output, backhaul input, and backhaul output.

The messaging logs are created using the built-in Linux application, tcpdump, which stores raw network packet data in a pcap format file. A pcap file is very straightforward. It contains a main header that identifies the byte order of the captured data, the version of file format being used, the timestamp accuracy, and the maximum length of data stored for each packet. Following the main header is one record for each packet captured which lists the timestamp measured in microseconds, the number of bytes in the original packet, the number of bytes of the packets captured in the file, followed by the actual binary packet data.

The RSE transmits its saved log files to a configured network destination at both a fixed interval (for example, five minutes) as well as when a configured size threshold is reached (for example, ten megabytes). This strategy allows the RSE to conserve local storage space; a busy RSE off-loads log files frequently, while a less busy RSE off-loads much smaller log files at more regular intervals. Care was taken to exclude the log file off-load process from being captured in the backhaul output log file. Otherwise, that file would uncontrollably expand.
Each RSE is configured to send a heartbeat message—RSE identifier and timestamp—to a network destination at regular intervals, usually one to five minutes. A System Monitor is configured with a list of RSE identifiers and administrator email addresses. When more than two consecutive expected heartbeat messages are missed, the system monitor sends a notification email to the identified administrators for them to investigate and resolve any problems.

The Weather Data Aggregator occupies the network destination address where RSE send their network communication log files. The Weather Data Aggregator receives the log files and reads the J2735 snapshot data from the pcap-formatted data. The J2735 snapshot data are then formatted again to a comma separated value (CSV) file format and published. The received RSE log files will also be stored at the Weather Data Aggregator long-term.

Like the RSEs, the Aggregator is configured to send a heartbeat message to a network destination at regular intervals, usually one to five minutes. The System Monitor is configured with the Aggregator’s identity and an administrator email address. When more than two consecutive expected heartbeat messages are missed, the system monitor sends a notification email to the identified administrator for investigation and resolution of any problems. The weather observations’ CSV format conforms to the WxDE format. Each record in the file contains values for unique vehicle identifier, timestamp, latitude, longitude, altitude, followed by the weather related values each in their own column.

The WxDE (as described in Section 2.3.1) will subscribe to weather observations from the aggregator. Collection of the subscribed data into the WxDE will require the configuration of an MRdWxS-D collector component. In a similar fashion, the VDT (also described in Section 2.3.1) will subscribe to weather data from the aggregator and need its own collection component configuration.

INFORM can retrieve weather observations from either the WxDE or Weather Data Aggregator, as it is a minimal exercise to create a specific output format for that system, if necessary. NYSDOT systems acquiring observation data from the aggregator can likewise retrieve weather observations from the same endpoints.

4.1.2 Deployment View

The deployment view depicts the equipment likely needed to implement the system as well as the network interconnections and supporting infrastructure hardware. The diagram elements should be familiar from the functional data flow diagram, but they are arranged into organizational boundaries to provide an understanding of what is where and who has operational responsibilities.
To gather weather-related vehicle data, it is first necessary to connect appropriate equipment to the probe vehicles. This takes the form of a data logger—a device capable of receiving and interpreting vehicle diagnostic information in its native format. A data logger specific to an available diagnostic bus is installed in the designated project vehicles: one type for J1979 data and another type for J1939 data. J1939 data loggers also receive and interpret data generated from aftermarket equipment connected to the same data bus.

Each probe vehicle also requires a DSRC OBE to transfer the data from the data logger wirelessly to nearby DSRC RSEs. Normal OBE operation continuously formats and stores J2735 messages derived from the data logger data until the OBE detects that it is in range of a RSE. Then the OBE sends the weather-related snapshot data to the RSE in last-in-first-out order.

RSEs are deployed in NYSDOT equipment cabinet points of presence with necessary antennae mounted on nearby mast arms. RSEs receive their power from the cabinet power bus, either through direct wiring or power-over-Ethernet. Their DSRC interface is connected to the mounted antenna and the IPv6 backhaul network interface is connected to a network switch in the cabinet.

It is at this point that the field equipment interacts with the NYSDOT network. The deployment diagram shows a likely configuration for network equipment in that environment, but is not intended to exhaustively detail the complex NYSDOT network, but only the limited view necessary to describe what is needed for this deployment.

RSEs automatically configure their IPv6 network address from the router announcement provided by a router connected to the same network VLAN. Domain name server addresses are provided through the DHCPv6 mechanism. While newer routers may support RFC 5006 and can provide DNS addresses through the announcement, it is not a given that existing NYSDOT routers or newly acquired RSE will support this option. This configuration is recommended so that RSE, which are expensive to configure locally, are more easily managed in the network environment.
RSE are configured to send heartbeat status and network log messages to specific network host names at regular intervals. When this occurs, the host name is resolved to an IPv6 address and the information is sent. The gateway router managing the RSE IPv6 network is configured with 6to4 tunnels so that the heartbeat and network log messages can be sent across IPv4 networks to the correct server destination.

The system monitor receives RSE heartbeat messages, and when messages are not received as expected, the system monitor will generate and send an administrative message to system administrators to investigate and resolve perceived RSE issues.

The weather data aggregator receives RSE network logs. The service then reads the J2735 Basic Safety Message Part 2 weather-related observations and formats them for distribution to other systems. This can take the form of comma-separated value files or other formats as described in the previous function data flow section to support receipt by the INFORM, Weather Data Environment, and other interested systems.
The Weather Data Environment, Vehicle Data Translator, and INFORM systems read the information from the weather data aggregator. To do this, the weather data aggregator needs to be network accessible from the network locations where those systems are hosted. This can be accomplished through existing IPv4 equipment and connections as IPv6 communication is handled by the configured 6-to-4 tunnel.

The proposed deployment diagram shows the weather data aggregator and system monitor services hosted within the NYSDOT network. Alternatively, these services can be hosted with Synesis Partners. The advantage of Synesis Partners hosting the weather data aggregator and system monitoring services is that it eliminates the need to find available equipment or acquire and maintain extra NYSDOT equipment and also eliminates configuring an SMTP service to deliver administrative monitoring messages for the system monitor, which may have agency network policy constraints. In the case of Synesis Partners hosting, the 6to4 tunnel would be configured for that external destination.

4.2 Operational Policies and Constraints

This section identifies known current and potential future constraints and risks in the development and operation of the MRdWxS-D.

Data Availability from Mobile Sensor Platforms

The availability of data from vehicles is subject to the sensors on the vehicle (both original equipment and aftermarket modifications) and the manufacturer’s implementation of the applicable standards for accessing the data from the CAN bus. As such, data that may be specified for acquisition or transmittal in downstream processes may not be available from the root sources.

Deployment Coverage

Unlike fixed ESS and their associated RWIS, the data coverage from mobile sensor platforms is variable in both geographic and temporal ranges. The availability of data will be highly dependent on the routes driven by the vehicles from which data are being collected, the intervals over which the vehicles are operated, and even by the frequency by which the vehicles encounter RSEs to receive their data transmissions. This concern could be mitigated with additional vehicles—for example, more trucks and transit vehicles—and routes.

Reliability of OBE/RSE Data Exchange

Reliable exchange of data between the vehicle OBE and the infrastructure RSE is limited in range to approximately 300 meters and may be less under some siting
and environmental conditions. For moving vehicles, this will constrain the time interval during which data exchange can occur. Since probe data accumulates on the vehicle OBE until it can be transmitted, it is possible for data to be backlogged for transmission on the OBE if RSEs to receive the data are not encountered frequently enough or for long enough intervals. The latency of data delivery to the aggregator will be somewhat variable until sufficient RSEs are deployed to facilitate regular data exchange. These potential limitations can be evaluated based on the data collected in this study.

**WxDE/VDT Data Collection**

Like the *Clarus* System before them, the WxDE and VDT use collector components specific to particular data sources to gather data for processing and presentation. These systems also operate independently of the MRdWxS-D. As such, the availability of processed MRdWxS-D data from the WxDE and VDT depends on the implementation and availability of collector components in those systems as well as continued operation of the MRdWxS-D itself. The presence of the MRdWxS-D collector component is assured in this project by the implementation team’s access to the WxDE and VDT, but the operational dependency is still subject to the reliability of data connections and intermittent service interruptions.

### 4.3 Modes of Operation

The modes of operation for the MRdWxS-D are:

**Normal** – The system is operating as expected. Data are being collected on the vehicle, compiled on the OBE, transmitted to the RSE, received and prepared for subscribers by the aggregator, and successfully collected by the WxDE/VDT.

**Degraded** – One or more of the system functions are not working properly or may not be available. Some types of malfunction may be known to the System Monitor, but the system will require operator intervention to restore to the Normal mode.

**Maintenance** – System maintenance may remove some components from Normal operation for finite intervals. Other components that are active during that time will continue to operate normally, but suspend their interaction with the component(s) in Maintenance mode. Components will be designed to resume operations gracefully and recover and reattempt appropriate data exchanges.
4.4 User Classes and Other Involved Personnel

HELP Vehicle Operators – Vehicle operators will be passive participants in the operation of the system. While operating their vehicles, OBES will collect connected vehicle road weather information and will communicate this information to RSEs along the route.

Snow Plow Truck and Maintenance Vehicle Operators – Drivers will be passive participants in the collection and communication of connected vehicle road weather data. If road weather applications like the Enhanced Maintenance Decision Support System (E-MDSS) were deployed, however, these vehicle operators would be recipients of the information generated by the E-MDSS. Operators of these vehicles would interact with appropriate in-vehicle devices to receive instructions on their actions during winter weather events.

Maintenance Personnel – This group of users would interact with application like the E-MDSS. They would receive recommendations on winter weather treatment strategies from the E-MDSS based on roadway segment-specific information from the VDT. They would use the decision support tools available through the E-MDSS and direct the actions of the snow plow and other maintenance vehicle operators based on the system outputs.

4.5 Support Environment

The support environments for the MRdWxS-D are straightforward. The weather data aggregator, system monitor, and associated SMTP services can be executed on a single server or even on an existing server that hosts other services. The primary constraint is storage space. At least one TB should be available. The aggregator and system monitor can be hosted within the NYSDOT network or at Synesis Partners’ hosting facility.

The project calls for two RSEs to be deployed. Once deployed, very little support should be required. The system monitoring service will alert administrators of RSE problems that require investigation and direct physical intervention should be non-existent to rare.

The bulk of the support occurs with the NYSDOT network components during the initial RSE deployment. This is the time when necessary firewall, router, and switch configurations should be made. Setup generally entails the selection of the switch and RSE IPv6 addresses and configuration of a 6to4 tunnel on the router, and allowing the traffic through intervening firewalls. Once this is completed
and tested no further changes or support should be necessary unless precipitated by administrative need.
5 OPERATIONAL SCENARIO

This section describes the operational scenario for normal operation of the MRdWxS-D. Applications of data gathered by the system could include any of those described in the Concept of Operations for Road Weather Connected Vehicle Applications. The applications themselves are not within the scope of the MRdWxS-D.

5.1 Description

This scenario describes the gathering of weather-related data from vehicles equipped with connected vehicles 5.9 GHz wireless devices operating on a roadway with compatible connected vehicle wireless communications and the provision of that data to appropriate data aggregation and publishing services. The general process is that weather-related data is gathered from vehicles by their OBEs, sent by DSRC to RSEs in range, logged on the RSE and sent to a weather data aggregation service, and provided by the aggregator to other subscribing systems. Users have access to the data through the subscribed systems, which may be providing additional value-added application-specific processing. Figure 3 illustrates these interactions and identifies typical actors in each of these roles.
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5.2 Steps

1. Vehicles equipped for connected vehicle data gathering operate on the roadways.
2. Sensors on the vehicle measure and report data to the vehicle’s data bus (typically a CAN bus).
3. The vehicle’s OBE obtains weather-related data from the data bus.
4. OBE formats data into a basic safety message.
5. OBE stores BSM for transmittal.
6. Vehicle comes in range of RSE; OBE receives service announcement from RSE.
7. OBE broadcasts saved BSM to RSE.
8. RSE logs incoming message(s).
9. RSE pushes logs to the data aggregator over the backhaul network.
10. Aggregator formats data for downstream systems.
11. WxDE collects data from aggregator.
13. VDT reads data from aggregator.
14. VDT synthesizes weather data from vehicle data provided by aggregator.
15. Users obtain data from WxDE.
16. [Optional] INFORM obtains data from WxDE.
6 **SUMMARY OF IMPACTS**

This section provides a summary of key impacts arising from a successful DSRC-based weather and road condition prototype application development and deployment.

6.1 **Research Perspective**

The MRdWxS-D will significantly advance the state of road weather and connected vehicle research.

- The ability to collect weather-related probe data from vehicles over DSRC will have been conclusively demonstrated.
- The use of SAE J2735 basic safety message part 2 for weather-related data will have been demonstrated over a sustained period of operations.
- The provision of data collected from vehicles over DSRC to the WxDE and VDT for connected vehicle applications research will have been demonstrated.
- Weather-related data from vehicles operating in New York will be collected for operational feedback and longer-term research.
- Developers of connected vehicle road weather applications will have an archive of operations data against which to validate their approaches.

6.2 **Operations Perspective**

The MRdWxS-D will provide new capabilities in both road weather and connected vehicle operations.

- The CTS PFS and NYSDOT will have developed a prototype connected vehicle capability to enhance DOT operations and kickstart other weather-related applications.
- Agencies wanting to collect weather-related connected vehicle probe data will have access to a demonstrated system and deployment experience.
- NYSDOT will have upgraded part of its connected vehicle field infrastructure for use in other studies, application development efforts and operations.
7 **ANALYSIS OF THE PROPOSED SYSTEM**

This section provides an analysis of the potential benefits, limitations, advantages, and disadvantages of DSRC-based weather and road condition collection.

### 7.1 Summary of Potential Benefits and Advantages

The MRdWxS-D will demonstrate key new capabilities to the advantage of all CV applications and deployers.

- It will confirm the results and experience with DSRC equipment and interoperability at similar installations (e.g., the Ann Arbor Safety Pilot).
- It will demonstrate operation of IPv6-based DSRC transactions within a heterogeneous IP network.
- It will collect a significant body of weather-related data using standard basic safety messages.
- It will demonstrate and provide usable statistics on data collection over DSRC for use in follow-on performance assessments and requirements generation.

### 7.2 Disadvantages and Limitations

Even at a conceptual stage, there are expected to be some challenges in the deployment, operations and extensibility of DSRC-based road and weather condition (probe data) applications.

- The types and discoverability of data available over a vehicle’s CAN bus create some uncertainty as to what weather-related data will actually be available.
- Recent DSRC deployments have encountered challenges in deployment and operation of heterogeneous IPv6/IPv4 networks. The range of potential issues is wide enough to create some risk for the project.
- The short range of DSRC creates challenges in the management of data latency. Basic safety messages are generated continuously in vehicle operations, but can only be downloaded over DSRC when a vehicle is in range of an RSE. If RSE contact is too infrequent, data messages can become so backlogged on the RSE that they cannot be cleared faster than they are generated. This also creates a need to study and clarify the best
download queuing algorithms for minimizing the net latency of the probe data being downloaded.

- While a significant body of research has already been undertaken in other IMO projects, there is still a need for additional research on synthesis of road and weather condition data from vehicular probe data. This is clearly a worthwhile research objective, but is also a project limitation in that the performance assessment of the data collection will be limited by not initially having enough information on data collection strategies, particularly in the balance of data types and collection intervals.

- Successful deployment of the system described in this ConOps will provide for demonstration and research purposes, but will be limited in geographical and temporal coverage. This will limit operational use to a similar geography and time domain.
8 REFERENCES

8.1 Referenced Documents

The following references were used in the development of this document.


8.2 Acronyms and Definitions

Acronyms used in the document are defined in Appendix A.
## APPENDIX A – ACRONYMS

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AASHTO</td>
<td>American Association of State Highway and Transportation Officials</td>
</tr>
<tr>
<td>AVL</td>
<td>Automatic Vehicle Location</td>
</tr>
<tr>
<td>BSM</td>
<td>Basic Safety Message</td>
</tr>
<tr>
<td>CAN bus</td>
<td>Controller Access Network bus</td>
</tr>
<tr>
<td>CTS PFS</td>
<td>Cooperative Transportation Systems Pooled Fund Study</td>
</tr>
<tr>
<td>CV</td>
<td>Connected Vehicle</td>
</tr>
<tr>
<td>DHCP</td>
<td>Dynamic Host Configuration Protocol</td>
</tr>
<tr>
<td>DMA</td>
<td>Dynamic Mobility Applications</td>
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<tr>
<td>DNS</td>
<td>Domain Name System</td>
</tr>
<tr>
<td>DOT</td>
<td>Department of Transportation</td>
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<tr>
<td>DSRC</td>
<td>Dedicated Short Range Communications</td>
</tr>
<tr>
<td>E-MDSS</td>
<td>Enhanced Maintenance Decision Support System</td>
</tr>
<tr>
<td>ESS</td>
<td>Environmental Sensor Station</td>
</tr>
<tr>
<td>FHWA</td>
<td>Federal Highway Administration</td>
</tr>
<tr>
<td>IEEE</td>
<td>Institute of Electrical and Electronics Engineers</td>
</tr>
<tr>
<td>IMO</td>
<td>Integrated Mobile Observations</td>
</tr>
<tr>
<td>INFORM</td>
<td>NYSDOT’s INformation FOR Motorists system</td>
</tr>
<tr>
<td>IP</td>
<td>Internet Protocol</td>
</tr>
<tr>
<td>MADIS</td>
<td>Meteorological Assimilation Data Ingest System</td>
</tr>
<tr>
<td>MDSS</td>
<td>Maintenance Decision Support System</td>
</tr>
<tr>
<td>MoPED</td>
<td>Mobile Platform Environmental Data</td>
</tr>
<tr>
<td>NCAR</td>
<td>National Center for Atmospheric Research</td>
</tr>
<tr>
<td>NOAA</td>
<td>National Oceanographic and Atmospheric Administration</td>
</tr>
<tr>
<td>NWS</td>
<td>National Weather Service</td>
</tr>
<tr>
<td>NYSDOT</td>
<td>New York State Department of Transportation</td>
</tr>
<tr>
<td>pcap</td>
<td>From packet capture; a Unix network system logging</td>
</tr>
<tr>
<td>Acronym</td>
<td>Description</td>
</tr>
<tr>
<td>---------</td>
<td>-------------</td>
</tr>
<tr>
<td>PFS</td>
<td>Pooled Fund Study</td>
</tr>
<tr>
<td>RFC</td>
<td>Remote Function Call</td>
</tr>
<tr>
<td>RWIS</td>
<td>Road Weather Information System</td>
</tr>
<tr>
<td>RWMP</td>
<td>Road Weather Management Program</td>
</tr>
<tr>
<td>SAE</td>
<td>Society of Automotive Engineers</td>
</tr>
<tr>
<td>SMTP</td>
<td>Simple Mail Transfer Protocol</td>
</tr>
<tr>
<td>tcpdump</td>
<td>A Unix network traffic packet analyzer application built over the pcap interface</td>
</tr>
<tr>
<td>USDOT</td>
<td>United States Department of Transportation</td>
</tr>
<tr>
<td>V2I</td>
<td>Vehicle-to-Infrastructure</td>
</tr>
<tr>
<td>V2V</td>
<td>Vehicle-to-Vehicle</td>
</tr>
<tr>
<td>VDT</td>
<td>Vehicle Data Translator</td>
</tr>
<tr>
<td>VLAN</td>
<td>Virtual Local Area Network</td>
</tr>
<tr>
<td>WxDE</td>
<td>Weather Data Environment</td>
</tr>
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</table>
5.9 GHz Dedicated Short Range Communication Vehicle-based Road and Weather Condition Application

Messaging Requirements

*Final Version 2*

*August 2013*

Prepared For:
Cooperative Transportation Systems Pooled Fund Study

By:
Synesis Partners LLC
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REVISION HISTORY

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<th>Version</th>
<th>Description</th>
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<td>1</td>
<td>submitted to CTS PFS for review, May 22, 2013</td>
</tr>
<tr>
<td>2</td>
<td>Incorporates changes in response to comments received on v0.1</td>
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</table>

Synesis Partners LLC
1. Introduction

Significant effort has been expended in the Federal Highway Administration’s (FHWA) Road Weather Management Program and in various federal and state connected vehicle programs to identify opportunities to acquire data from vehicles acting as mobile sensor platforms. It is also well-recognized that weather has a significant impact on the year-round operations of the nation’s roadway system. This 5.9 GHz Dedicated Short Range Communication (DSRC) Vehicle-based Road and Weather Condition Application project is the synergistic result of those converging opportunities.

Accurate, timely and route-specific weather information allows traffic and maintenance managers to better operate and maintain roads under adverse conditions. The research system developed by this project will collect weather observation data from mobile sensors on transportation agency vehicles; transmit the data by way of DSRC roadside equipment (RSE) to one or more collection systems; and ultimately make the data available to other information systems such as the New York State DOT INFORM system and the U.S. DOT’s Weather Data Environment. In this way, the additional weather information from mobile platforms will eventually enable traffic managers and maintenance personnel to implement operational strategies that optimize the performance of the transportation system by mitigating the effects of weather on the roadways.

This document will define the mobile data messaging requirements against which the research application will be designed and implemented. The desired data elements will first be identified, and then be compared against the data elements that are available. The comparison exposes the gaps between the intent and the implementation and illustrates that not all desired data elements may be captured in practice.

Following the identification of data elements, applicable connected vehicle communication and messaging standards are reviewed. These in turn, drive the message formats and the subsequently documented messaging requirements.

1.1 References


5.9 GHz DSRC Vehicle-based Road and Weather Condition Application
Messaging Requirements


ASD Spec v. 3.0; USDOT Aftermarket Safety Device Specification v. 3.0.

“5.9GHz DSRC Roadside Equipment” Device Specification v.3.0, USDOT, March1, 2012.


### 1.2 Definitions and Acronyms

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
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<tbody>
<tr>
<td>ASD</td>
<td>After-market Safety Device. A specific implementation of on-board DSRC equipment connected directly to a vehicle data bus, with the additional purpose of providing safety-related feedback to the vehicle operator.</td>
</tr>
<tr>
<td>CAN</td>
<td>Controller Area Network. An electrical specification and signaling protocol developed by Bosch to facilitate simple data communication between connected equipment control units.</td>
</tr>
<tr>
<td>Clarus Initiative</td>
<td>A Federal Highway program supporting the open sharing of weather data with the goal of enabling transportation agency decision support systems that improve safety and reduce costs.</td>
</tr>
<tr>
<td>Clarus System Instance</td>
<td>Existing Clarus System software functionality and data captured at a specified and agreed upon date and time. The instance is expected to evolve into the WxDE and is not intended to replace the current operational Clarus System.</td>
</tr>
</tbody>
</table>
5.9 GHz DSRC Vehicle-based Road and Weather Condition Application
Messaging Requirements

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>DSRC</td>
<td>Dedicated Short Range Communication. A low-latency, line-of-sight wireless data transmission standard designed for interactions between vehicles and infrastructure in a dynamic transportation environment.</td>
</tr>
<tr>
<td>Interim Environment</td>
<td>Temporary environment in which the Clarus instance is hosted and maintained, until the WxDE becomes available.</td>
</tr>
<tr>
<td>FTP</td>
<td>File Transfer Protocol</td>
</tr>
<tr>
<td>HTTP</td>
<td>Hyper-Text Transfer Protocol</td>
</tr>
<tr>
<td>IEEE</td>
<td>Institute of Electrical and Electronics Engineers.</td>
</tr>
<tr>
<td>OBE</td>
<td>On-board equipment. DSRC equipment connected directly to a vehicle data bus.</td>
</tr>
<tr>
<td>PID</td>
<td>Parameter identifier. A unique code used in a controller area network to request specific equipment operational and state data.</td>
</tr>
<tr>
<td>PGN</td>
<td>Parameter Group Number. A unique identifier used as a network address in the SAE J1939 data standard to group similar data parameters.</td>
</tr>
<tr>
<td>PSID</td>
<td>Provider service identifier.</td>
</tr>
<tr>
<td>RSE</td>
<td>Road-side equipment. DSRC equipment deployed near a roadway or intersection.</td>
</tr>
<tr>
<td>SAE</td>
<td>Society of Automotive Engineers.</td>
</tr>
<tr>
<td>SPN</td>
<td>Suspect Parameter Number. A lower-level identifier within a PGN that describes what a particular data value represents, its update frequency, and its unit of measure.</td>
</tr>
<tr>
<td>STOL</td>
<td>Saxton Transportation Operations Laboratory</td>
</tr>
<tr>
<td>U.S. DOT</td>
<td>United States Department of Transportation</td>
</tr>
<tr>
<td>WDE or WxDE</td>
<td>Weather Data Environment</td>
</tr>
</tbody>
</table>

2. Analysis

The analysis, data element details, and resulting message requirements described in this document may appear to be brief. This is due mainly to the extensive groundwork performed under many previous U.S. DOT connected vehicle research projects. Ultimately, the messaging requirements are simply directives to implement the applicable connected vehicle standards. However, this document serves to provide some context for the referenced standards and describe how they apply to the Weather Condition Application project goals. This document may be updated when new information—perhaps such as aftermarket equipment parameters that may provide...
data elements of interest—is uncovered during the execution of the project aftermarket that was not initially known to the project.

2.1 Standards
The Open Systems Interconnection (OSI) model is a conceptual model that characterizes communications system functions by grouping similar functions into one of seven logical layers: physical, data link, network, transport, session, presentation, and application.

In the context of connected vehicles, the physical layer is formed by the radio and radio control that conforms to IEEE 802.11p and is inherent in the OBE and RSE. The IEEE 1609.x series of Wireless Access in Vehicular Environments (WAVE) standards cross-cuts the OSI model somewhat: 1609.0 contains an overall architecture of the WAVE system; 1609.1 defines remote management services; 1609.2 defines security services for messages; 1609.3 defines integration of common networking services such as Internet Protocol; and 1609.4 defines multi-channel radio operation. SAE J2735 occupies the presentation layer in the OSI model since it provides data encapsulated as messages.

The network, transport, and session layers handle information routing, guaranteed delivery, and persistent connection functions. The messages being used for this project do not require any communication functions in those layers. The Weather Data Environment and New York State INFORM systems occupy the application layer, but are also outside the scope of this message requirements document.

This project will deploy equipment conforming to the latest versions of the OBE (ASD v. 3.0) and RSE specifications (v. 3.0) and transmitted messages will need to conform to IEEE 1609.2 to support the inclusion of security certificates as they become available. The SAE J2735 standard applies to the message formatting necessary to convey weather-related J1939 observations.

Ideally, the SAE J2735 probe vehicle data and “A la Carte” messages would be used to present both standard weather-related parameters and any additional weather-related J1939 parameters not covered directly by the probe vehicle data message. However, at the time of this writing, RSE only support receiving the Basic Safety Message (BSM). Consequently, BSM part 2 will be used instead.

2.2 Data Elements
Two SAE standards, J1939 and J1979, were consulted to determine what weather-related elements are available from vehicle data buses. Another SAE standard, J2735, was consulted to determine what weather-related elements are desired by connected vehicle applications. J1979 is reviewed for the case of non-heavy vehicles being available for
this research project. J1939 is specifically for heavy vehicles such as snowplows. J2735 is useful independent of the vehicle data bus.

Three weather-related data gaps will be identified: J1939 and J1979 data elements of interest that are not directly represented by a J2735 message, data elements in BSM part 2 that are not directly available from the common J1939 or J1979 data elements, and data elements of interest that are provided by third-party equipment but defined by the manufacturer.

2.2.1 J1939 and J1979 Data Elements Not Represented in J2735

Two weather-related data elements are apparent in the common set of parameter identifiers (PIDs) for J1979: identifier 51 for barometric pressure and identifier 70 for ambient air temperature. The remaining PIDs primarily relate to emission controls as that is the focus of the diagnostic test mode standard. Other weather-related parameters may be available dependent upon the vehicle manufacturer, but there is no guarantee that they can be discovered or are available on the CAN bus.

J1939 parameter group numbers (PGN) and their associated suspect parameter numbers (SPN) for weather-related data are excerpted from the J1939 companion spreadsheet and included in Appendix A for reference. Most of the J1939 PGNs record engine performance, emissions compliance, input controls, and diagnostics. The weather-related J1939 parameter groups can be summarized as fifth-wheel, blade, lights, ambient, and future. The future data elements—water depth, wind, environmental, salinity, and meteorological station—are not yet fully defined and appear to be directed more toward fixed weather observation platforms than vehicles. It is presumed that mobile friction is derived from a fifth-wheel measuring device, but all installed fifth-wheel devices may not be specifically for that purpose.

The vehicle status data frame captures all of the available weather data elements from J1979 and most of what is available from J1939, except for road surface temperature and blade status.

2.2.2 J2735 Data Elements Not Represented by J1939 and J1979

The J2735 standard defines data elements and data frames which are frequently used and reused within other data frames and messages. The J2735 basic safety message (BSM) Part 2 consists of several J2735 data frames including the Vehicle Status data frame, which in turn contains the desired data elements (and is also referenced by the Probe Vehicle Data Message). The Vehicle Status data frame is therefore examined for the weather-related data elements as it applies to all messages that incorporate it. BSM Part 2 with expanded data frames is included in Appendix B, copied from the Vehicle Information Exchange Needs document. Pertinent weather data elements from the Vehicle Status data frame are amplified in bold.
There are fourteen weather-related data elements in the vehicle status data frame, repeated here from Appendix B for convenience:

- Exterior lights
- Wiper status front
- Wiper rate (front)
- Wiper status rear
- Wiper rate (rear)
- Sun data
- Rain data
- Air temperature
- Air pressure
- Is raining
- Rain rate
- Precipitation situation
- Solar radiation
- Mobile Friction

There is a J1939-specific data frame (DF_J1939-Data Items) referenced within the J2735 vehicle status data frame that focuses on heavy vehicle components such as tire pressure and weight per axle, but it does not include any additional weather elements.

The vehicle status data frame includes solar and rain data that are not directly available from either J1939 or J1979 by default, but may be available from other aftermarket equipment.

2.2.3 Third-Party Data Elements

The third-party equipment data gap is most easily understood by examining the currently participating integrated mobile observation (IMO) states: Nevada, Michigan, and Minnesota. Nevada has a few vehicles that report air temperature, relative humidity, atmospheric pressure, and road temperature; but not all vehicles are equipped with every type of sensor. Michigan is similar to Nevada in that they have a few vehicles reporting identical parameters with the addition of dew point temperature. Minnesota, in contrast, captures the same data as Nevada and Michigan with more vehicles and additionally captures material type, rate, granularity, and concentration parameters from Dickey John road treatment equipment. The Minnesota snowplow truck deployment is likely similar to the equipment in New York identified for this project and is used for the gap reference here.

Aftermarket equipment for heavy vehicles has its own manufacturer-defined program group numbers provided via its own J1939 data bus. Weather sensors deployed to non-heavy vehicles may also have their own PIDs and data buses. Data from the added
equipment could fill in the missing solar and rain data gaps as well as provide extra weather-related data not listed in this document. The vehicles proposed for this project will be inspected and inventoried to determine what weather-related data can be captured on a case-by-case basis.

2.3 Requirements
Messaging requirements for this project are based on and constrained by the standards and previously successful connected vehicle research projects. The requirements appear obvious and straightforward, but this is due to the focused and well-defined scope of this research project.

1. Messages requiring digital signatures shall conform to the ToBeSigned message format defined by IEEE 1609.2.
2. Messages shall be able to represent all weather-related data collected from a heavy vehicle J1939 data bus.
3. Messages shall be able to represent all weather-related data collected from a vehicle J1979 data bus.
4. Messages shall be able to represent all weather-related data collected from a third-party equipment data bus.
5. Messages shall contain all available weather-related data elements defined by SAE J2735 DF_VehicleStatus in the MSG_BasicSafetyMessage.
6. Messages shall contain weather-related data elements not defined by SAE J2735 DF_VehicleStatus as SAE J2735 MSG_BasicSafetyMessage free-form local content.
### Appendix A – J1939 Weather-Related Parameters

Excerpted from J1939 Companion Spreadsheet

<table>
<thead>
<tr>
<th>PGN</th>
<th>SPN</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>61458</td>
<td>3317</td>
<td>Fifth Wheel Roll Warning Indicator</td>
</tr>
<tr>
<td></td>
<td>3308</td>
<td>Fifth Wheel Vertical Force</td>
</tr>
<tr>
<td></td>
<td>3309</td>
<td>Fifth Wheel Drawbar Force</td>
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<tr>
<td></td>
<td>3310</td>
<td>Fifth Wheel Roll Moment</td>
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<tr>
<td>61460</td>
<td>3366</td>
<td>Relative Blade Height and Blade Rotation</td>
</tr>
<tr>
<td></td>
<td>3367</td>
<td>Relative Blade Height Figure of Merit</td>
</tr>
<tr>
<td></td>
<td>3332</td>
<td>Blade Rotation Angle Figure of Merit</td>
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<tr>
<td></td>
<td>3365</td>
<td>Relative Blade Height</td>
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<td></td>
<td>3331</td>
<td>Blade Rotation Angle</td>
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<tr>
<td>64942</td>
<td>3307</td>
<td>Fifth Wheel Error Status</td>
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<td></td>
<td>3312</td>
<td>Fifth Wheel Lock Ready to Couple Indicator</td>
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<td></td>
<td>3313</td>
<td>Fifth Wheel Lock Couple Status Indicator</td>
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<td></td>
<td>3311</td>
<td>Fifth Wheel Slider Position</td>
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<td></td>
<td>3316</td>
<td>Fifth Wheel Slider Lock Indicator</td>
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<td>2873</td>
<td>Work Light Switch</td>
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<td></td>
<td>2872</td>
<td>Main Light Switch</td>
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<td></td>
<td>2876</td>
<td>Turn Signal Switch</td>
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<td></td>
<td>2875</td>
<td>Hazard Light Switch</td>
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<td></td>
<td>2874</td>
<td>High-Low Beam Switch</td>
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<td></td>
<td>2878</td>
<td>Operators Desired Back-light</td>
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<td></td>
<td>2877</td>
<td>Operators Desired – Delayed Lamp Off Time</td>
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<td>64973</td>
<td>2864</td>
<td>Front Non-operator Wiper Switch</td>
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<td></td>
<td>2863</td>
<td>Front Operator Wiper Switch</td>
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<tr>
<td></td>
<td>2865</td>
<td>Rear Wiper Switch</td>
</tr>
<tr>
<td></td>
<td>2869</td>
<td>Front Operator Wiper Delay Control</td>
</tr>
<tr>
<td></td>
<td>2870</td>
<td>Front Non-operator Wiper Delay Control</td>
</tr>
<tr>
<td></td>
<td>2871</td>
<td>Rear Wiper Delay Control</td>
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<td></td>
<td>2867</td>
<td>Front Non-operator Washer Switch</td>
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<td>Front Operator Washer Switch</td>
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<td></td>
<td>2868</td>
<td>Rear Washer Function</td>
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<tr>
<td>65088</td>
<td>2404</td>
<td>Running Light</td>
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<td></td>
<td>2352</td>
<td>Alternate Beam Head Light Data</td>
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<td></td>
<td>2350</td>
<td>Low Beam Head Light Data</td>
</tr>
<tr>
<td></td>
<td>2348</td>
<td>High Beam Head Light Data</td>
</tr>
</tbody>
</table>
### PGN | SPN | Definition
--- | --- | ---
2388 | Tractor Front Fog Lights
2386 | Rotating Beacon Light
2390 | Rear Fog Lights
65089 | Running Light
2351 | Alternate Beam Head Light Data
2349 | Low Beam Head Light Data
2347 | High Beam Head Light Data
2387 | Tractor Front Fog Lights
2385 | Rotating Beacon Light
2389 | Rear Fog Lights
65269 | Barometric Pressure
108 | Ambient Air Temperature
171 | Road Surface Temperature
79 | Water Depth
128267 | Wind Data
130306 | Environmental Parameters
130321 | Salinity Station Data
130323 | Meteorological Station Data
Appendix B – The Basic Safety Message (Parts 1 and 2)

The Basic Safety Message (BSM) is one of a set of messages defined in the SAE Standard J2735, Dedicated Short Range Communications (DSRC) Message Set Dictionary. Each message in the standard, including the BSM, is made up of a set of data frames, which in turn are made up either of other data frames or data elements. Data elements are atomic, and are not further subdivided. In a few cases, the text, formal name, and ASN.1 definition found in J2735 provides conflicting information as to whether or not an item is a data frame or data element. For purposes of this analysis, it doesn’t really matter.

The BSM consists of two parts: Part 1 is sent in every BSM message and Part 2 consists of a large set of optional elements. Not all elements are available from all vehicles, and which elements are sent, if available, will be based on event criteria that are not specified in J2735.

The major data frames and data elements are listed here. Each item in the list is identified as either a data frame (DF) or data element (DE). If the data frame is not decomposed in this appendix, additional information on its content can be found in SAE J2735. Administrative components such as message ID number and time stamps are not listed in order to keep the list concise and emphasize the informational content that may be of value to mobility applications.

NOTE: Data elements in bold are weather-related

Part 1 (mandatory)

- Position (local 3D) (DF)
  - Latitude (DE)
  - Longitude (DE)
  - Elevation (DE)
  - Positional accuracy (DE)
- Motion (DF)
  - Transmission and speed (DF)
    - Transmission state (DE)
    - Speed (DE)
  - Heading (DE)
  - Steering wheel angle (DE)
- Acceleration set (DF)
  - Longitudinal acceleration (DE)
  - Lateral acceleration (DE)
  - Vertical acceleration (DE)
5.9 GHz DSRC Vehicle-based Road and Weather Condition Application
Messaging Requirements

- Yaw rate (DE)

- Brake system status (DF)
  - Brake applied status (DE)
  - Brake status not available (DE)
  - Traction control state (DE)
  - Antilock brake status (DE)
  - Stability control status (DE)
  - Brake boost applied (DE)
  - Auxiliary brake status (DE)

- Vehicle size (DF)
  - Vehicle width (DE)
  - Vehicle length (DE)

Part 2 (all elements optional, sent according to criteria to be established)

- Vehicle safety extension (DF)
  - Event flags (DE) – A data element consisting of single bit event flags:
    - Hazard lights
    - Intersection stop line violation
    - ABS activated
    - Traction control loss
    - Stability control activated
    - Hazardous materials
    - Emergency response
    - Hard braking
    - Lights changed
    - Wipers changed
    - Flat tire
    - Disabled vehicle
    - Air bag deployment
  - Path history (DF)
    - Full position vector (DF)
      - Date and time stamp (DE)
      - Longitude (DE)
      - Latitude (DE)
5.9 GHz DSRC Vehicle-based Road and Weather Condition Application
Messaging Requirements

- Elevation (DE)
- Heading (DE)
- Transmission and speed (DF) – same as in Part 1
- Positional accuracy (DE)
- Time confidence (DE)
- Position confidence set (DF)
  - Position confidence (DE)
  - Elevation confidence (DE)
- Speed and heading and throttle confidence (DF)
  - Speed confidence (DE)
  - Heading confidence (DE)
  - Throttle confidence (DE)
- GPS status (DE)
- Count (DE) – number of “crumbs” in the history
- Crumb data – set of one of 10 possible path history point set types, consisting of various combinations of:
  - Latitudinal offset from current position (DE)
  - Longitudinal offset from current position (DE)
  - Elevation offset from current position (DE)
  - Time offset from the current time (DE)
  - Accuracy (DF) – See J2735 standard for more information
  - Heading (DE) – NOT an offset, but absolute heading
  - Transmission and speed (DF) – same as in Part 1, NOT an offset
- Path Prediction (DF)
  - Radius of curve (DE)
  - Confidence (DE)
- RTCM Package (DF) – RTCM (Radio Technical Commission for Maritime Services) is a standardized format for GPS messages, including differential correction messages. J2735 states “The RTCMPackage data frame is used to convey a select sub-set of the RTCM messages (message types 1001 TO 1032) which deal with differential corrections between users. Encapsulates messages are those defined in RTCM Standard 10403.1 for Differential GNSS (Global Navigation Satellite Systems)Services -Version 3 adopted on October 27, 2006 and its successors.
  - Full position vector (DF) – see full contents above under Path history
  - RTCM header (DF)
5.9 GHz DSRC Vehicle-based Road and Weather Condition Application
Messaging Requirements

- GPS status
- Antenna offset
  - GPS data – see SAE J2735 and RTCM standards for more information

- Vehicle status (DF)
  - Exterior lights (DE)
  - Light bar in use (DE)
  - Wipers (DF)
    - Wiper status front (DE)
    - Wiper rate (front) (DE)
    - Wiper status rear (DE)
    - Wiper rate (rear) (DE)
  - Brake system status (DF) – same as in Part 1
  - Braking pressure (DE)
  - Roadway friction (DE)
  - Sun sensor (DE)
  - Rain sensor (DE)
  - Ambient air temperature (DE)
  - Ambient pressure (DE)
  - Steering, sequence of:
    - Steering wheel angle (DE)
    - Steering wheel angle confidence (DE)
    - Steering wheel angle rate of change (DE)
    - Driving wheel angle (DE)
  - Acceleration set (DF) – same as in Part 1
  - Vertical acceleration threshold (DE)
  - Yaw rate confidence (DE)
  - Acceleration confidence (DE)
  - Confidence set (DF)
    - Acceleration confidence (DE)
    - Speed confidence (speed, heading, and throttle confidences (DF)
    - Time confidence (DE)
    - Position confidence set (DF)
    - Steering wheel angle confidence (DE)
    - Throttle confidence (DE)
5.9 GHz DSRC Vehicle-based Road and Weather Condition Application
Messaging Requirements

- Object data, sequence of:
  - Obstacle distance (DE)
  - Obstacle direction (DE)
  - Time obstacle detected (DE)
- Full position vector (DF) – see contents under path history
- Throttle position (DE)
- Speed and heading and throttle confidence (DF) – same as above under “Full position vector”
- Speed confidence (DE) – same as above under “Speed and heading and throttle confidence”
- Vehicle data (referred to as a “complex type” in J2735, rather than an element or frame)
  - Vehicle height (DE)
  - Bumper heights (DF)
    - Bumper height front (DE)
    - Bumper height rear (DE)
  - Vehicle mass (DE)
  - Trailer weight (DE)
  - Vehicle type (DE)
- Vehicle identity (DF)
  - Descriptive name (DE) – typically only used for debugging
  - VIN string (DE)
  - Owner code (DE)
  - Temporary ID (DE)
  - Vehicle type (DE)
  - Vehicle class (drawn from ITIS code standard)
- J1939 data (DF)
  - Tire conditions (DF) – see J2735 standard for list of data elements
  - Vehicle weight by axle (DF) – see J2735 standard for list of data elements
  - Trailer weight (DE)
  - Cargo weight (DE)
  - Steering axle temperature (DE)
  - Drive axle location (DE)
  - Drive axle lift air pressure (DE)
  - Drive axle temperature (DE)
  - Dive axle lube pressure (DE)
5.9 GHz DSRC Vehicle-based Road and Weather Condition Application
Messaging Requirements

- Steering axle lube pressure (DE)
- Weather report, defined as a sequence of the following:
  - Is raining (DE) – defined in NTCIP standard
  - Rain rate (DE) – defined in NTCIP standard
  - Precipitation situation (DE) – defined in NTCIP standard
  - Solar radiation (DE) – defined in NTCIP standard
  - Mobile friction (DE) – defined in NTCIP standard
- GPS status (DE)
5.9 GHz Dedicated Short Range Communication Vehicle-based Road and Weather Condition Application

Test Plan

Version 1.1

December 2013

Prepared For:
Cooperative Transportation Systems Pooled Fund Study

By:
Synesis Partners LLC
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REVISION HISTORY

<table>
<thead>
<tr>
<th>Version</th>
<th>Description</th>
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<tr>
<td>0.1</td>
<td>submitted to CTS PFS for review, October 11, 2013</td>
</tr>
<tr>
<td>1.0</td>
<td>submitted updated draft to CTS PFS, November 25, 2013</td>
</tr>
<tr>
<td>1.1</td>
<td>submitted final Test Plan to CTS PFS, December 13, 2013</td>
</tr>
</tbody>
</table>
1 INTRODUCTION

The following subsections of the System Test Plan (STP) provide an overview of the STP.

1.1 Purpose

The purpose of this document is to describe the verification and validation plan for the 5.9 GHz Dedicated Short Range Communication Vehicle Based Road and Weather Condition Application.

The objective of the testing is to uncover defects in the system. This includes nonconformance with the stated requirements and unexpected or undesired side effects of system operation. Even moderately complex systems are nearly impossible to adequately test when fully assembled. Therefore, careful consideration is given to adequately test small units and subsets of the system independently.

1.2 Scope

The scope of this project is to develop, test, deploy and operate 5.9 GHz dedicated short range communication (DSRC) applications for road and weather condition data in maintenance and highway emergency local patrol (HELP) vehicles. The system to be developed will be capable of obtaining data including that from SAE J1939 and J1979 diagnostic buses and various peripheral devices on maintenance vehicles; transmitting this data to compliant 5.9 GHz DSRC roadside equipment (RSE); sending the data from RSEs to a data aggregation server; and finally converting and feeding data to the Weather Data Environment (WxDE) for use in determining and predicting road and weather conditions. It is envisioned that this application will be used by agency maintenance vehicles of the members of the CTS PFS along connected vehicle test beds.

The OBE in this system will read the desired data from controller area network (CAN) buses on the connected vehicles and format those data into a basic safety message (BSM) that includes both Part 1 and Part 2. If the OBE is not within range of an RSE, determined by the absence of a Wireless Access in Vehicular Environments (WAVE) Service Announcement, the BSM is stored for transmission at a later time. When an OBE detects the presence of a WAVE Service Announcement, current weather-related data will be transmitted as part of normal BSM operation and not stored, while previously-stored BSMSs will be transmitted at a significantly faster rate than the standard 10 Hz in last-in-first-out order so that the most recent weather related data are sent to the RSE first.
Stored BSMs will be deleted upon transmission and, when storage becomes scarce, the oldest BSM will be deleted first to make room for newer data.

1.3 Definitions, Acronyms, and Abbreviations

This document may contain terms, acronyms, and abbreviations that are unfamiliar to the reader. A dictionary of these terms, acronyms, and abbreviations can be found in Appendix A.

1.4 References

The following documents contain additional information pertaining to this project and the requirements for the system:

5.9 GHz Dedicated Short Range Communication Vehicle Based Road and Weather Condition Application Concept of Operations, May 2013, Synesis Partners LLC.

5.9 GHz Dedicated Short Range Communication Vehicle Based Road and Weather Condition Application Messaging Requirements, May 2013, Synesis Partners LLC.


1.5 Overview

The remaining sections of the document contain a review of the system elements to be tested, the approach to testing, tasks and resources required to perform the testing, and any risks or contingencies that must be considered in the creation of the test plan.

Section 2 – Test Items describes what hardware and software configuration items are covered by the test plan. Configuration items may be completely software, completely hardware, or combinations of hardware and software. This section also identifies any features or requirements that will not be tested.

Section 3 – Approach describes the approach or methods to be utilized for each type of testing in this plan.
Section 4 – Activities and Resources describes what must be done to perform the testing. This includes a list of the test deliverables, a description of the required test environment, the test participants, and a description of any special staffing or training required for the tests.

Section 5 – Risks and Contingencies identifies any high risk assumptions made during the development of the test plan. For each risk, a contingency plan is identified that is intended to minimize or eliminate the impact of the risk on the execution of the plan.
2 TEST ITEMS

This section describes what items or components of the system are covered by the test plan. Subsystems may be completely software, hardware, or combinations of hardware and software.

2.1 Programs and Modules

System testing is performed on the system as a whole, on major subsystems as appropriate, and on the individual units that make up the system. The proposed deployment diagrams (Figure 1 and Figure 2) illustrate the relationships among the system’s components and units for the purpose of identifying the specific hardware configuration items (HCIs) and software configuration items (SCIs) to be tested. Table 1 provides a brief description of each of these configuration items.

![Figure 1 - Proposed Network Element Deployment](image)

Figure 1 reduces the proposed network element deployment to the minimal interfaces required for the system to operate. For example, the NYSDOT network implementation likely contains significantly more components and interconnections than are depicted within the diagram. These additional components are external to the configuration items covered by this test plan and do not provide any useful detail to those that are.
### Table 1 - Hardware and Software Configuration Items

<table>
<thead>
<tr>
<th>HCI</th>
<th>SCI</th>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td></td>
<td>RSE-1</td>
<td>Physical installation of the RSE including mounting arm, antenna placement and orientation, and power and communication wiring.</td>
</tr>
<tr>
<td>X</td>
<td></td>
<td>RSE-2</td>
<td>Configuration settings of a RSE, such as network addresses, security keys, important server addresses, and log file and heartbeat transmission intervals.</td>
</tr>
<tr>
<td>X</td>
<td></td>
<td>POE-1</td>
<td>Physical installation of a power-over-Ethernet (PoE) network switch to supply power and communication needs to RSE.</td>
</tr>
<tr>
<td>X</td>
<td></td>
<td>POE-2</td>
<td>Configuration settings for the management of PoE switches such as network addresses, security credentials, and user permission to remotely reset RSE power.</td>
</tr>
<tr>
<td>X</td>
<td></td>
<td>FRW-1</td>
<td>Configuration of the NYSDOT network firewall so that approved hosts can send information to and receive information from the logically isolated internal IPv6 RSE network.</td>
</tr>
<tr>
<td>X</td>
<td></td>
<td>EGR-1</td>
<td>Configuration of the NYSDOT network router responsible for tunneling and routing IPv6 communication between the logically isolated RSE IPv6 network and the external aggregation server over the IPv4 Internet.</td>
</tr>
<tr>
<td>X</td>
<td></td>
<td>EGR-2</td>
<td>Configuration of the weather data aggregation network router responsible for tunneling and routing IPv6 communication between its local IPv6 network and the NYSDOT logically isolated RSE IPv6 network over the IPv4 Internet.</td>
</tr>
<tr>
<td>X</td>
<td></td>
<td>FRW-2</td>
<td>Configuration of the weather data aggregation network firewall so that approved hosts can send information to and receive information from the external NYSDOT logically isolated IPv6 RSE network.</td>
</tr>
<tr>
<td>X</td>
<td></td>
<td>WDA-1</td>
<td>The server that hosts the weather data aggregator and system monitoring software within the weather data aggregation network.</td>
</tr>
<tr>
<td>HCI</td>
<td>SCI</td>
<td>Name</td>
<td>Description</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>------</td>
<td>-------------</td>
</tr>
<tr>
<td>X</td>
<td>WDA-2</td>
<td>The weather data aggregation software that receives log files from the NYSDOT RSE and processes those log files into weather observations passed on to the Weather Data Environment.</td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>WDA-3</td>
<td>The system monitor software that receives heartbeat information from NYSDOT RSE and reports any detected problems to administrators for resolution.</td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>WDE-1</td>
<td>The Weather Data Environment that will store and present NYSDOT RSE weather data observations received from and processed by the weather data aggregator.</td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>OBE-1</td>
<td>The physical installation of OBE that includes a mounting bracket and the OBE itself.</td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>OBE-2</td>
<td>The physical installation of a vehicle power interface that detects when the vehicle ignition is stated and stopped so that the OBE is powered when the vehicle is in operation and unpowered otherwise thus preserving the vehicle battery when parked.</td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>OBE-3</td>
<td>The J1939 cable used to connect OBE to a heavy vehicle CAN data bus.</td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>OBE-4</td>
<td>The J1979 cable used to connect OBE to a consumer vehicle CAN data bus, otherwise known as OBD-II.</td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>OBE-5</td>
<td>An optional serial cable connecting the OBE to common Dickey John road treatment equipment.</td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>OBE-6</td>
<td>An optional serial cable connecting the OBE to a mounted IceSight sensor that detects road ice and precise ambient air temperature.</td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>OBE-7</td>
<td>The GPS antenna connected to OBE used to determine vehicle location.</td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>OBE-8</td>
<td>The DSRC antenna used by the OBE to detect the presence of RSE and transmit weather-related observations when an RSE is within radio range.</td>
<td></td>
</tr>
</tbody>
</table>
The OBE software application hosted by OBE hardware that reads the position and sensor inputs to produce Basic Safety Messages containing weather-related observations and send those messages to RSE using a store-and-forward algorithm.

There is nothing unexpected shown in Figure 2. OBEs are deployed in vehicles and require power and communication connections to operate. The majority of the sensors are found on the heavy vehicles, but the IceSight sensor alternatively could be installed on other trucks, if desired.

2.2 Features to Be Tested

The following classes of functions will be covered by this plan:

Power

- Vehicle power interfaces properly start and shut down OBE
- PoE network switches properly start and shut down RSE

Communication

- OBE acquire IPv6 DSRC addresses, but local RSE is unreachable via IP
- OBE acquire IPv6 DSRC addresses, but RSE network is unreachable via IP
- BSMs are created and stored by OBE
- BSMs are transmitted from OBE and received by RSE J2735 service
- RSE has IPv6 addresses but NYSDOT network is unreachable
• RSE has IPv6 addresses and can only reach WDA network
• RSE regularly transmits heartbeat information
• RSE regularly transmits log files
• PoE switches can only reach WDA network
• WDA server can securely connect to PoE switches
• WDA server can securely connect to RSE
• WDA server cannot reach internal NYSDOT network

Data Collection

• WDA server can read and process RSE log files
• WDA server can read and process RSE heartbeat information
• WDA server can transmit weather observations to WDE
• WDA server can detect RSE failures
• WDA server can notify administrators to resolve RSE failures
• WDE presents weather related vehicle data

2.3 Features not to Be Tested

The features not included in this test plan and that will not be verified specifically by test cases are those that are intrinsically verified by other components of the system. For example, it is presumed that NYSDOT has a functioning enterprise network connected to the Internet using IPv4 addressing. Switches and other networking components within that context are expected to operate properly to facilitate data transport between the NYSDOT and weather data aggregator networks. It is also presumed that selected vehicles for this project are functional and that infrastructure for deployment such as power, cabinets, and mounting arms exist and meet physical specifications sufficient to support the deployment of RSEs.
3 APPROACH

This section describes the approach or methods to be utilized for each type of testing in this plan.

3.1 General Approach

The objective for the system acceptance process is to exercise the hardware and software to demonstrate compliance to requirements and that desired features function as expected. The test personnel will use the concept of operations and requirements documentation to prepare test cases and scripts. This process consists of three steps:

1. Review of requirements and features
2. Assignment of verification methodology
3. Assignment of each test type to test cases

It is neither technically feasible, nor economically desirable, to rigorously test every conceivable system element. In assigning a verification method, this plan identifies what items must be tested, and what requirements and features can be validated by the most effective methods. Requirements and features will be verified through three different methods:

- **Inspection** is a means of verifying a requirement or feature visually. This is typically done for physical requirements (e.g., the box shall be painted brown) or for those requirements that are global in nature and cannot be tested explicitly (e.g. a requirement specifying a constraint in the methodology used to design the system). In the case of hardware requirements, inspection may include review of the environmental and electrical tests performed as a part of the hardware acceptance process. Inspection can also include review of vendor provided documentation and accepting statements of compliance as proof that the requirement is met.

- **Analysis** is a means of verifying a requirement or feature by exercising a portion or derivative of the system design and comparing the results to an expected result. Analysis may also be used when a portion of the design has already been tested elsewhere and verification is performed by showing the similarity of the current design to that which was previously tested or analyzed. This method is also used for requirements that cannot be directly tested, but can only be verified through related analytical means.
- **Test** involves the physical and logical comparison between an actual system output when a test case is performed and an expected result.

For each requirement assigned the **Test** method, the requirement is demonstrated by the execution of one or more test cases. Test cases are scenarios that allow logically related requirements to be verified together by performing an action. This reduces the total number of tests required and typically results in testing that is similar to *normal* operation of the system. Requirements verified by test can also be aggregated into separate test cases when a complete test environment may not be available. In cases such as this, assigning separate test cases can reduce the amount of time required for testing when the test environment utilizes a critical resource and there is a desire to minimize the time the critical resource is used.

To demonstrate compliance, Table 2 contains the traceability between requirements, configuration items, verification methods, and test case. References to the system requirements in the concept of operations document are prepended with “RQ” and references to the messaging requirements from their own document are prepended with “MR”. References are grouped together where they overlap.

Once the test cases have been developed, the test environment is identified. The test environment provides facilities needed to support the proper execution of the test cases. The components and boundaries that comprise the system test environment are specified in Section 4.3.

### Table 2 – System Verification Matrix

<table>
<thead>
<tr>
<th>Reference</th>
<th>Description</th>
<th>Item</th>
<th>Method</th>
<th>Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>RQ-100</td>
<td>The system shall acquire weather-related data from vehicles.</td>
<td>OBE-1</td>
<td>Analysis</td>
<td>TC-1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>OBE-2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>OBE-9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RQ-110</td>
<td>The system shall be able to acquire weather-related data from a heavy</td>
<td>OBE-3</td>
<td>Analysis</td>
<td>TC-1</td>
</tr>
<tr>
<td>MR-002</td>
<td>vehicle J1939 data bus.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RQ-120</td>
<td>The system shall be able to acquire weather-related data from a vehicle</td>
<td>OBE-4</td>
<td>Analysis</td>
<td>TC-1</td>
</tr>
<tr>
<td>MR-003</td>
<td>J1979 data bus.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reference</td>
<td>Description</td>
<td>Item</td>
<td>Method</td>
<td>Test</td>
</tr>
<tr>
<td>-----------</td>
<td>------------------------------------------------------------------------------</td>
<td>-------------</td>
<td>---------</td>
<td>------</td>
</tr>
<tr>
<td>RQ-130 MR-004</td>
<td>The system shall be able to acquire weather-related data from a RS-232 serial data bus.</td>
<td>OBE-5, OBE-6</td>
<td>Analysis</td>
<td>TC-1</td>
</tr>
<tr>
<td>RQ-200</td>
<td>The system shall assemble weather-related data acquired from vehicles into messages.</td>
<td>OBE-7, OBE-9</td>
<td>Analysis</td>
<td>TC-2</td>
</tr>
<tr>
<td>RQ-210 MR-005</td>
<td>The system shall encode weather-related data elements defined in the SAE J2735 DF_VehicleStatus data frame into a message conforming to the MSG_BasicSafetyMessage specification.</td>
<td>OBE-7, OBE-9</td>
<td>Analysis</td>
<td>TC-2</td>
</tr>
<tr>
<td>RQ-220 MR-006</td>
<td>The system shall encode weather-related data elements not defined in the SAE J2735 DF_VehicleStatus data frame into free-form local content within a message conforming to the SAE J2735 MSG_BasicSafetyMessage specification.</td>
<td>OBE-7, OBE-9</td>
<td>Analysis</td>
<td>TC-2</td>
</tr>
<tr>
<td>RQ-300</td>
<td>The system shall transmit messages containing weather data from vehicles to roadside units over 5.9 GHz DSRC.</td>
<td>RSE-1, RSE-2, OBE-8</td>
<td>Analysis</td>
<td>TC-2</td>
</tr>
<tr>
<td>RQ-350 MR-001</td>
<td>The system shall encode digital signatures according to the ToBeSigned message format defined by IEEE 1609.2.</td>
<td>OBE-9</td>
<td>Analysis</td>
<td>TC-2</td>
</tr>
<tr>
<td>RQ-400</td>
<td>The system shall aggregate probe data from RSEs.</td>
<td>POE-1, FRW-1, EGR-1, EGR-2, FRW-2, WDA-1, WDA-2</td>
<td>Test</td>
<td>TC-3</td>
</tr>
<tr>
<td>RQ-450</td>
<td>The system shall associate probe data with its vehicular sources.</td>
<td>WDA-2, OBE-9</td>
<td>Test</td>
<td>TC-3</td>
</tr>
<tr>
<td>Reference</td>
<td>Description</td>
<td>Item</td>
<td>Method</td>
<td>Test</td>
</tr>
<tr>
<td>-----------</td>
<td>------------------------------------------------------------------------------</td>
<td>--------</td>
<td>-----------</td>
<td>------</td>
</tr>
<tr>
<td>RQ-500</td>
<td>The system shall make weather and road condition data available to other systems.</td>
<td>EGR-2</td>
<td>Inspection</td>
<td>TC-4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FRW-2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>WDA-1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RQ-510</td>
<td>The system shall make weather and road condition data available to other systems in the form of subscriptions.</td>
<td>WDA-2</td>
<td>Inspection</td>
<td>TC-4</td>
</tr>
<tr>
<td>RQ-520</td>
<td>The system shall make weather and road condition data available to the WxDE.</td>
<td>WDA-2</td>
<td>Inspection</td>
<td>TC-4</td>
</tr>
<tr>
<td>RQ-530</td>
<td>The system shall make weather and road condition data available to the VDT.</td>
<td>WDA-2</td>
<td>Inspection</td>
<td>TC-4</td>
</tr>
<tr>
<td>RQ-600</td>
<td>The system shall monitor the state of its operations.</td>
<td>WDA-3</td>
<td>Test</td>
<td>TC-5</td>
</tr>
<tr>
<td>RQ-610</td>
<td>The system shall monitor the state of its RSE operations.</td>
<td>POE-2</td>
<td>Test</td>
<td>TC-5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>WDA-3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RQ-620</td>
<td>The system shall monitor the state of its aggregator operations.</td>
<td>WDA-3</td>
<td>Test</td>
<td>TC-5</td>
</tr>
</tbody>
</table>

Generally, sets of requirements are grouped together for individual test cases. This facilitates testing when the testing methodology used is the same among the different requirements and when the functions to be tested are closely related. Table 3 further associates test cases with project tasks and general test script actions to illustrate when test scripts are performed and how they transition from lab testing to field installation and testing. Test scripts will contain detailed step-by-step instructions on how particular tests are to be conducted and their results interpreted. Testing results will be included in the test report. The first five test cases, 1 through 5, are directly derived from requirements. The last three test cases, 6 through 8, are related to project tasks and contain the necessary steps to fulfill those project tasks.

Test Case 1 will confirm that OBE can successfully acquire weather-related data from the various available data buses. Many different values from each of the available sensors are expected so analysis must be used. The OBE rolling data log will be compared against the vendor sensor specification to verify that weather-related data values are within the range of a sensor and make sense given the
local environmental circumstances, i.e. an air temperature of 140 F would indicate a problem.

Test Case 2 evaluates the transport mechanisms of the vehicle weather-related data over DSRC. BSM are typically sent at 10 Hz, so analysis must be used for the test method. Both OBE stored BSM, and RSE log files are examined for the data format conforming to the BSM specification and that the associated digital signature matches its specification. Analyzing the RSE log file against the OBE stored BSM will confirm that DSRC was used since that is the only means for OBE to deliver BSM to the RSE.

Test Case 3 evaluates vehicle identification with the aggregation of weather-related data. The aggregation server log will be compared to the expected vehicle identifiers. Since there are only a few vehicles for this project, using the direct test method is reasonable.

Test Case 4 uses the inspection testing method to verify that weather-related observations are being collected by the weather data environment. The aggregation server can be inspected to verify subscription files are produced, and the graphical user interface for the WxDE can be used to verify that the weather-related data are present with associated VDT quality checks and road conditions.

Test Case 5 verifies that monitoring software correctly identifies system problems and notifies administrators to fix the problems. Malfunctions can be simulated by moving processed weather observation files and heartbeat logs from their expected locations. System monitoring software can then be verified that is sends email messages to the configured administrator email addresses with the correct description of the problem that needs to be repaired.

Test Case 6 verifies the field installation and operation of OBEs. Its scripts are similar to Test Cases 1 and 2 in that they verify OBE operation, but the testing environment is different. The Test Case 6 testing environment contains HELP vehicle and plow trucks with external antennas (as well as Dick John equipment that were not available for the initial system testing). Additionally, the OBE field installation test case evaluates independent power control hardware that protects the OBEs from noisy vehicle power supplies and prevents OBEs from discharging vehicle batteries when vehicles are not operating.

Test Case 7 verifies the field installation and operation of RSEs. Just as Test Case 6 shares common scripts with previous test cases, Test Case 7 also shares some scripts from Test Case 3. The RSE field testing environment consists of RSE mounted on poles exposed to the elements as well as relying on power supplied
from PoE switches installed in cabinets and using a completely different network.

Test Case 8 verifies the end-to-end system deployment. At this stage, it is important to verify that remote power cycling (used to reboot RSEs when necessary) is possible to minimize the need for on-site maintenance. This test case evaluates OBEs continuously collecting sensor data from operating vehicles and successfully detecting RSEs under moving conditions. Test Case 8 also evaluates each component’s ability within the system to store and forward information when some components are unavailable and the weather data aggregator server’s ability to identify component problems so that they may be addressed quickly.

Table 3 – Test Cases and Test Scripts by Task

<table>
<thead>
<tr>
<th>Task</th>
<th>Test Case</th>
<th>Test Script Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.7 Prepare and Test OBEs</td>
<td>TC-1</td>
<td>Verify OBE reads J1979 data</td>
</tr>
<tr>
<td></td>
<td>TC-1</td>
<td>Verify OBE reads IceSight data</td>
</tr>
<tr>
<td></td>
<td>TC-2</td>
<td>Verify OBE reads GPS data</td>
</tr>
<tr>
<td></td>
<td>TC-2</td>
<td>Verify OBE formats data as BSM</td>
</tr>
<tr>
<td></td>
<td>TC-2</td>
<td>Verify OBE stores BSMs</td>
</tr>
<tr>
<td></td>
<td>TC-2</td>
<td>Verify OBE transmits BSMs</td>
</tr>
<tr>
<td>4.8 Prepare and Test RSEs</td>
<td>TC-2</td>
<td>Verify RSE receives BSM from OBE</td>
</tr>
<tr>
<td></td>
<td>TC-3</td>
<td>Verify RSE forwards BSM to weather data services</td>
</tr>
<tr>
<td></td>
<td>TC-5</td>
<td>Verify RSE transmits heartbeat message</td>
</tr>
<tr>
<td>4.9 Install and Field Test OBEs</td>
<td>TC-6</td>
<td>Verify OBE reads J1939 data from plow trucks</td>
</tr>
<tr>
<td></td>
<td>TC-6</td>
<td>Verify OBE reads J1979 data from HELP vehicles</td>
</tr>
<tr>
<td></td>
<td>TC-6</td>
<td>Verify OBE reads IceSight data</td>
</tr>
<tr>
<td></td>
<td>TC-6</td>
<td>Verify OBE reads Dickie John data</td>
</tr>
<tr>
<td></td>
<td>TC-6</td>
<td>Verify OBE reads GPS data</td>
</tr>
<tr>
<td></td>
<td>TC-6</td>
<td>Verify OBE transmits BSMs</td>
</tr>
<tr>
<td></td>
<td>TC-6</td>
<td>Verify vehicle power control correctly starts up and shuts down OBE</td>
</tr>
<tr>
<td>4.10 Install and Field Test RSEs</td>
<td>TC-7</td>
<td>Verify IPv6 switches power RSEs</td>
</tr>
<tr>
<td></td>
<td>TC-7</td>
<td>Verify RSE receives BSM from OBE</td>
</tr>
<tr>
<td></td>
<td>TC-7</td>
<td>Verify RSE forwards BSM to weather data services</td>
</tr>
<tr>
<td></td>
<td>TC-7</td>
<td>Verify RSE transmits heartbeat message</td>
</tr>
<tr>
<td><strong>Task</strong></td>
<td><strong>Test Case</strong></td>
<td><strong>Test Script Description</strong></td>
</tr>
<tr>
<td>----------</td>
<td>--------------</td>
<td>----------------------------</td>
</tr>
<tr>
<td>4.11 Deploy Weather Data Service(s) to Center</td>
<td>TC-3</td>
<td>Verify data are received from RSE</td>
</tr>
<tr>
<td></td>
<td>TC-3</td>
<td>Verify vehicle sources are identified</td>
</tr>
<tr>
<td></td>
<td>TC-4</td>
<td>Verify subscriptions are created for WxDE</td>
</tr>
<tr>
<td></td>
<td>TC-4</td>
<td>Verify subscriptions are created for VDT</td>
</tr>
<tr>
<td>4.12 Deploy Clarus Collector</td>
<td>TC-4</td>
<td>Verify WxDE collector receives subscription</td>
</tr>
<tr>
<td></td>
<td>TC-4</td>
<td>Verify VDT collector receives subscription</td>
</tr>
<tr>
<td>4.13 Perform Integrated System Tests</td>
<td>TC-5</td>
<td>Verify the system receives RSE heartbeat messages</td>
</tr>
<tr>
<td></td>
<td>TC-5</td>
<td>Verify the system reports expected RSE messages are absent</td>
</tr>
<tr>
<td></td>
<td>TC-5</td>
<td>Verify the system reports expected OBE messages are absent</td>
</tr>
<tr>
<td></td>
<td>TC-5</td>
<td>Verify the system reports data aggregation is unavailable</td>
</tr>
<tr>
<td></td>
<td>TC-8</td>
<td>Verify remote PoE control</td>
</tr>
<tr>
<td></td>
<td>TC-8</td>
<td>Verify OBE stores BSM when not in range of RSE</td>
</tr>
<tr>
<td></td>
<td>TC-8</td>
<td>Verify OBE transmits BSM when in range of RSE</td>
</tr>
<tr>
<td></td>
<td>TC-8</td>
<td>Verify RSE stores BSMs when weather data aggregator unavailable</td>
</tr>
<tr>
<td></td>
<td>TC-8</td>
<td>Verify RSE forwards BSMs when weather data aggregator is available</td>
</tr>
</tbody>
</table>

### 3.2 Unit Testing

Unit testing will be performed by the system developers at the completion of each software or hardware module. Unit tests evaluate the following:

- Code paths
- Decision conditions
- Error handling conditions
- Calculations
- Numerical accuracy, including round-off errors
Database query performance

The methods and results of the unit testing are used to help prepare the final test scripts. Unit testing and results are not typically maintained as quality records or formal documentation.

3.3 Integration Testing

Integration testing is the testing of incrementally larger assemblies of units up to the complete system. Integration testing will be performed as the final system is assembled. Integration testing evaluates the following:

- Module interfaces
- Module interaction

The methods and results of integration testing will be used to help prepare the final test scripts. Integration testing and results are not typically maintained as quality records or formal documentation.

3.4 Acceptance Testing

Acceptance testing is typically conducted under the guidance or direct control of the client. The coverage for acceptance testing is usually the minimum acceptable functionality necessary to demonstrate the completeness of the delivered system. The requirements referenced in Table 2 form the basis of the system acceptance testing as they relate directly to the test cases and results as evidence.

This plan is intended to cover all of the testing required for system acceptance. The system may be accepted as tested, or accepted with exceptions, or accepted with additional changes.

3.5 Evaluation of Test Results

A “Passed” test indicates that the observed output of executing a test script complies with the expected output. Test scripts are composed of one or more individual steps, some of which may have an observed output that contributes to the overall passing of the test. In other words, a “Passed” test is indicated by a test script in which all of its steps meet the expected output. Test script steps may include comments that provide further testing context or record other notable system behaviors.

A “Failed” test indicates that there is a discrepancy between the expected output and the actual output for at least one step of a test script. Comments may be recorded for each step to document any additional information during execution.
of the test, deviations from the test script, if any, or anomalies discovered during the testing.

Test observations and data will be documented in the “results column” of the test script. Formal comments received during test script execution are recorded as an addendum and included as part of the completed test report.

3.6 Suspension and Resumption

3.6.1 Suspension Criteria

Testing activities will be suspended whenever the system has failed critical steps within test scripts related to system operation and when system applications fail to operate correctly. Application failures occur when the testing results are inconsistent with the "Expected Results" listed in the test scripts. Critical tests are defined to be those whose failure prohibits further execution of the test script.

Testing may continue after a test failure if testing can be continued and there is potential to discover other failures in subsequent test script steps. After corrections are made, the extent of regression testing that will be performed will be determined, coordinated with the client if it occurs as part of acceptance testing, and completed.

3.6.2 Resumption Requirements

The test resumption process requires that new versions of system components and configurations be produced following a suspension.

The areas of the design that were modified in the new component versions are tested along with any required regression testing. Regression testing is the process of testing changes to a system to make sure that existing unmodified components still work with the new changes. This is required for those functions that were affected by the defect found at the time of suspension to ensure that it is an isolated defect. Additional regression testing is required if the defect fix is not localized or if the fix caused other components or functions to be modified.

The extent of any regression testing to be performed in acceptance testing will be jointly determined between the client and consultant team.
4 ACTIVITIES AND RESOURCES

4.1 Test Deliverables

Test Plans identify system components to be tested, the testing methods to be used, and group components with related requirements into test cases. Test cases describe each testing goal and the environment needed to execute testing and contain one or more test scripts. Test scripts may further describe adjustments to the testing environment and list step-by-step actions and the results of those actions along with any formal comments. This Test Plan and the Test Report containing the test scripts and the results of their execution make up the complete set of test deliverables.

4.2 Testing Activities and Participants

This section contains a work breakdown of the effort needed to prepare the test scripts, acquisition and setup of testing environments, assembly and execution of the test scripts, and evaluation of the results.

Table 4 summarizes the testing efforts and activities and lists the participants and the location of the activity.

<table>
<thead>
<tr>
<th>Effort</th>
<th>Participants</th>
<th>Location</th>
<th>Test Case</th>
</tr>
</thead>
<tbody>
<tr>
<td>OBE application testing</td>
<td>Synesis</td>
<td>KS</td>
<td>TC-1, TC-2</td>
</tr>
<tr>
<td>IceSight integration testing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RSE configuration</td>
<td>Synesis, PB</td>
<td>KS, MD</td>
<td>TC-2, TC-3, TC-5</td>
</tr>
<tr>
<td>RSE IPv6 connectivity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weather Data Aggregator server</td>
<td>Synesis</td>
<td>KS</td>
<td>TC-3, TC-4, TC-5</td>
</tr>
<tr>
<td>WDA IPv6 Tunnel</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vehicle Data Translator Server</td>
<td>NCAR</td>
<td>CO</td>
<td>TC-4</td>
</tr>
<tr>
<td>OBE, RSE, PoE integration testing</td>
<td>Synesis</td>
<td>NY</td>
<td>TC-6</td>
</tr>
<tr>
<td>OBE, RSE, PoE acceptance testing</td>
<td>Synesis, NYSDOT</td>
<td>NY</td>
<td>TC-7, TC-8</td>
</tr>
<tr>
<td>NYSDOT IPv6 tunnel</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4.3 Environmental Needs

The testing environments need dual-stacked IPv4 and IPv6 network routers, switches, and firewalls. The availability of at least one PoE network switch and either native or tunneled IPv6 Internet connectivity are also required.

The availability of the weather data aggregator server is necessary to test RSE heartbeat and log file transmission. Additionally, independent workstations may be needed to remotely connect and login to OBE and RSE for configuration, application deployment, and testing.

Super user credentials for each device need to be securely stored and shared among team members. Public and private device keys need to be shared among connected equipment to enable key-authenticated login. Servers should restrict remote users to their home directories and require elevation to access protected server resources.

4.4 Staffing and Training Needs

Staff must possess at least a minimum of experience and several skills to successfully assemble testing environments and properly execute test scripts:

- Familiarity with Linux operating systems
- Familiarity with secure shell (SSH) and secure copy (SCP) Linux applications
- Familiarity with configuration of Linux public and private keys
- Familiarity with configuration Linux user permissions
- Experience with RSE documentation and configuration
- Experience with OBE documentation and configuration
- Experience with dual-stacked IPv4 and IPv6 networks and network components
- Experience with IPv6 transition technologies and configuration
- Experience with heavy vehicle power and communication systems
- Experience with commercial vehicle power and communication systems
- Experience with SAE J2735 communication
- Experience with IEEE 1609.x protocols
- Experience with DSRC communication technologies

RISKS AND CONTINGENCIES

The topic of hardware interoperability occurs invariably when discussing the current state of connected vehicle research. At this point, there exists a qualified product list from which the equipment in this project was selected. The equipment selected for this project has also been show to interoperate in related
projects such as the Safety Pilot test bed in Ann Arbor, Michigan. While there remain few vendors in this space, if the selected equipment does not sufficiently interoperate, it is possible to select a different vendor.

One of the more recent challenges in connected vehicle research is the move to IPv6 network technology. While IPv6 is not necessarily new, the United States is the pioneer in Internet communication and as such the networking communities within it maintain a significant investment in IPv4 infrastructure. To ease the transition to IPv6, specifications and methods were created to transport IPv6 over IPv4 infrastructure.

There are a couple of tunneling protocols used to send IPv6 data packets over IPv4 networks. The simplest tunneling protocol is intended to be used on this project since the communication is essentially point to point: each RSE sends its data to one aggregation server. If the first tunneling approach does not work, the second tunneling solution that uses a third party IPv6 broker can be attempted. It is also possible to configure each RSE with its own logical IPv6/IPv4 tunnel or to deploy an additional network appliance that would handle the tunneling locally.

The risk of not having IPv6 networking connections available is relatively low given the number of options to achieve it, and that only vary with the level of configuration and procurement effort.

Another challenge related to connected vehicle research is the management of security certificates and certificate revocation lists from a security certificate management system (SCMS). This project is using public fleet vehicles and there is no concern of exposing personally identifiable information or wirelessly stalking vehicle operators. Consequently, a few long-term certificates will be used as an alternative to a complete SCMS deployment. The weather data aggregation server has sufficient capacity to host the SCMS if it is determined necessary at a later time.
APPENDIX A - DEFINITIONS

The following table provides the definitions of all terms, acronyms, and abbreviations required to properly interpret this System Test Plan.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>BSM</td>
<td>Basic Safety Message</td>
</tr>
<tr>
<td>CAN</td>
<td>Controller Area Network. An electrical specification and signaling protocol developed by Bosch to facilitate simple data communication between connected equipment control units.</td>
</tr>
<tr>
<td>Clarus Initiative</td>
<td>A Federal Highway program supporting the open sharing of weather data with the goal of enabling transportation agency decision support systems that improve safety and reduce costs.</td>
</tr>
<tr>
<td>Clarus System Instance</td>
<td>Existing Clarus System software functionality and data captured at a specified and agreed upon date and time. The instance is expected to evolve into the WxDE and is not intended to replace the current operational Clarus System.</td>
</tr>
<tr>
<td>DSRC</td>
<td>Dedicated Short Range Communication. A low-latency, line-of-sight wireless data transmission standard designed for interactions between vehicles and infrastructure in a dynamic transportation environment.</td>
</tr>
<tr>
<td>Interim Environment</td>
<td>Temporary environment in which the Clarus instance is hosted and maintained, until the WxDE becomes available.</td>
</tr>
<tr>
<td>FTP</td>
<td>File Transfer Protocol</td>
</tr>
<tr>
<td>GHz</td>
<td>Gigahertz</td>
</tr>
<tr>
<td>GPS</td>
<td>Global Positioning System</td>
</tr>
<tr>
<td>HCI</td>
<td>Hardware Configuration Item</td>
</tr>
<tr>
<td>HTTP</td>
<td>Hyper-Text Transfer Protocol</td>
</tr>
<tr>
<td>IEEE</td>
<td>Institute of Electrical and Electronics Engineers</td>
</tr>
<tr>
<td>IPv4</td>
<td>Internet Protocol version 4</td>
</tr>
<tr>
<td>IPv6</td>
<td>Internet Protocol version 6</td>
</tr>
<tr>
<td>KS</td>
<td>Kansas</td>
</tr>
<tr>
<td>MD</td>
<td>Maryland</td>
</tr>
<tr>
<td>KS</td>
<td>Kansas</td>
</tr>
<tr>
<td>MD</td>
<td>Maryland</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>----------</td>
<td>---------------------------------------------------------------------------</td>
</tr>
<tr>
<td>NCAR</td>
<td>National Center for Atmospheric Research</td>
</tr>
<tr>
<td>NY</td>
<td>New York</td>
</tr>
<tr>
<td>NYSDOT</td>
<td>New York State Department of Transportation</td>
</tr>
<tr>
<td>OBE</td>
<td>On-board equipment. DSRC equipment connected directly to a vehicle data bus.</td>
</tr>
<tr>
<td>PB</td>
<td>Parsons Brinckerhoff</td>
</tr>
<tr>
<td>PID</td>
<td>Parameter identifier. A unique code used in a controller area network to request specific equipment operational and state data.</td>
</tr>
<tr>
<td>PGN</td>
<td>Parameter Group Number. A unique identifier used as a network address in the SAE J1939 data standard to group similar data parameters.</td>
</tr>
<tr>
<td>PoE</td>
<td>Power over Ethernet</td>
</tr>
<tr>
<td>PSID</td>
<td>Provider service identifier</td>
</tr>
<tr>
<td>RSE</td>
<td>Roadside equipment. DSRC equipment deployed near a roadway or intersection.</td>
</tr>
<tr>
<td>SAE</td>
<td>Society of Automotive Engineers</td>
</tr>
<tr>
<td>SCI</td>
<td>Software Configuration Item</td>
</tr>
<tr>
<td>SCMS</td>
<td>Security Certificate Management System</td>
</tr>
<tr>
<td>SP</td>
<td>Synesis Partners</td>
</tr>
<tr>
<td>SPN</td>
<td>Suspect Parameter Number. A lower-level identifier within a PGN that describes what a particular data value represents, its update frequency, and its unit of measure.</td>
</tr>
<tr>
<td>STOL</td>
<td>Saxton Transportation Operations Laboratory</td>
</tr>
<tr>
<td>STP</td>
<td>System Test Plan</td>
</tr>
<tr>
<td>U.S. DOT</td>
<td>United States Department of Transportation</td>
</tr>
<tr>
<td>WAVE</td>
<td>Wireless Access in Vehicular Environments</td>
</tr>
<tr>
<td>WDA</td>
<td>Weather Data Aggregator</td>
</tr>
<tr>
<td>WDE or WxDE</td>
<td>Weather Data Environment</td>
</tr>
</tbody>
</table>
5.9 GHz Dedicated Short Range Communication Vehicle-based Road and Weather Condition Application

Installation Guide

Version 1.0

August 2015

Prepared For:
Connected Vehicle Pooled Fund Study

By:
Synesis Partners LLC
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## REVISION HISTORY

<table>
<thead>
<tr>
<th>Version</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>Initial version.</td>
</tr>
</tbody>
</table>

1 INTRODUCTION

1.1 Purpose

The purpose of this document is to describe the installation and installation testing of the on-board equipment (OBE) for the 5.9 GHz Dedicated Short Range Communication Vehicle Based Road and Weather Condition Application.

1.2 Scope

The scope of the project is to develop, test, and prepare to deploy 5.9 GHz dedicated short range communication (DSRC) capabilities for road and weather condition data in maintenance and highway emergency local patrol (HELP) vehicles. The system is capable of obtaining vehicle data from SAE J1939 and J1979 diagnostic buses and various peripheral devices on maintenance vehicles; transmitting this data to compliant 5.9 GHz DSRC roadside equipment (RSE); and providing the data on the RSE to agency systems when requested. It is envisioned that this application will be deployed on agency maintenance vehicles of the members of the Connected Vehicle (CV) Pooled Fund Study (PFS) along connected vehicle test beds.

Installation and installation testing of the OBE includes installing and configuring included firmware system components and the Road Weather application to each OBU; mounting each OBU to an appropriate location in a designated vehicle; mounting the antenna and power management assembly,” and connecting the communication and power cabling. Installation and testing of the RSE included configuration and preparation of the RSE; mounting the RSE to its supports in the field location; and installing the backhaul communications and power connections.

1.3 Definitions, Acronyms, and Abbreviations

This document may contain terms, acronyms, and abbreviations that are unfamiliar to the reader. A dictionary of these terms, acronyms, and abbreviations can be found in Appendix A.

1.4 References

The following documents contain additional information pertaining to this project and the requirements for the system:

5.9 GHz Dedicated Short Range Communication Vehicle Based Road and Weather Condition Application Concept of Operations, May 2013, Synesis Partners LLC.
1.5 Overview

The remaining sections of the document describe the system elements to be installed, the tasks and resources needed for installation, the installation instructions, and any risks or contingencies that must be considered.

Section 2 – Installation Items describes the components to be installed.

Section 3 – Installation Tools and Resources describes tools, personnel skills, and environment needed to successfully install the system components.

Section 4 – OBE Installation Guide provides the installation instructions for the OBE components.

Section 5 – RSE Installation Guide provides the installation instructions for the RSE components.

Section 6 – System Installation Testing provides instructions for the end-to-end testing of the installed system.
2 INSTALLATION ITEMS

This section describes the system items and components included in the installation. Subsystems may be completely software, hardware, or combinations of hardware and software.

2.1 System View

The OBEs for which installation is described in this guide are part of a larger system with existing and new components deployed in vehicles, at the roadside, and in back offices. Figure 1 illustrates the scope, types of equipment, and communication paths involved.

![Figure 1 - Major System Components (Source: Synesis Partners LLC)](image)

Figure 2 illustrates the on-board equipment for which installation instructions are provided in this document. Figure 2 identifies the on-board components and their connections for the light commercial vehicle (in this case, a Ford F250 or F350) and the heavy vehicle (a Mack truck). OBU connections provide power, access to communication antennas, and data connections to on-board sensors. Sensor connections are made to the vehicle data buses (J1979 OBD-II on commercial light vehicles; J1939 on heavy vehicles); to the DICKEY-john plow and treatment equipment; and to the IceSight device.
Figure 2 - Vehicle Components Deployment (Source: Synesis Partners LLC)

2.2 Installation Parts List

Installation instructions are provided for the components in Table 1.

Table 1 - OBE Installation Components (Source: Synesis Partners LLC)

<table>
<thead>
<tr>
<th>HW</th>
<th>SW</th>
<th>ID</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>OBE-0</td>
<td>OBE</td>
</tr>
<tr>
<td>X</td>
<td></td>
<td>OBE-1</td>
<td>Mounting bracket for IceSight sensor (not provided)</td>
</tr>
<tr>
<td>X</td>
<td></td>
<td>OBE-2</td>
<td>ChargeGuard vehicle power interface</td>
</tr>
<tr>
<td>X</td>
<td></td>
<td>OBE-3</td>
<td>J1939 cable (used to connect OBE to a heavy vehicle CAN data bus)</td>
</tr>
<tr>
<td>X</td>
<td></td>
<td>OBE-4</td>
<td>J1979 cable (used to connect OBE to a light vehicle CAN data bus, otherwise known as OBD-II port)</td>
</tr>
<tr>
<td>X</td>
<td></td>
<td>OBE-5</td>
<td>Serial DE9 cable connecting the OBE to common DICKEY-john road treatment equipment</td>
</tr>
<tr>
<td>X</td>
<td></td>
<td>OBE-6</td>
<td>Serial cable connecting the OBE to a mounted IceSight sensor</td>
</tr>
<tr>
<td>X</td>
<td></td>
<td>OBE-7</td>
<td>DSRC/GPS antenna</td>
</tr>
<tr>
<td>X</td>
<td></td>
<td>OBE-9</td>
<td>OBE software</td>
</tr>
</tbody>
</table>
Table 2 - RSE Installation Components (Source: Synesis Partners LLC)

<table>
<thead>
<tr>
<th>HW</th>
<th>SW</th>
<th>ID</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td></td>
<td>RSE-1</td>
<td></td>
</tr>
<tr>
<td>X</td>
<td></td>
<td>RSE-2</td>
<td></td>
</tr>
<tr>
<td>X</td>
<td></td>
<td>POE-1</td>
<td></td>
</tr>
<tr>
<td>X</td>
<td></td>
<td>POE-2</td>
<td>Configuration settings on the PoE switch (not needed on an unmanaged switch)</td>
</tr>
</tbody>
</table>

Table 3 - Heartbeat Monitoring Service Installation Components (Source: Synesis Partners LLC)

<table>
<thead>
<tr>
<th>HW</th>
<th>SW</th>
<th>ID</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td></td>
<td>HBT-1</td>
<td>Configuration settings for the RSU heartbeat monitor</td>
</tr>
</tbody>
</table>
3 INSTALLATION TOOLS AND RESOURCES

3.1 Tools

Tools needed for OBE installation and installation testing include:

- Laptop or other workstation with a secure shell application (PuTTY) and secure copy application (WinSCP)
- Ethernet cable
- Small slotted screwdriver
- Medium slotted screwdriver
- Small Phillips screwdriver
- Wire cutter/stripper
- Wire terminal crimmer
- Agency-approved silicone adhesive.

Tools needed for RSE installation and installation testing include:

- Adjustable wrench
- Small slotted screwdriver
- Medium slotted screwdriver
- Medium Phillips screwdriver
- Pliers
- All-weather electrical tape
- All-weather double sided foam tape
- Bucket truck
- Safety equipment
- Wire crimpers/strippers
- Snips
- Ethernet cable crimmer
- RJ45 connectors
- Electric drill
- Outdoor extension cord
• Miscellaneous electrical wiring
• Laptop with secure shell application (PuTTY)
• Two Ethernet cables
• Test network switch
• Workstation with secure shell application (PuTTY) and secure copy application (WinSCP)
• Server for heartbeat monitor installation
• Current Oracle Java JDK or JRE

3.2 Personnel
Staff should have some minimal experience and skills to successfully install and test the OBE:
• Experience with OBE documentation and configuration
• Experience with heavy vehicle power and communication systems
• Experience with light vehicle power and communication systems
• Experience with configuring network interface cards
• Experience with establishing secure shell terminal sessions

3.3 Environmental Needs
There are no particular environmental needs for installation of the OBEs and RSEs.
4 OBE INSTALLATION GUIDE
This section describes installation of the OBU and other on-board equipment.

4.1 Light Vehicle (with OBD-II Data Port) DSRC OBU Configuration
The steps listed below describe the configuration of the DSRC OBU in light vehicles with OBD-II data ports, specifically Ford F250/350 HELP vehicles. Data to be collected from the OBD-II port have to be identified and configured on the OBU to enable collection. This task may require tools including a laptop or other workstation, a secure shell terminal application such as PuTTY, a secure copy application such as WinSCP, Ethernet cable, and will take about thirty minutes to complete.

<table>
<thead>
<tr>
<th>Step</th>
<th>Action</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Connect OBU to network switch with Ethernet cable where configuration workstation is also connected or connect Ethernet cable directly between workstation and OBU. Add address from default OBU subnet to workstation network interface.</td>
<td>If a network switch option is chosen, the OBU will attempt to use DHCP to acquire an address. In the absence of DHCP, the MK2 will automatically generate a network address in the form 169.254.ABC.DEF, where DEF is the last two hex digits of the serial number in decimal format and ABC is the next to last two hex digits of the serial number in decimal format: 0104E548002054 --&gt; 169.254.0x20.0x54 = 169.254.32.84</td>
</tr>
<tr>
<td>2</td>
<td>Use a terminal application (PuTTY) to connect to the OBU network address using Telnet protocol and login as root.</td>
<td>The OBU uses the standard Telnet port 23 and the default root password is blank.</td>
</tr>
<tr>
<td>3</td>
<td>Use vi to edit the CAN configuration in the /opt/cohda/bin/rc.can file. Set the CAN0 “br_presdiv” divisor to 7, set the CN1 “br_presdiv” divisor to 14 and save the file.</td>
<td>The CAN bus driver timing is based on 3500 kbps (kilobits per second). Therefore, 7 corresponds to a light vehicle bus speed of 500 kbps (3500 / 7 = 500) and 14 corresponds to a typical heavy vehicle bus speed of 250 kbps.</td>
</tr>
<tr>
<td>4</td>
<td>Set a password for root using the passwd command.</td>
<td>Be sure to record the password along with the device hardware identifier into the appropriate configuration management or asset tracking system.</td>
</tr>
<tr>
<td>5</td>
<td>Securely copy (WinSCP) the RdWx application, RdWx.conf, startup.sh, upload.sh to the /mnt/ubi/dbg directory.</td>
<td>You may also remain logged in to the OBU through the Telnet terminal during this operation.</td>
</tr>
</tbody>
</table>
6. Execute `chmod 700` for both `/mnt/ubi/dbg/RdWx` and `/mnt/ubi/dbg/startup.sh` This informs the operating system that RdWx and startup.sh are executable.

7. Use `vi` to edit the `/etc/rc.local` file on the OBU to execute `/mnt/ubi/dbg/startup.sh`. The RdWx application startup script will now run every time the OBU boots.

8. Use `vi` to edit the default `/mnt/ubi/dbg/RdWx.conf` file to set the desired OBD-II capture parameters. The default RdWx.conf file for light vehicles should be sufficient. Only the RdWx, GPS, and J1979 need to be set active. Additional known PID filters for weather-related data can be set during this step by adding the desired label to the params entry and the corresponding PID filter and conversion.

9. Type the `halt` command into the Telnet session. This will logout of the terminal session, properly shutdown the device, and disconnect. The OBU is now ready to be installed in a vehicle.

4.2 Light Vehicle (with OBD-II Data Port) DSRC OBU Installation

The steps listed below describe the installation of the DSRC OBU in light vehicles with OBD-II data ports, specifically Ford F250/350 HELP vehicles. This task may require tools including small slotted screwdriver, medium slotted screwdriver, small Phillips screwdriver, agency-approved silicone adhesive, wire cutter/stripper, wire terminal crimper, optional wire terminal connectors, and will take about ninety minutes to complete.

![Cohda MK II, Front View](Synesis_Partners_LLC)

Figure 3 - Cohda MK II, Front View (Source: Synesis Partners LLC)
### Figure 4 - Cohda MK II, Rear View (Source: Synesis Partners LLC)

<table>
<thead>
<tr>
<th>Step</th>
<th>Action</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mount OBU to floorboard rear driver side. Silicone adhesive or other appropriate method can be used to securely fasten the device.</td>
<td><img src="image1.png" alt="Image of Cohda MK II rear view" /></td>
</tr>
<tr>
<td>2</td>
<td>Attach DSRC/GPS antenna to roof. Radio reception will be better if placed in front of other roof-mounted equipment such as a light bar.</td>
<td><img src="image2.png" alt="Image of Cohda MK II with DSRC/GPS antenna" /></td>
</tr>
<tr>
<td>3</td>
<td>Attach antenna cable clips and route antenna cable to OBU. The thinner antenna cable is attached to the GPS connector and the thicker antenna cables are attached to the 5 GHz connectors (ANT1/ANT3).</td>
<td><img src="image3.png" alt="Image of Cohda MK II with antenna cable" /></td>
</tr>
<tr>
<td>4</td>
<td>Attach CAN/power cable routing clips. The provided clips have foam adhesive, which will probably fail due to the small area, rough surface, and cable forces placed on it. It is recommended to reinforce the mounting clip adhesion with silicone or other appropriate adhesive.</td>
<td><img src="%7B%7D" alt="Image of installed CAN/power cable routing clips" /></td>
</tr>
<tr>
<td>Step</td>
<td>Instruction</td>
<td></td>
</tr>
<tr>
<td>------</td>
<td>-------------</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Run CAN/power cable under rocker panel.</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Connect CAN terminals to OBU vehicle interface connector (“VIC”).</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Mount ChargeGuard to OBU (or alternative location). This can also be accomplished with silicone adhesive.</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Connect power terminals to ChargeGuard. Butt-crimp the inline fuse holder to the red power wire from the CAN cable. Connect the black ground wire from the CAN cable and black wire pair on the OBU power cable to the ground terminal of the ChargeGuard. Connect the red wire pair from the OBU power cable to the ChargeGuard power output. Connect the loose end of the fuse holder to the ChargeGuard power input. Confirm there is a fuse in the fuse holder. Optionally, crimp appropriate wire terminations to wire ends to make</td>
<td></td>
</tr>
</tbody>
</table>
### 4.3 Heavy Vehicle (with J1939 Data Port) DSRC OBU Configuration

The steps listed below describe the configuration of the DSRC OBU in heavy vehicles with J1939 data ports. Data to be collected from the CAN bus has to be identified and configured on the OBU to enable collection. This task may require tools including a laptop or other workstation, a secure shell terminal application such as PuTTY, a secure copy application such as WinSCP, Ethernet cable, and will take about thirty minutes to complete.

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>Connect ChargeGuard to OBU. Insert the square connector end of the OBU power cable into the power input of the OBU.</td>
</tr>
<tr>
<td>10</td>
<td>Connect CAN/power cable to OBD-II port.</td>
</tr>
<tr>
<td>Step</td>
<td>Action</td>
</tr>
<tr>
<td>------</td>
<td>------------------------------------------------------------------------</td>
</tr>
</tbody>
</table>
| 1    | Connect OBU to network switch with Ethernet cable where configuration  | If a network switch option is chosen, the OBU will attempt to use DHCP to acquire an address. In the absence of DHCP, the MK2 will automatically generate a network address in the form 169.254.ABC.DEF, where DEF is the last two hex digits of the serial number in decimal format and ABC is the next to last two hex digits of the serial number in decimal format: 0104E548002054 --\>
<p>|      | workstation is also connected or connect Ethernet cable directly between |                                                                                                                                         |
|      | workstation and OBU. Add address from default OBU subnet to workstation |                                                                                                                                         |
|      | network interface.                                                     |                                                                                                                                         |
| 2    | Use a terminal application (PuTTY) to connect to the OBU network address| The OBU uses the standard Telnet port 23 and the default root password is blank.                                                                                                                      |
|      | using Telnet protocol and login as root.                               |                                                                                                                                         |
| 3    | Use vi to edit the CAN configuration in the /opt/cohda/bin/rc.can file.| The CAN bus driver timing is based on 3500 kbps (kilobits per second). Therefore, 7 corresponds to a light vehicle bus speed of 500 kbps (3500 / 7 = 500) and 14 corresponds to a typical heavy vehicle bus speed of 250 kbps. If the J1939 diagnostic connector is a green color, then that is a high-speed bus and a value of 7 should be used instead of 14. |
|      | Set the CANO “br_presdiv” divisor to 7, set the CN1 “br_presdiv” divisor|                                                                                                                                         |
|      | to 14 and save the file.                                               |                                                                                                                                         |
| 4    | Set a password for root using the passwd command.                      | Be sure to record the password along with the device hardware identifier into the appropriate configuration management or asset tracking system.                                                   |
| 5    | Securely copy (WinSCP) the RdWx application, RdWx.conf, startup.sh,    | You may also remain logged in to the OBU through the Telnet terminal during this operation.                                                                                                         |
|      | upload.sh to the /mnt/ubi/dbg directory.                               |                                                                                                                                         |
| 6    | Execute chmod 700 for both /mnt/ubi/dbg/RdWx and /mnt/ubi/dbg/startup.sh| This informs the operating system that RdWx and startup.sh are executable.                                                                                                                              |
| 7    | Use vi to edit the /etc/rc.local file on the OBU to execute /mnt/ubi/| The RdWx application startup script will now run every time the OBU boots.                                                                                                                             |
|      | dbg/startup.sh.                                                        |                                                                                                                                         |
| 8    | Use vi to edit the default /mnt/ubi/dbg/RdWx.conf file to set the     | The default RdWx.conf file for light vehicles should be sufficient. Only the RdWx, GPS, and J1939 need to be set active. Additional known PID filters for                                |
|      | desired J1939 capture parameters.                                       |                                                                                                                                         |</p>
<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>Use vi to edit the serial port startup configuration in the <code>/opt/cohda/bin/inittab.internal_gps</code> file. Comment out the line <code>::respawn:/sbin/getty -L ttymxc1 115200 vt100</code> by placing a # at the beginning and save the file. Then execute the sync command and reboot. The two OBU serial ports default to specific functions, and this step frees the external port so it can be used with Dickey-John equipment.</td>
</tr>
<tr>
<td>10</td>
<td>Change the serial port baud rate to 19200 with by executing “fw_setenv console ttymxc0,19200” excluding the double quotes. This is the data rate compatible with Dickey-John control point terminals.</td>
</tr>
</tbody>
</table>
| 11   | Configure the network interface for an IceSight sensor. Enter three commands (including the double quotes) to permanently set the OBU IP address to the 192.168.1.x network:  
  - `fw_setenv static_ip_addr "192.168.1.181"`  
  - `fw_setenv static_ip_mask "255.255.255.0"`  
  - `fw_setenv static_ip_bcast "192.168.1.255"`  
  Optionally, set the network gateway and name server parameters if known:  
  - `fw_setenv static_ip_gw "192.168.1.x"`  
  - `fw_setenv static_ip_ns "192.168.1.y"`  
  Depending on how many devices are to be deployed, it is possible to set the final octet of the network address to different values and associate them with the hardware address for configuration management. The range can be 192.168.1.1 to 192.168.1.254 excluding 192.168.1.180, which is the address of the IceSight. |
| 12   | Type reboot in the terminal. Note that after a reboot, the OBU will now have a new network address which must be updated on the workstation to continue further terminal interaction with the unit. |
| 13   | Reconnect to the OBU with the terminal application to verify the new network address was set. This verifies that the OBU will be able to communicate with the IceSight sensor. |
4.4 **Heavy Vehicle (with J1939 Data Port) DSRC OBU Installation**

The steps listed below describe the installation of the DSRC OBU in heavy vehicles with J1939 data ports, specifically Mack snow plow trucks. This task may require tools including small slotted screwdriver, medium slotted screwdriver, small Phillips screwdriver, agency-approved silicone adhesive, wire cutter/stripper, wire terminal crimper, optional wire terminal connectors, and will take about ninety minutes to complete.
<table>
<thead>
<tr>
<th>Step</th>
<th>Action</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mount OBU to dashboard front passenger side. Verify that this does not obstruct vehicle operator vision or violate vehicle safety laws. A different position may need to be chosen.</td>
<td><img src="image1" alt="Image of OBU mounted on dashboard" /></td>
</tr>
<tr>
<td>2</td>
<td>Attach DSRC/GPS antenna to roof. Newer heavy vehicle have fiberglass roofs so an appropriately grounded metal mounting plate may need to be fabricated and fastened to the roof prior to mounting the antenna. Alternatively, a different antenna with the same electromagnetic characteristics and cable terminals but different mounting options may be available for procurement.</td>
<td><img src="image2" alt="Image of antenna attached to roof" /></td>
</tr>
<tr>
<td>3</td>
<td>Attach antenna cable clips and route antenna cable to the OBU. Use silicone adhesive where needed to reinforce clip positioning.</td>
<td><img src="image3" alt="Image of antenna cable routing" /></td>
</tr>
<tr>
<td>4</td>
<td>Attach J1939 cable routing clips</td>
<td></td>
</tr>
<tr>
<td>Step</td>
<td>Instructions</td>
<td></td>
</tr>
<tr>
<td>------</td>
<td>-------------</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Run J1939 cable under dashboard</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Connect J1939 cable DE9 connector to OBU</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Mount ChargeGuard to OBU (or alternative location)</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Connect J1939 cable power terminals to ChargeGuard</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Connect ChargeGuard to OBU. Butt-crimp the inline fuse holder to the red power wire from the CAN cable. Connect the black ground wire from the CAN cable and black wire pair on the OBU power cable to the ground terminal of the ChargeGuard. Connect the red wire pair from the OBU power cable to the ChargeGuard power output. Connect the loose end of the fuse holder to the ChargeGuard power input. Confirm there is a fuse in the fuse holder. Optionally, crimp appropriate wire terminations to wire ends to make ChargeGuard insertion easier.</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Connect J1939 cable to J1939 diagnostic port on vehicle</td>
<td></td>
</tr>
</tbody>
</table>
4.5 **DICKEY-john Control Point Cable Installation (Optional)**

The steps listed below describe the installation of the cable connecting the Dickey John control point to the DSRC OBU. This task may require tools including small slotted screwdriver, and will take about five minutes to complete.

<table>
<thead>
<tr>
<th>Step</th>
<th>Action</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Locate the DICKEY-john Control Point in the vehicle cab. Connect the serial DE9 cable to the Control Point and tighten the screw fasteners. A small screwdriver may be used if finger-tightening is difficult.</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Connect the serial DE9 cable from DICKEY-john Control Point to OBU (“RS232”) and tighten the screw fasteners.</td>
<td><img src="image.png" alt="Image" /></td>
</tr>
<tr>
<td>3</td>
<td>Loop and secure excess serial cable out of the way.</td>
<td></td>
</tr>
</tbody>
</table>

4.6 **IceSight Installation (Optional)**

The steps listed below describe the installation of the cable connecting the IceSight weather sensor to the DSRC OBU. This task may require tools including mounting bracket, lock washers, bolts, nuts, ratchet set adjustable wrench, split loom tubing, cutters/knife, cable zip ties, miscellaneous 24 AWG red and black wires, and will take about sixty minutes to complete.

<table>
<thead>
<tr>
<th>Step</th>
<th>Action</th>
<th>Notes</th>
</tr>
</thead>
</table>
| 1    | Attach IceSight mount to passenger front side guard | • 45 degree incline  
• Minimum of 3 feet to pavement (this is angled distance, not height)  
• Mount on bumper cross beam support facing rear  
• Protected by bumper but in clear view of pavement |
<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Attach IceSight to mount. The IceSight comes with two ¼” threaded shafts for mounting.</td>
</tr>
<tr>
<td>3</td>
<td>Enclose IceSight cable in split loom tubing</td>
</tr>
<tr>
<td>4</td>
<td>Run cable through engine compartment</td>
</tr>
</tbody>
</table>
5. Secure cable and tubing to grill

6. Run cable through existing penetration in firewall under dashboard on passenger side and secure

7. Connect RJ45 plug to Ethernet jack (“LAN”) on OBU

8. Connect IceSight power cable to ChargeGuard. Strip and insert bare end of the 24 AWG red wire into red side of IceSight power cable connector. Strip and insert bare end of the 24 AWG black wire into black side of IceSight power cable connector. Secure wiring with electrical table or heat shrink tubing. Alternatively, substitute a different termination being careful to keep track of which wire is position (red side) and negative (black side). Screw the red wire to the ChargeGuard power output and the black wire to the ChargeGuard common ground.

4.7 OBU Installation Testing

The steps listed below describe the testing of the DSRC OBU for proper installation and operation. This task may require tools including laptop or workstation, Ethernet cable, secure shell application such as PuTTY, and will take about sixty minutes to complete.
<table>
<thead>
<tr>
<th></th>
<th>Turn on the vehicle ignition and verify that the OBU becomes active after 5 minutes.</th>
<th>ChargeGuard configuration determines the initial startup delay. The LEDs on the front of the OBU will change color a few times and finally settle on both red when the device is on and ready. If this test fails, check both the ChargeGuard configuration, power cable connections, and verify there is a fuse in the inline fuse holder.</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Drive the vehicle around the area for at least one configured interval of data collection.</td>
<td>RdWx.conf file defaults the data collection to ten minutes per file.</td>
</tr>
<tr>
<td>3</td>
<td>If this did not occur in the previous data gathering step, deliberately drive by an RSU location. Verify that RSU communication was at least attempted.</td>
<td>When OBU come into range of RSU, the top LED will flash between red and green to indicate DSRC radio activity.</td>
</tr>
<tr>
<td>4</td>
<td>Return the vehicle to the test trip origin and turn the ignition off. Verify the OBU turns off after 5 minutes.</td>
<td>ChargeGuard configuration also determines the shutdown delay. The LEDs will change from both red to dark.</td>
</tr>
<tr>
<td>5</td>
<td>Using a workstation connected to the same network as the RSE, use SSH to connect to the RSU or RSUs that were driven by during the test data gathering run. Verify that there are files with nearly current time stamps on the RSU in the /home/RdWx/data directory.</td>
<td>This step verifies that data files are successfully transmitted from OBE to RSE.</td>
</tr>
<tr>
<td>6</td>
<td>Using the gzip command, decompress one of the recent data files.</td>
<td>This verifies that the file is complete and uncorrupted.</td>
</tr>
<tr>
<td>7</td>
<td>Using vi, edit the now uncompressed data files and verify that there are data values.</td>
<td>This step verifies the data content of the files. The content will vary based on what is configured to be captured by the RdWx.conf file. The best outcome is that there is at least one data value in each column. If a column contains no data for the file duration, it is possible that a value was not provided during the test interval, but a verification of the RdWx configuration is probably a good idea.</td>
</tr>
<tr>
<td>8</td>
<td>After fixing any encountered problems, repeat the previous steps for at least one of the light vehicle and heavy vehicle</td>
<td></td>
</tr>
</tbody>
</table>
deployments, if not all of them.
5 RSE INSTALLATION GUIDE

This section describes installation of the DSRC RSU and other supporting roadside equipment.

5.1 Savari RSU Software Preparation

The steps listed below describe the RdWx application software preparation for the Savari DSRC RSU. This task may require tools including laptop, two Ethernet cables, a power-over-Ethernet network switch, secure shell application (PuTTY), secure copy application (WinSCP), and will take about fifty minutes to complete.

These steps can be followed after a RSE is deployed to field since network connectivity and power will have been tested at that point as is sufficient for this purpose. It is helpful if the person following these steps is familiar with GNU/Linux operating systems, creating users and directories, and is comfortable editing configuration files.

<table>
<thead>
<tr>
<th>Step</th>
<th>Action</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ensure the PoE switch is connected to power and the RSU is on. Wait for RSU to boot.</td>
<td>RSU perform an extensive storage test on initial boot that can take up to twenty minutes. There is a green LED indicator that illuminates when the device is ready.</td>
</tr>
<tr>
<td>2</td>
<td>Configured the laptop or workstation to have a network address on the 169.254.0.x subnet, excluding 169.254.0.1, which is the RSU default IPv4 address.</td>
<td>The Savari RSU has a default local IP address of 169.254.0.1. A different IPv4 or IPv6 address may be used if it is known that one was previously applied to the unit at hand. It is also possible to ping the IPv6 “all routers” address of FE01::2 and then connect to the unit at hand using its IPv6 link-local address that begins with FE80:: contained in the ping response.</td>
</tr>
<tr>
<td>3</td>
<td>Connect to the RSU address using an SSH terminal and login with root using default password or password provided by a connected vehicle network administrator.</td>
<td>The default password can be found in the release notes documentation for the specific version of firmware installed on RSE.</td>
</tr>
<tr>
<td>4</td>
<td>Set a password for root using the passwd command.</td>
<td>Be sure to record the password along with the device hardware identifier into the appropriate configuration management or asset tracking system.</td>
</tr>
<tr>
<td>5</td>
<td>Use vi to edit the /etc/group file and add the line “RdWx:x:101:RdWx” excluding the quotes and save the file.</td>
<td>Some RSU firmware deliberately do not include a useradd or adduser command so new users need to be added manually.</td>
</tr>
<tr>
<td>Step</td>
<td>Description</td>
<td></td>
</tr>
<tr>
<td>------</td>
<td>-------------</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Use vi to edit the <code>/etc/passwd</code> file and add the line &quot;RdWx:x:101:101:RdWx:/home/RdWx:/bin/ash&quot; excluding the quotes and save the file.</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Set the RdWx password by issuing the <code>passwd RdWx</code> command.</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Create the RdWx user directories by issuing these commands excluding the quotes: <code>mkdir /home/RdWx</code>, <code>mkdir /home/RdWx/data</code>, <code>mkdir /home/RdWx/newfiles</code>, <code>mkdir /home/RdWx/update</code>, and <code>mkdir /home/RdWx/.ssh</code>. The RdWx directories are where the RdWx application stores its files and contains the application supporting scripts and password-less logon key.</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Using a secure copy application, copy the README_RSU.txt, cleanup.sh, make_manifests.sh, senddata.sh files to &quot;/home/RdWx/&quot;. These are the RSE scripts for the RdWx application.</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Using a secure copy application, copy the public RdWx key created from the steps in Appendix F to the RSU and append it to the /home/RdWx/.ssh/authorized_keys file. This enables the password-less login from OBE to RSE.</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Change the RdWx directories to be owned by the RdWx user by issuing the command without the quotes “chown –R RdWx:RdWx /home/RdWx“. This grants permission to the RdWx application user to operate on its directories and files.</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Use vi to edit the <code>/etc/crontabs/root</code> file and add the line excluding quotes “0 0 * * * /home/RdWx/cleanup.sh /home/RdWx/data 300 &gt; /dev/null”. This enables the daily schedule to remove uncollected RdWx application data files when there are more than 300 of them.</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Use vi to edit the <code>/etc/crontabs/root</code> file and add the line excluding quotes “*/5 * * * * &lt;IPv6 address&gt; /home/RdWx/senddata.sh /home/RdWx/data &gt; /dev/null”. This is an optional step if a destination address has not been determined. Otherwise, the command enables a regular five-minute schedule to push RdWx application data files to other servers. A valid IPv6 server address should be substituted for the “&lt;IPv6 address&gt;” tag.</td>
<td></td>
</tr>
</tbody>
</table>
| 14   | Use vi to edit the `/etc/config/network` file The network administrator will need to
and add appropriate IPv6 addressing information to the lan, dsrnet0, and dsrnet1 interfaces.

be consulted to determine the IPv6 addresses. This information should also be recorded in an appropriate configuration management tool.

15 While editing the /etc/config/network file, add the “option mtu ‘1280’” line to the lan interface section, excluding the double quotes but including the single quotes. Save the network configuration file.

Setting the MTU to 1280 in the network configuration file helps in cases where the upstream IPv6 network is tunneled over IPv4. It reduces fragmentation resends and mysterious failures when intervening network hardware adjusts the do-not-fragment bit in the packets.

16 Issue a “/etc/init.d/network restart” command excluding the quotes.

This will apply the updated network configuration immediately.

17 Issue ping commands to test that the IPv4 and IPv6 network configuration is working.

This can be done from the workstation being used to configure RSE, or from another workstation on a network connected to the PoE switch. Field installers also perform this test, but this step helps ensure everything works before committing deployment labor.

18 Issue the syshalt command.

This puts RSE into its shutdown state so that it can be disconnected from power and delivered to field technicians for deployment.

5.2 Savari RSU Hardware Preparation

The steps listed below describe the configuration of the Savari DSRC RSU. This task may require tools including adjustable wrench, medium slotted screwdriver, medium Phillips screwdriver, pliers, all-weather electrical tape, and all-weather double-sided foam tape, and will take about thirty minutes to complete.
## Figure 5 - Savari RSU Preparation for Installation (Source: Synesis Partners LLC)

<table>
<thead>
<tr>
<th>Step</th>
<th>Action</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Install antenna surge protectors</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Connect antenna surge protector grounding cable</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Connect antenna surge protector quick- disconnect cable</td>
<td>All-weather double-sided foam tape can be used.</td>
</tr>
<tr>
<td>4</td>
<td>Install antennae</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Apply sealant around antenna penetrations</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Connect and secure GPS antenna</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Tape off 110VAC cable (if using PoE)</td>
<td>Use electrical tape and/or trim off exposed end</td>
</tr>
<tr>
<td>8</td>
<td>Attach mounting bracket</td>
<td></td>
</tr>
</tbody>
</table>
5.3 Savari RSU Installation

The steps listed below describe the field installation of the Savari DSRC RSU. This task may require tools including bucket truck, safety equipment, wire crimpers/strippers, snips, Ethernet cable crimper, RJ45 connectors, adjustable wrench, small slotted screwdriver, medium Phillips screwdriver, electric drill, outdoor extension cord, miscellaneous electrical wiring, and will take about sixty minutes to complete.

![Image of Savari RSU Mounting](image_url)

**Figure 6 - Typical Savari RSU Mounting (Source: Synesis Partners LLC)**

<table>
<thead>
<tr>
<th>Step</th>
<th>Action</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Attach RSU mounting bracket to pole</td>
<td>Extra time may be needed if no usable mounting point is readily available.</td>
</tr>
<tr>
<td>2</td>
<td>Connect antenna surge protector quick-disconnect to electrical ground</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Slide screw cap over Ethernet cable</td>
<td>Ethernet cable may need to be trimmed and re-terminated.</td>
</tr>
<tr>
<td>4</td>
<td>Apply sealant to Ethernet cable</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Connect PoE cable to RSU RJ45 receptacle</td>
<td></td>
</tr>
</tbody>
</table>
6. Screw Ethernet cap over connection to seal

5.4 **Backhaul Installation**

The steps listed below describe the field installation of the backhaul communications connection to the Savari DSRC RSU. This task may require tools including bucket truck, safety equipment, wire crimpers/stripers, snips, Ethernet cable crimper, RJ45 connectors, adjustable wrench, small slotted screwdriver, medium Phillips screwdriver, electric drill, outdoor extension cord, miscellaneous electrical wiring, and will take about sixty minutes to complete provided no cabinet cleanup, rearranging, or additional electrical work is necessary.

<table>
<thead>
<tr>
<th>Step</th>
<th>Action</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Install 48VDC power supply in cabinet</td>
<td>If using a PoE single port injector, this power supply is unnecessary.</td>
</tr>
<tr>
<td>2</td>
<td>Connect 48VDC power supply cord</td>
<td>Small slotted screwdriver can be used.</td>
</tr>
<tr>
<td>3</td>
<td>Install PoE surge protector</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Connect PoE surge protector to ground</td>
<td></td>
</tr>
<tr>
<td>Step</td>
<td>Task</td>
<td>Details</td>
</tr>
<tr>
<td>------</td>
<td>------</td>
<td>---------</td>
</tr>
<tr>
<td>5</td>
<td>Install PoE switch</td>
<td>Alternatively, single-port PoE injector.</td>
</tr>
<tr>
<td>6</td>
<td>Connect PoE switch frame ground</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Connect PoE switch to 48VDC power supply</td>
<td>Skip this step when using PoE injector.</td>
</tr>
<tr>
<td>8</td>
<td>Verify grounding and electrical connections</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Connect backhaul transceiver to PoE switch</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Connect PoE switch to PoE surge protector</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Connect RSE Ethernet cable to PoE surge protector</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Connect 48VDC power supply cord to power</td>
<td>In the case of PoE injector, connect to available 5-15/20R.</td>
</tr>
</tbody>
</table>

Figure 8 - In-cabinet Component Installation (Source: Synesis Partners LLC)
## 5.5 Savari RSU Installation Testing

The steps listed below describe the field installation testing of the Savari DSRC RSU. This task may require tools including laptop, two Ethernet cables, test network switch, secure shell application (PuTTY), and will take about thirty minutes to complete.

<table>
<thead>
<tr>
<th>Step</th>
<th>Action</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Wait for RSU to boot</td>
<td>RSU perform an extensive storage test on initial boot that can take up to twenty minutes. There is a green LED indicator that illuminates when the device is ready.</td>
</tr>
<tr>
<td>2</td>
<td>Connect test laptop to PoE switch or connect test switch to input side of injector and then connect laptop to test switch.</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Open terminal to RSU default local IP address</td>
<td>The Savari RSU has a default local IP address of 169.254.0.1.</td>
</tr>
<tr>
<td>4</td>
<td>Login with root using default password or password provided by a connected vehicle network administrator.</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Verify RSU IPv6 address</td>
<td>Run the ifconfig command for eth0, ath0, and ath1. Confirm that IPv6 addressing matches that provided by the connected vehicle network administrator.</td>
</tr>
<tr>
<td>6</td>
<td>Ping IPv6 backhaul server</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Secure shell (SSH) IPv6 to backhaul server</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Verify RSU log file upload server IPv6 address</td>
<td>These verification steps are performed through the Savari web interface. Open the local address with port 8080 and enter the default user name and password from the Savari hardware manual or those provided by the connected vehicle network administrator.</td>
</tr>
<tr>
<td>9</td>
<td>Verify RSU heartbeat server IPv6 address</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Verify RSU alarm status server IPv6 address</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Verify RSU BSM forward server IPv6 address</td>
<td></td>
</tr>
</tbody>
</table>
### 5.6 Heartbeat Service Installation and Testing

The steps listed below describe the installation of the RSU heartbeat monitor. This task may require tools including workstation, server, current Oracle Java JDK or JRE, secure shell application (PuTTY), secure copy application (WinSCP), and will take about fifteen minutes to complete.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>Verify RSU IPv6 service configuration</td>
</tr>
<tr>
<td>13</td>
<td>Verify the file upload configuration</td>
</tr>
<tr>
<td>14</td>
<td>Verify RSU applications started</td>
</tr>
<tr>
<td>15</td>
<td>Verify RSU log files are being created</td>
</tr>
<tr>
<td>16</td>
<td>Logout of terminal application by typing exit.</td>
</tr>
<tr>
<td>17</td>
<td>Disconnect test laptop from PoE switch</td>
</tr>
<tr>
<td>18</td>
<td>Connect test laptop to cell modem</td>
</tr>
<tr>
<td>19</td>
<td>SSH to backhaul server</td>
</tr>
<tr>
<td>20</td>
<td>Ping IPv6 to RSU</td>
</tr>
<tr>
<td>21</td>
<td>SSH IPv6 to RSU</td>
</tr>
<tr>
<td>22</td>
<td>Logout of SSH session with RSU issuing the exit command.</td>
</tr>
<tr>
<td>23</td>
<td>Verify log files are copied to backhaul server by executing a directory listing with the ls –a command for the destination log file directories.</td>
</tr>
<tr>
<td>24</td>
<td>Log out of the backhaul server SSH session issuing the exit command and disconnect from the cell modem.</td>
</tr>
<tr>
<td>Step</td>
<td>Action</td>
</tr>
<tr>
<td>------</td>
<td>--------</td>
</tr>
<tr>
<td>1</td>
<td>Install the heartbeat monitor software. Java may need to be installed first. A good location for the software is /opt/heartbeat. Installation consists of copying the .jar file to the directory.</td>
</tr>
<tr>
<td>2</td>
<td>Test the heartbeat monitor</td>
</tr>
</tbody>
</table>
6 SYSTEM INSTALLATION TESTING

This section describes installation testing of the OBE, RSE and communications.

The steps listed below describe the testing of the installed system. This task may require tools including a laptop, Ethernet cable, secure shell terminal application (PuTTY), portable network switch, installed OBU, deployed RSE, test server IPv6 address, and will take about sixty minutes to complete.

<table>
<thead>
<tr>
<th>Step</th>
<th>Action</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Configure the laptop network adapter to have an address in the 192.168.1.x subnet.</td>
<td>This enables the laptop to communicate with the OBU.</td>
</tr>
<tr>
<td>2</td>
<td>Connect the laptop to the OBU using the Ethernet cable.</td>
<td>If testing a vehicle with IceSight sensors, it is necessary to use a network switch to connect the laptop, IceSight, and OBU.</td>
</tr>
<tr>
<td>3</td>
<td>Drive the OBU-equipped vehicle within 300 meters of a deployed RSU.</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Login to the OBU with the SSH terminal application.</td>
<td>Use the root credentials from the configuration data recorded from the installation.</td>
</tr>
<tr>
<td>5</td>
<td>Verify receipt of the IPv6 wave service advertisement.</td>
<td>Issue an “ip -6 neigh show” command and see that the listed network neighbors includes a radio address from the nearby RSU.</td>
</tr>
<tr>
<td>6</td>
<td>Verify acquiring IPv6 address.</td>
<td>Issue an “ifconfig wave-data” command and see that the router portion of the IPv6 address is from the nearby RSU radio network.</td>
</tr>
<tr>
<td>7</td>
<td>Verify RSU communication.</td>
<td>Issue a ping6 command to the RSU radio IPv6 address.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Issue a ping6 command to the RSU inside Ethernet IPv6 address.</td>
</tr>
<tr>
<td>8</td>
<td>Verify other host communication.</td>
<td>Issue a ping6 command to a designated test server IPv6 address.</td>
</tr>
<tr>
<td>9</td>
<td>Verify observations can be sent to another host.</td>
<td>Through the SSH terminal, issue another ssh command and connect to the nearby RSU using the RdWx user credentials. From the new embedded terminal, manually run the RSU upload.sh script</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>giving it the test server IPv6 address. The upload script will output progress to the terminal. See that the output successfully completes. Issue the exit command to close the embedded terminal.</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Disconnect the test laptop.</td>
<td>Issue the exit command and disconnect the laptop from the OBU or switch. Reconnect the IceSight sensor to the OBU as needed.</td>
</tr>
<tr>
<td>11</td>
<td>Optionally repeat these steps for each OBU and potentially at different RSU locations.</td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX A - DEFINITIONS

The following table provides the definitions of all terms, acronyms, and abbreviations required to properly interpret this document.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>BSM</td>
<td>Basic Safety Message</td>
</tr>
<tr>
<td>CAN</td>
<td>Controller Area Network. An electrical specification and signaling protocol developed by Bosch to facilitate simple data communication between connected equipment control units.</td>
</tr>
<tr>
<td>CV</td>
<td>Connected Vehicle(s)</td>
</tr>
<tr>
<td>DSRC</td>
<td>Dedicated Short Range Communication. A low-latency, line-of-sight wireless data transmission standard designed for interactions between vehicles and infrastructure in a dynamic transportation environment.</td>
</tr>
<tr>
<td>FTP</td>
<td>File Transfer Protocol</td>
</tr>
<tr>
<td>GHz</td>
<td>Gigahertz</td>
</tr>
<tr>
<td>GPS</td>
<td>Global Positioning System</td>
</tr>
<tr>
<td>HCI</td>
<td>Hardware Configuration Item</td>
</tr>
<tr>
<td>HTTP</td>
<td>Hyper-Text Transfer Protocol</td>
</tr>
<tr>
<td>IEEE</td>
<td>Institute of Electrical and Electronics Engineers</td>
</tr>
<tr>
<td>IPv4</td>
<td>Internet Protocol version 4</td>
</tr>
<tr>
<td>IPv6</td>
<td>Internet Protocol version 6</td>
</tr>
<tr>
<td>NY</td>
<td>New York</td>
</tr>
<tr>
<td>NYSDOT</td>
<td>New York State Department of Transportation</td>
</tr>
<tr>
<td>OBE</td>
<td>On-board equipment</td>
</tr>
<tr>
<td>OBU</td>
<td>On-board unit. In this context, more specifically the DSRC equipment connected directly to a vehicle data bus.</td>
</tr>
<tr>
<td>PFS</td>
<td>Pooled Fund Study</td>
</tr>
<tr>
<td>PGN</td>
<td>Parameter Group Number. A unique identifier used as a network address in the SAE J1939 data standard to group similar data parameters.</td>
</tr>
<tr>
<td>PID</td>
<td>Parameter identifier. A unique code used in a controller area network to request specific equipment operational and state data.</td>
</tr>
<tr>
<td>PoE</td>
<td>Power over Ethernet</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>------</td>
<td>------------</td>
</tr>
<tr>
<td>PSID</td>
<td>Provider service identifier</td>
</tr>
<tr>
<td>PuTTY</td>
<td>A secure shell application</td>
</tr>
<tr>
<td>RSE</td>
<td>Roadside equipment. DSRC equipment deployed near a roadway or intersection.</td>
</tr>
<tr>
<td>SAE</td>
<td>Society of Automotive Engineers</td>
</tr>
<tr>
<td>SCMS</td>
<td>Security Certificate Management System</td>
</tr>
<tr>
<td>SP</td>
<td>Synesis Partners</td>
</tr>
<tr>
<td>SPN</td>
<td>Suspect Parameter Number. A lower-level identifier within a PGN that describes what a particular data value represents, its update frequency, and its unit of measure.</td>
</tr>
<tr>
<td>U.S. DOT</td>
<td>United States Department of Transportation</td>
</tr>
<tr>
<td>WAVE</td>
<td>Wireless Access in Vehicular Environments</td>
</tr>
<tr>
<td>WinSCP</td>
<td>Windows Secure Copy Program</td>
</tr>
</tbody>
</table>
APPENDIX B - OBU-TO-OBD-II CABLE CONSTRUCTION

This appendix describes the construction of the cable connecting the OBU serial port to the light vehicle OBD-II port. This task may require tools including needle-nose pliers, lead-free solder, variable temperature solder iron, glue, wire cutter/stripper, electrical tape, and will take about sixty minutes to complete.

<table>
<thead>
<tr>
<th>Action</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Get the right-angle OBD-II connector bottom and top pieces, adapter circuit board, and five connector pins.</td>
</tr>
<tr>
<td>2</td>
<td>Using need-nose pliers, gently insert pins with the hilt on the inside of the connector housing into positions 4, 5, 6, 14, and 16. Push the pins in until they stop at the hilt. The housing clip is the bottom row of pins and they are numbered from the top left as row 1 pins 1 to 8 and from the bottom left as row 2 pins 9 to 16.</td>
</tr>
<tr>
<td>3</td>
<td>Remove about 1 inch of cable sheath. Then strip ¼” of wire insulation from each of the four wires. Twist the wire ends a few times to minimize strand fraying.</td>
</tr>
</tbody>
</table>
4 Gently insert the stripped wire ends into the adapter circuit board and solder. It may be easier to insert each wire and solder it in turn. The black wire goes to the “—”, the green wire goes to “H”, and white wire goes to “L” and the red wire goes to “+”.

5 Firmly press the adapter circuit board into the connector housing so that each pin protrudes through its solder point. Solder the circuit board into place being careful not to melt the housing.

6 Route the connector cable to the right or left depending on the position of the target vehicle’s OBD-II port and the desired location of the OBU. For Ford vehicles, this is typically to the left.

7 Put a bead of glue around the end of the connector cap, line the hole up with the cable position, and press the connector cap into place.

8 Cut and remove about 12 inches of cable sheathing from the free end. Then split about 4 more inches of sheathing, but leave all but ½” intact. Cut the red wire to 8 inches, cut the green and white wires to about 1 inch, and leave the black wire long. Wrap electric tape ½” above the red and black wire protrusion to a diameter of about ¼”.
<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>Strip about ¼” of insulation from the green and white wires and twist strands a few times to minimize fraying. Crimp DE9 clips onto exposed wire ends, crimp, and solder.</td>
</tr>
<tr>
<td>10</td>
<td>The back of the DE9 connector is numbered on the top row pins 1 to 5, and the bottom row left to right pins 6 to 9. Insert the white wire clip into pin position 2 and push until it clicks into place. Insert the green wire clip into pin position 7 and push until it clicks into place.</td>
</tr>
<tr>
<td>11</td>
<td>Insert the DE9 connector assembly into the DE9 housing and press the electrical tape wrapped cable into the cable channel. Remove or add electrical tape as needed to provide some strain relief. Balance the DE9 screw terminals into their slots. Press the top portion of the DE9 housing to the bottom portion and screw halves together with small screws and nuts.</td>
</tr>
</tbody>
</table>
# APPENDIX C - OBU-TO-J1939 CABLE CONSTRUCTION

This appendix describes the construction of the cable connecting the OBU serial port to the heavy vehicle J1939 connector. This task may require tools including lead-free solder, variable temperature solder iron, wire cutter/stripper, wire connector crimpers, electrical tape, and will take about sixty minutes to complete.

<table>
<thead>
<tr>
<th>Step</th>
<th>Action</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Get the J1939 and trim about 3/8” of insulation from the purple/brown wire pair. Trim about 3/8” of insulation from the brown/green/yellow wire triplet.</td>
<td><img src="image1.jpg" alt="Image" /></td>
</tr>
<tr>
<td>2</td>
<td>Trim an appropriate amount of insulation from the red, black, green, and white wires from the 4-wire cable. Bond the purple wire to the red wire, the brown wire to the black wire, the yellow wire to the smaller green wire, and the larger green wire to the white wire. This can be accomplished with butt-end crimp connectors, direct soldering with heat shrink/electrical tape, or other appropriate method that results in a solid electrical and physical connection.</td>
<td><img src="image2.jpg" alt="Image" /></td>
</tr>
<tr>
<td>3</td>
<td>Cut and remove about 12 inches of cable sheathing from the free end. Then split about 4 more inches of sheathing, but leave all but ½” intact. Cut the red wire to 8 inches, cut the green and white wires to about 1 inch, and leave the black wire long. Wrap electric tape ½” above the red and black wire protrusion to a diameter of about ¼”.</td>
<td><img src="image3.jpg" alt="Image" /></td>
</tr>
<tr>
<td>Step</td>
<td>Description</td>
<td></td>
</tr>
<tr>
<td>------</td>
<td>-------------</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Strip about ¼” of insulation from the green and white wires and twist strands a few times to minimize fraying. Crimp DE9 clips onto exposed wire ends, crimp, and solder.</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>The back of the DE9 connector is numbered on the top row pins 1 to 5, and the bottom row left to right pins 6 to 9. Insert the white wire clip into pin position 8 and push until it clicks into place. Insert the green wire clip into pin position 4 and push until it clicks into place.</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Insert the DE9 connector assembly into the DE9 housing and press the electrical tape wrapped cable into the cable channel. Remove or add electrical tape as needed to provide some strain relief. Balance the DE9 screw terminals into their slots. Press the top portion of the DE9 housing to the bottom portion and screw halves together with small screws and nuts.</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Optionally, cut lengths of spare red and black wires, trim about ¼” inch of insulation from each, twist the ends to minimize fraying, and insert the exposed ends into the IceSight power connector with the corresponding color. Secure the connection with electrical tape or heat-shrink tubing.</td>
<td>![Image of a cable connector]</td>
</tr>
</tbody>
</table>
**APPENDIX D - CHARGEGUARD CONFIGURATION**

This appendix describes the configuration of the ChargeGuard unit for deployment with the DSRC OBU. This task may require tools including small slotted screwdriver, and will take about five minutes to complete.

<table>
<thead>
<tr>
<th>Step</th>
<th>Action</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Open the rubber flap on the top of the ChargeGuard unit.</td>
<td><img src="image1.png" alt="Image" /></td>
</tr>
<tr>
<td>2</td>
<td>Set the operating mode switch position to “AC”. Set the timeout switches to 1-off/2-on/3-on. This corresponds to a delay of 15 minutes. Other shutdown delay times are possible according to the chart:</td>
<td><img src="chart.png" alt="Chart" /></td>
</tr>
<tr>
<td>3</td>
<td>Close the rubber flap and press its edges back into the sealing grooves.</td>
<td><img src="image2.png" alt="Image" /></td>
</tr>
</tbody>
</table>
**APPENDIX E - OBU SOFTWARE INSTALLATION/UPDATE**

This appendix describes the installation and update of manufacturer’s software on the OBU. This task may require tools including laptop or workstation, secure shell terminal application, secure copy application (WinSCP), Ethernet cable, and will take about fifteen minutes to complete.

<table>
<thead>
<tr>
<th>Step</th>
<th>Action</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Connect the laptop or workstation to the OBU using an Ethernet cable.</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Set the laptop or workstation IP address to the appropriate subnet, either 169.254.x.y or 192.168.1.z depending if the OBU has been configured for one subnet or the other.</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Securely copy the new firmware to the OBU in the /mnt/ubi directory.</td>
<td>Use the root credentials set for the OBU.</td>
</tr>
<tr>
<td>4</td>
<td>Connect to the OBU as root using secure shell.</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Determine which firmware image slot is available, either image-a or image-b.</td>
<td>Execute the “fim –l” command to list the installed images.</td>
</tr>
<tr>
<td>6</td>
<td>If necessary, delete the oldest previous image to free space.</td>
<td>Execute the “fim –d image-x” command, substituting a or b for x.</td>
</tr>
<tr>
<td>7</td>
<td>Install the new firmware.</td>
<td>Execute a “fim –i image-x /mnt/ubi/&lt;firmware filename&gt;” command, substituting a or b for x and the correct filename for &lt;firmware filename&gt;.</td>
</tr>
<tr>
<td>8</td>
<td>Set the new firmware as active.</td>
<td>Execute a “fim –a image-x” command to set the new firmware to be used upon reboot.</td>
</tr>
<tr>
<td>9</td>
<td>Delete the source firmware.</td>
<td>Issue a “rm /mnt/ubi/&lt;firmware filename&gt;” to remove the now unneeded firmware source and free storage space.</td>
</tr>
<tr>
<td>10</td>
<td>Reboot the OBU.</td>
<td>Issue a “reboot” command.</td>
</tr>
<tr>
<td>11</td>
<td>Reconnect to the OBU using the secure shell application.</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Verify the new firmware is running.</td>
<td>Issue a “fim –l” command and see that a “A” designation is displayed beside the</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td><strong>13</strong></td>
<td>If the OBU now needs to be installed in a vehicle, halt the device. Otherwise, proceed to the next step.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Issue a “halt” command so the OBU can be powered off and installed in a vehicle.</td>
<td></td>
</tr>
<tr>
<td><strong>14</strong></td>
<td>Logout of the secure shell application.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Issue an “exit” command.</td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX F - SECURE KEY GENERATION

This appendix describes the procedure for generating a secure public/private key pair for securing IPv6 communication for an OBE. This task may require tools including laptop or workstation, secure shell terminal application, secure copy application (WinSCP), Ethernet cable, and will take about thirty minutes to complete.

<table>
<thead>
<tr>
<th>Step</th>
<th>Action</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Connect the laptop or workstation to the OBU using an Ethernet cable.</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Set the laptop or workstation IP address to the appropriate subnet, either 169.254.x.y or 192.168.1.z depending if the OBU has been configured for one subnet or the other.</td>
<td>Use the root credentials provided by the set for the OBU.</td>
</tr>
<tr>
<td>3</td>
<td>Login to the OBU using the secure shell terminal application.</td>
<td>Use the root credentials provided by the set for the OBU.</td>
</tr>
<tr>
<td>4</td>
<td>Change the directory to /mnt/ubi. This sets the working directory where the public/private keys will be saved.</td>
<td>This sets the working directory where the public/private keys will be saved.</td>
</tr>
<tr>
<td>5</td>
<td>Generate the keypair. Issue the “dropbearkey –rsa –f RdWx” command.</td>
<td>Issue the “dropbearkey –rsa –f RdWx” command.</td>
</tr>
<tr>
<td>6</td>
<td>Use the secure copy application to save the public and private keys to a safe, known location.</td>
<td>This would probably be some configuration or password management system.</td>
</tr>
<tr>
<td>7</td>
<td>Logout from the OBU and disconnect the Ethernet cable. Issue the “exit” command.</td>
<td>Issue the “exit” command.</td>
</tr>
<tr>
<td>8</td>
<td>Connect to and securely copy the RdWx private key to the /mnt/ubi directory for each OBU.</td>
<td>This provides the private key to the RdWx application so it can copy road weather observation files to RSU.</td>
</tr>
<tr>
<td>9</td>
<td>Use the secure shell application to connect to RSE participating in the RdWx application and create the RdWx user.</td>
<td>Use root credentials and IPv6 addresses for RSU provided by the connected vehicle network administrator.</td>
</tr>
<tr>
<td>10</td>
<td>Use the secure copy application to securely copy the RdWx public key to the /home/RdWx directory.</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Using the SSH terminal, append the RdWx public key to the /home/RdWx/.ssh/authorized_keys file.</td>
<td>Issue a “cat RdWx.id.rsa &gt;&gt; /home/RdWx/.ssh/authorized_keys” command. Create the .ssh directory as needed.</td>
</tr>
</tbody>
</table>
12 | Logout of the RSU and repeat steps 9 to 11 for each RSU. | This provisions the RSE to receive road weather observation files from the OBE.