Integrating Mobile Observations (IMO) 3.0 in Minnesota

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Final Report – November 11, 2017
Publication Number
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Minnesota Department of Transportation (MnDOT) continued its partnership with the Federal Highway Administration (FHWA) to continue the evaluation of Integrated Mobile Observations (IMO), which encompasses the acquisition, transmission, storage, and use of mobile observations to improve operational and financial efficiencies. A major component of this third phase of IMO was the development, installation and operation of a hybrid communication method on an urban corridor that included both cellular communications and Dedicated Short Range Communications (DSRC). The effort included DSRC hardware installation for six roadside units and five vehicles, and the development of new network and software protocols to meet communications and data collection objectives. Additionally, work continued to advance specific mobile applications across MnDOT. Highlights included upgrades to forecasting and data management for the Enhanced Maintenance Decision Support System (EMDSS) and Motorist Advisory Warning (MAW); the installation of cameras on snowplows and integration of roadway condition photos into the MnDOT 511 traveler information system; and the implementation of a fleet management system with data collected from the onboard Controller Area Network Bus (CANBus) and compiled and displayed via online dashboards. MnDOT compiled best practices and recommendations for other agencies considering or developing similar deployments.
Acknowledgments

Joe Huneke with MnDOT’s Office of Maintenance wishes to thank the members of MnDOT’s Road Weather Technology Group for their contributions to this research project.

- Jeffery Jansen, Team Leader
- Jakin Koll, Implementation Coordinator
- Jon Bjorkquist, Road Weather Information System (RWIS) Coordinator
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Executive Summary

Through this project, Minnesota Department of Transportation (MnDOT) continued its partnership with the Federal Highway Administration (FHWA) to continue the evaluation of Integrated Mobile Observations (IMO).

IMO encompasses the acquisition, transmission, storage and use of mobile observations to improve operational and financial efficiencies of the agency. The current work, IMO phase 3 (or IMO 3.0), builds on MnDOT’s successes with and lessons learned from two preceding phases (IMO 1.0 and IMO 2.0) to further improve existing processes and enhance the capabilities of mobile data acquisition systems.

Background — IMO 1.0 and IMO 2.0

IMO 1.0

In IMO 1.0, MnDOT installed Automated Vehicle Location (AVL) and Mobile Data Computer (MDC) collection units on 80 snowplows and utilized mobile data to produce an “end of shift report” which resulted in labor savings and significant improvements to data quality when compared to past practices of manual data recording and entry. MnDOT was also able to establish an interface with the Controller Area Network Bus (CANBus) in both light- and heavy-duty vehicles. This interface allowed for the capture and transmittal of internal vehicle data as well as data from sensors retrofitted to older vehicles for which the CAN data set was not as robust. MnDOT was able to establish the CAN interface using both J1939 and J1979 protocols depending on vehicle type.

IMO 2.0

In IMO 2.0, MnDOT continued to refine equipment and software used in IMO 1.0 and began a statewide deployment of these units. A data acquisition strategy was developed using the AVL vendor’s AT500 MDCs, with data transmitted via cellular data service, stored on the servers operated by MnDOT’s AVL contractor, and disseminated to users via a real-time Transmission Control Protocol/Internet Protocol (TCP/IP) interface. MDCs integrated with the Maintenance Decision Support System (MDSS) and CANBus interfaces, along with other sensors, were installed on more than 500 vehicles, including plow trucks, pickup trucks and mowers. Data acquisition was measured and monitored, with researchers addressing gaps in cellular coverage and data-routing protocols. MnDOT also continued work in developing road weather applications, which were advanced further in IMO 3.0.

Implementation of DSRC

Researchers aimed to develop, install and operate a hybrid communication method that included cellular communication statewide and used Dedicated Short Range Communication (DSRC) on a corridor. Of particular interest was a sustainable, interoperable system that could lead to statewide deployment.
MnDOT Maintenance relied on expertise from MnDOT Traffic Management section in selecting the DSRC equipment, as MnDOT Maintenance had no experience with this type of equipment. MnDOT Traffic Management section chose the Arada/Lear equipment for the DSRC deployment.

For the DSRC corridor, a 3-mile stretch was selected along I-35W starting at 66th Street, south of Minneapolis in Richfield, heading north to downtown Minneapolis and I-94. DSRC hardware installation included six roadside units (RSUs) affixed to roadway structures and onboard units (OBUs) installed on five vehicles.

Each demonstration vehicle operating on the corridor was to be capable of using both cellular and DSRC communication methods. DSRC was to be the preferred method whenever available, but vehicles were to automatically revert to cellular communication in areas where DSRC coverage was interrupted or unavailable.

System engineering and architecture challenges involved integrating the DSRC components with the AVL system and MDC, and ensuring proper communications among OBUs, RSUs and the server at the data center.

To address communication coverage gaps, researchers employed a “store-and-forward” approach, by which MDC messages were duplicated; one copy was sent and a second was marked as “waiting to send” pending acknowledgment of receipt by the server. Another approach used to determine connectivity across the system was the use of “heartbeat” messages to measure the success of each OBU’s encounter with an RSU.

Excellent results were obtained, with tests demonstrating that all cached messages were able to be passed and acknowledged through the DSRC link. Several tests were conducted during which a vehicle was operated for several hours, accumulating almost 2,000 DSRC-cached messages. Upon the vehicle’s entry into the local test corridor, all messages were offloaded through the established DSRC link in less than 5 seconds.

**Mobile Applications**

**Pikalert® — Enhanced Maintenance Decision Support System (EMDSS) and Motorist Advisory Warning (MAW)**

The Pikalert System from the National Center for Atmospheric Research (NCAR), with support from FHWA, provides high-precision road weather guidance. It assesses current weather and road conditions based on observations from connected vehicles, road weather information stations, radar, and weather model analysis fields. It also forecasts future weather and road conditions out to 72 hours utilizing information from numerical weather models. A number of science and engineering enhancements and improvements were made to the Pikalert System to promote diagnosis and forecast accuracy as well as to improve the capability of the Pikalert display. MnDOT supported NCAR’s efforts by providing field data and feedback on the accuracy of applications and models.

*Enhanced Maintenance Decision Support System*
NCAR’s EMDSS provides road maintenance personnel with the capability to obtain road advisories, warnings, and treatment information for road maintenance purposes. EMDSS display application covers a 72-hour forecast period and is useful for both strategic maintenance planning and tactical decision-making. EMDSS has a map-based display including radar coverage. EMDSS also allows the user to drill down and investigate Road Weather Information System (RWIS) and road segment data. The drill-down capability includes RWIS camera images and RWIS weather plots.

Motorist Advisory Warning

NCAR’s MAW provides motorists with the capability to obtain road advisories and warnings for pre-trip planning or for making tactical decisions when en route. The MAW display application is useful for pre-trip planning and lets the motorist investigate what weather impacts are expected along potential routes over the next 24 hours. The MAW phone application is useful for en route travel as it warns the motorist of potential weather impacts up ahead. The MAW phone application can be used in a hands-off manner as the warnings and alerts are issued vocally. The MAW display and phone applications require MAW server technology to provide the necessary input.

Traveler Information — Snowplow Cameras and MnDOT 511

MnDOT installed network video dash- and ceiling-mounted cameras on 226 snowplows, approximately one-quarter of MnDOT’s total snowplow fleet. The cameras were integrated with the onboard mobile data computer/automated vehicle location (MDC/AVL) equipment and automatically captured snapshots of road conditions during plowing. The following key operational features were selected and implemented:

- The dash cameras automatically recorded images whenever the MDC/AVL system was on.
- A camera recorded an image of the road ahead of the plow.
- Images were taken once every 5 minutes and were only retained if the plow was moving at least 10 miles per hour.
- The cameras were capable of taking operator-initiated snapshots and video clips.
- Video clips were able to be marked as three categories: accident, general interest, or work zone.

The system sent the plow camera images and metadata (geolocation, plow, camera and conditions) to a MnDOT server upgraded to accommodate the data. MnDOT set a data retention schedule for mobile snapshots (two days) and video segments (four days for non-accidents, retain-until-downloaded for accidents) as well as for the data server (14 days for snapshots).

Plow images were incorporated into several facets of MnDOT’s 511 travel information system, including the desktop website, the mobile website and the 511 app. Plow images plotted at 10-minute intervals on the 511 maps provided motorists with up-to-the-minute, easily accessible information on road conditions. The images were also incorporated into MnDOT’s internal website called Condition Acquisition and Reporting System.

Records Automation

Originally planned efforts related to records automation for herbicide application were not further developed as part of this project due to competing priorities.
However, MnDOT used existing opportunities with snowplow instrumentation to capture several data points related to plow operation and distribution of winter maintenance materials. On instrumented snowplows, the onboard AVL was instrumented to record, on a periodic basis, vehicle longitude and latitude; controller information (vehicle speed, chemical application rate); sensor data (road temperature, air temperature); operator inputs, if any; and data recorded from the camera interface.

**Fleet Management Systems and Vehicle Maintenance Information**

MnDOT implemented a system to collect vehicle data from the onboard CANBus. The data includes maintenance information, such as whether a vehicle’s dash lights indicate the need for immediate or near-term service, as well as other data about the vehicle. MnDOT partnered with truck manufacturer Navistar, which is able to interpret the CAN trouble codes of Navistar vehicles as well as those of other makes. Navistar also has a web-based dashboard system that allows for the display of all vehicles’ statuses and the transmission of daily reports to MnDOT maintenance supervisory staff. Vehicles may be filtered according to fault severity, including derate condition (“limp home”), stop now, service immediately, service soon, or maintenance-related.

**Lessons Learned and Recommendations**

Recommendations, best practices and challenges relating to implementation of DSRC and mobile applications include the following.

**Implementation of DSRC — Programmatic**

- A significant portion of DSRC’s payload is already predetermined for use with basic safety messages and for vehicle-to-infrastructure and vehicle-to-vehicle communications. Only 30 percent is available for advanced mobile applications. An agency should consider whether this is enough to meet its needs.
- DSRC may have limited application, particularly in a rural state. With a range of approximately 1,000 meters, there may be significant cost implications to placing required infrastructure on long rural routes.
- Some of what an agency would want to collect for maintenance purposes needs to be recorded for later analysis. This project was more focused on the immediate (or near-term) needs related to immediate weather response.

**Implementation of DSRC — Technical**

- Agencies should create software engineering specification for this type of project. This may be difficult to do for an initial deployment, as software and protocols are being developed mid-process, but it would be valuable for future deployments.
- Consider security early and at each step. Data path and device security is of utmost importance, and must be planned-in from the earliest stages of software design.
- Secure detailed and usable documentation from DSRC equipment providers. This should include background information about the overall structure of the software and explanation about its organization.
For very complex technical projects such as this DSRC integration, an agency should work closely with a vendor against a well-crafted set of technical requirements.

An RSU test site was valuable. A suggested location so close to the investigators’ offices turned out to facilitate ease of development, field-testing and safety.

DSRC software testing took significant time, with extensive back-and-forth between the manufacturers and investigators. Understand upfront the significant time and effort that rewriting software will likely take.

Preserve institutional knowledge and plan for staff succession.

Mobile Application — Enhanced MDSS

Some of the suggestions the supervisors had for NCAR’s EMDSS were overlays for radar (since added) and weather observations at airport and RWIS locations; precipitation rates; and easier-to-read graphs or tables.

Mobile Application — Motorist Advisory Warning

Some of the suggestions/comments the supervisors had for NCAR’s MAW were that it tends to report worse conditions than really exist. It was found that an improvement in the precipitation analysis was needed for both EMDSS and MAW. Some suggestions were given on how to possibly improve this, such as using dew point depression to get a better idea if precipitation that is showing up on radar is likely reaching the ground or not. These suggestions have since been addressed.

Expanded options for action needed should be developed for the MAW application as it seemed to use “delay travel,” “seek alternate route,” or “drive slowly and use extreme caution” for light snow as well as heavy snow.

MnDOT supervisors already have the Pooled Fund MDSS, which provides most of the same information or even more. Moreover, there was very limited time to evaluate the system due to the very busy winter that Minnesota had.

Mobile Application — Snowplow Cameras and MnDOT 511

Additional outreach should be done with plow drivers to clearly communicate the system’s benefits and foster broader use. This can be coupled with training and follow-up instruction on use of the camera’s features to encourage drivers to use the manual snapshot and video features when warranted.

An agency should address drivers’ concerns about privacy directly (i.e., “Big Brother is watching”) and understand that these concerns have lessened over time. Supervisors should be advised not to overreact to these concerns.

Concerns about in-cab distraction issues can be addressed by adjusting the system configuration or hardware. This might include making dash camera screens dimmable at the driver’s option, or placing screens and cameras out of critical sightlines.
Mobile Application — Fleet Management Systems and Vehicle Maintenance Information

- MnDOT spent significant time and effort trying to set up its own system for capturing CANBus codes before working with vehicle manufacturer Navistar. Other agencies should consider working with vehicle manufacturers early in the process.
- It can be difficult finding the right person at a vehicle manufacturer who can provide assistance with interpreting CANBus codes.
- The online maintenance reporting is set up for and will benefit dispatchers with large and diverse fleets.
- Clearly define the goal from the beginning and make sure all vendor partners are clear about the data the agency wants to collect and how it will be displayed.
Chapter 1. Background and Goals

Through this project, Minnesota Department of Transportation (MnDOT) continued its partnership with the Federal Highway Administration (FHWA) to continue the evaluation of Integrated Mobile Observations (IMO).

IMO encompasses the acquisition, transmission, storage, and use of mobile observations to improve operational and financial efficiencies of the agency. This work, IMO phase 3 (or IMO 3.0), builds on MnDOT’s successes with and lessons learned from two preceding phases (IMO 1.0 and IMO 2.0) to further improve existing processes and enhance the capabilities of mobile data acquisition systems.

Background — IMO 1.0

In IMO 1.0, MnDOT installed Automated Vehicle Location (AVL) and Mobile Data Computer (MDC) collection units on 80 snowplows and utilized mobile data to produce an “end of shift report” which resulted in labor savings and significant improvements to data quality when compared to past practices of manual data recording and entry. MnDOT was also able to establish an interface with the Controller Area Network Bus (CANBus) in both light- and heavy-duty vehicles. This interface allowed for the capture and transmittal of internal vehicle data as well as data from sensors retrofitted to older vehicles for which the CAN data set was not as robust. MnDOT was able to establish the CAN interface using both J1939 and J1979 protocols depending on vehicle type.

Background — IMO 2.0

In IMO 2.0, MnDOT continued to refine equipment and software used in IMO 1.0 and began a statewide deployment of these units. Major tasks of IMO 2.0 included:

- Developing data acquisition strategy.
- Deploying units.
- Measuring and monitoring data acquisition.
- Implementing and operating road weather applications.

Developing Data Acquisition Strategy

Data from the MnDOT IMO 2.0 project was collected using the AVL vendor’s MDCs. Data was transmitted via cellular data service, stored on the servers operated by MnDOT’s AVL contractor, and disseminated to users via a real-time TCP/IP interface. A website was provided for MnDOT users to view the data, and a data dictionary was compiled, allowing NCAR to receive and reassemble the data in near-real time. In cases where the cellular communication network was temporarily unavailable, data was held on the MDC and forwarded when communication was restored.
Deploying Units

An MDC integrated with the MDSS system, CANBus interface, and other sensors were installed on vehicles as detailed in Table 1. A complete MDC installation, as seen from the operator’s side, is shown in Figure 1 (photo of MDC hardware installed on the rear interior wall of the snowplow truck cab, between the driver and passenger seats).

Table 1. IMO 2.0 deployment

<table>
<thead>
<tr>
<th>MDC Count</th>
<th>Model years</th>
<th>Vehicle type</th>
</tr>
</thead>
</table>
| 307       | 2004 - 2009 | • Sterling LT 8511 single-axle dump trucks  
|           |             | • Sterling LT 9511 tandem-axle dump trucks |
| 175       | 2010 - 2013 | • Navistar International MaxForce Workstar single-axle dump trucks  
|           |             | • Navistar International MaxForce Workstar tandem-axle dump trucks |
| 20        | 2006 - 2013 | • Ford light-duty pickup trucks |
| 5         | 1997 - 2011 | • Mowers |

Figure 1. MDC installation

The cost of the in-vehicle hardware, including the MDC/AVL, temperature sensors, and cameras, is shown in Table 2.
Table 2. Hardware costs

<table>
<thead>
<tr>
<th>Hardware</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>MDC/AVL</td>
<td>$2,250</td>
</tr>
<tr>
<td>Pavement temperature sensors</td>
<td>$800</td>
</tr>
<tr>
<td>Plow camera kit addition</td>
<td>$330</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$3,380</strong></td>
</tr>
</tbody>
</table>

Measuring and Monitoring Data Acquisition

**Communications**

Communication from the MDC platform to the data center, located in downtown Minneapolis, was accomplished using a cellular data network. However, there were many locations throughout rural Minnesota where tower “handoffs” from one cell tower to another initially caused the MDC to lose its connection. In order to provide near-seamless cellular connectivity, it was necessary to write a customized connection manager to solve frequent disconnection events.

**Server**

MnDOT purchased a dedicated server to be placed at the AVL contractor’s data center that had the latest version of Postgres/PostGIS open source software. All MnDOT data was routed to this server, and the server reinterpreted each incoming message to a single MapServer spatial coordinate. MnDOT successfully demonstrated fast, useful web-client products driven from this high-speed database, including a “mark” feature (to mark locations of weeds, potholes, guardrail hits, etc.) and an ArcGIS map AVL vehicle tracking website that displayed the location and information that the AVL-equipped vehicles were collecting.

Implementing and Operating Road Weather Applications

MnDOT continued work in developing and implementing road weather applications:

- Collection of camera imagery.
- Enhanced MDSS.
- Information for vehicle maintenance and fleet management systems.
- Records automation.
- Mower application.
- Motorist advisory warning.

Efforts were continued with IMO 3.0; the latest progress on these activities is detailed in this report.
Goals — IMO 3.0

FHWA’s Road Weather Management Program sought to continue refining previous IMO work and to expand the goals to include development, installation and operation of a hybrid communication method on an urban corridor that included both cellular communications and DSRC. Of particular interest was a sustainable, interoperable system that could lead to statewide deployment.

FHWA listed seven critical tasks to be conducted as part of IMO 3.0:

- Task 1. Project management.
- Task 2. Create data acquisition strategy.
- Task 4. Measure and monitor data acquisition.
- Task 5. Implement and operate road weather applications.
  - Application 1. Operate DSRC on a corridor
  - Application 2. Enhanced MDSS.
  - Application 3. Information for vehicle maintenance and fleet management systems.
  - Application 5. Traveler information.

Report Organization

Tasks 1 and 7 are administrative and are not addressed in this report.

Tasks 2, 3 and 4 and Application 1 of Task 5 are detailed in Chapter 2. Implementation of DSRC.

Applications 2 through 6 of Task 5 are detailed in Chapter 3. Mobile Applications.

Statements of benefit (Task 6) appear throughout Chapters 2 and 3.

Additional guidance appears in Chapter 4. Lessons Learned and Recommendations.
Chapter 2. Implementation of DSRC


Goals

As previously stated, the goal for the DSRC portion of the IMO 3.0 project was the development, installation and operation of a hybrid communication method on an urban corridor that included both cellular communications and DSRC. Of particular interest was a sustainable, interoperable system that could lead to statewide deployment.

Proposed DSRC Approach

MnDOT proposed the following:

- Select a demonstration corridor.
- Purchase, test, install and operate DSRC-enabled roadside and in-vehicle units.
- Integrate information collected using DSRC with data collected using current cellular wireless data transmission.
- Use AVL telematics units installed in agency vehicles.

Each demonstration vehicle operating on the corridor should be capable of using both cellular and DSRC communication methods. DSRC was to be the preferred method whenever available, but vehicles should automatically revert to cellular communication in areas where DSRC coverage was interrupted or unavailable.

Infrastructure Planning

DSRC Corridor Selection

MnDOT chose a 3-mile stretch along I-35W starting at 66th Street, south of Minneapolis in Richfield, heading north to downtown Minneapolis and I-94, as illustrated in Figure 2 (a Google map with the described corridor marked in a black box).
DSRC Vendor and Equipment Selection

MnDOT chose to use DSRC equipment manufactured by Arada Systems (owned by Lear Corporation) for both the roadside units (RSUs) and in-vehicle onboard units (OBUs). Six RSUs and five OBUs were purchased from Arada.

MnDOT Maintenance relied on expertise from MnDOT Traffic Management section in selecting the DSRC equipment, as MnDOT Maintenance had no experience with this type of equipment. MnDOT Traffic Management section chose the following Arada/Lear equipment for the DSRC deployment:
• RSU — LocoMate RSU-201 Commando Roadside Unit, see Figure 3 (photo of RSU, vertically oriented).

• OBU — LocoMate ASD OBU-205 Onboard Unit, see Figure 4 (photo of OBU, horizontally oriented with antennae pointing up).

Figure 3. LocoMate RSU-201 Commando Roadside Unit (Source: Arada)

Figure 4. LocoMate ASD OBU-205 Onboard Unit (Source: Arada)
RSU Test Location Selection

An RSU test location was selected, located at the intersection of I-35W and the southbound 98th Street ramp, approaching from the west. This location was about 4 miles south of the “main” demonstration corridor.

The 98th Street test site was chosen because it was close to the offices of the investigators and software design team. With considerably less traffic, this location allowed investigators to iteratively test the MDC/AVL/DSRC integration in a somewhat safer environment. Because the software was in a constant state of flux during development, the location allowed developers to field-test new ideas without having to drive north into the typically heavier traffic of I-35W.

Identification and Installation of RSU Locations

MnDOT Maintenance and Regional Transportation Management Center (RTMC) staff identified the number and locations of RSUs needed for this project. Six RSUs were purchased. RTMC staff installed the six RSUs at half-mile intervals on Intelligent Lane Control Structures (ILCS) and equipment cabinets along the demonstration corridor. The selected ILCS span the entire highway, six lanes in each direction, providing relatively easy access for RSU installation.

- All cabinet-mounted RSUs were located on the side of the highway, except for one located in the center median.
- All installed RSU antennae delivered maximum power of 34 dBm, had a gain of 12 dBi, were omnidirectional and had a 360° beam width.

Mobile Planning

DSRC Demonstration Vehicles

The following vehicles were chosen as DSRC demonstration vehicles for the five purchased OBU. Table 3 details all five vehicles. Each column represents one of the five vehicles, showing the vehicle make, model and year and the installed equipment.
Table 3. DSRC demonstration vehicles and equipment

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Make</th>
<th>Model</th>
<th>Year</th>
<th>GPS Receiver</th>
<th>ATE-SA10 add-on sensor box</th>
<th>Spreader</th>
<th>CANBus</th>
<th>Vaisala add-on road and air temp. sensor</th>
<th>Camera</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>L8511 Single Axle</td>
<td>2004</td>
<td>GlobalSat</td>
<td>Yes</td>
<td>Dickey-John</td>
<td>J1939</td>
<td>None</td>
<td>No</td>
</tr>
<tr>
<td>204507</td>
<td>Sterling</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>210143</td>
<td>Ford</td>
<td>F-150</td>
<td>2010</td>
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<td>Yes</td>
<td>None</td>
<td>None</td>
<td>None</td>
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</tr>
<tr>
<td>213393</td>
<td>Ford</td>
<td>F-150</td>
<td>2013</td>
<td>GlobalSat</td>
<td>No</td>
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<td>214525</td>
<td>International Navistar</td>
<td>7500 Single Axle</td>
<td>2014</td>
<td>Fangtec</td>
<td>Yes</td>
<td>Force 6100</td>
<td>J1939</td>
<td>Non-HD</td>
<td>No</td>
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<td>215551</td>
<td>International Navistar</td>
<td>7600 Tandem Axle</td>
<td>2015</td>
<td>GlobalSat</td>
<td>Yes</td>
<td>Force 6100</td>
<td></td>
<td>Non-HD</td>
<td>No</td>
</tr>
</tbody>
</table>

OBU Installation Procedure

After performing extensive bench testing in the lab and conducting in-vehicle testing in the field, investigators compiled a short instruction guide for MnDOT OBU equipment installers. These instructions appear in Appendix A.

Engineering and Architecture

Given the challenges that a heavy-truck DSRC integration project presents, three engineering goals were identified that would characterize this project and its results:

- Demonstrate a complete DSRC integration with the production AVL system acting as a host.
- Demonstrate and quantify robust DSRC-to-infrastructure (vehicle-to-infrastructure, or V2I) information exchange.
- Demonstrate and quantify full two-way communication between the in-vehicle AVL system and the data center using DSRC.

DSRC components were integrated with the AVL system and the MDC: On the mobile side, an OBU connected to a host MDC, while on the infrastructure side, the RSU connected to a logical server running at the investigators’ data center.
Multiple RSUs

There can be multiple connections made to a deployed collection of RSUs. For example, an OBU-equipped vehicle can connect to multiple RSUs located along its route. When an in-vehicle OBU comes into range of an RSU, it connects and communicates. When an in-vehicle OBU travels beyond the range of its current RSU, it disconnects. This sequence repeats for subsequent RSUs it encounters along its route.

Connection Dynamics

The DSRC devices control the sequence of connections. That is, both the in-vehicle MDCs and the data center–resident logical server must wait for the DSRC devices to contact and connect to them. Software designed by the investigators is unable to take charge and control the sequence of communication. Success or failure is completely dependent on OBU vendor firmware.

Heartbeat Messages

In order to determine what is connected to what, two new DSRC heartbeat messages were designed and implemented:

- The MDC emitted a heartbeat message to the DSRC OBU.
- The server emitted a heartbeat to all connected RSUs.

The mobile-to-server message was used as a metric to measure the success of each OBU’s encounter with an RSU. A field-to-server message was emitted by the MDC once every second. This message was emitted to the OBU with the assumption that the DSRC fabric would forward it to the logical server instance running at the data center through a connected RSU.

A server-to-field message was emitted by the data center server every 2 seconds. This message was intentionally designed to be very short and was emitted to each connected RSU. Each RSU broadcasted the received message, allowing connected OBUs to receive it.

DSRC Message Store-and-Forward

As a built-in redundancy feature to ensure no data was lost, the MDC duplicated every generated message. Each duplicated message was placed into the two new DSRC tables within the mobile database, marked as “waiting to send.” Each duplicated message was also immediately sent to the OBU, if a functional connection existed.

When an appropriate message was received from the server, the message ID field was used to mark the corresponding database record as “acknowledged.” Note that all MDC messages are sent continuously via a cellular connection, and the same messages are sent via DSRC when a DSRC connection is established.
Mobile Environment

Before all the reconfigured DSRC equipment was turned over to MnDOT, extensive field-testing was carried out. The following configuration was installed in a passenger test vehicle:

- An MDC with modified software, featuring changes allowing it to connect with an Arada LocoMate OBU.
- The LocoMate OBU with modified firmware running on a new IPV-4 TCP/IP client.

The OBU was installed on the dashboard of the vehicle. The DSRC antennae were attached to the OBU, aligned vertically, and positioned to “look through” the vehicle’s windshield. The MDC was installed in the back-seat area of the vehicle.

Next, a test corridor was established between 106th Street to the south and 82nd Street to the north, just south of I-494. The test vehicle drove through this corridor several times for each of the five OBUs, all connecting to RSU-1, the test roadside unit, at 98th Street.

Results

Excellent results were obtained. Testing demonstrated that all cached messages were able to be passed and acknowledged through the DSRC link. Several tests were conducted during which the vehicle was operated for several hours, accumulating almost 2,000 DSRC-cached messages.

Upon the vehicle’s entry into the local test corridor, all messages were offloaded through the established DSRC link in less than 5 seconds. Examination of the archived data at the data center confirmed this performance.

The route and range for northbound travel was approximately 2.3 miles. The approximate connect location was about 100 feet past the 106th Street entrance ramp, on the highway, and the approximate loss location was three-quarters of the distance past the 94th Street exit, between the 94th Street and 90th Street exits.

The route and range for southbound travel was approximately 1.9 miles. The approximate connect location was past the 94th Street bridge, after emerging from under the bridge, and the approximate loss location was about 100 feet from the start of the 106th Street exit.

Handover

MDC reconfiguration and complete testing of all OBU/RSU equipment was completed on February 25, 2017. Since RSU-1 was already installed for testing, the remaining five RSUs and all five OBUs were handed over to MnDOT the following week. MnDOT coordinated with RTMC to get the RSUs installed along the demonstration corridor, while members of the MnDOT AVL team installed the OBUs in the five candidate vehicles.
Chapter 3. Mobile Applications

Pikalert — Enhanced Maintenance Decision Support System (EMDSS) and Motorist Advisory Warning (MAW)

Overview

The Pikalert System from the National Center for Atmospheric Research (NCAR), with support from FHWA, provides high-precision road weather guidance. It assesses current weather and road conditions based on observations from connected vehicles, road weather information stations, radar, and weather model analysis fields. It also forecasts future weather and road conditions out to 72 hours utilizing information from numerical weather models.

As connected-vehicle observations become more and more prevalent with the advent of autonomous vehicles, Pikalert is designed to utilize these observations effectively. In particular, a number of quality-check algorithms have been incorporated to guarantee that erroneous observations are flagged and eliminated. Pikalert then assembles the observations that have passed the quality checks, associates them with the appropriate road segments, and then uses them in assessing the road segment weather conditions. Detailed reports can then be generated characterizing the status of the various road segments.

Pikalert currently focuses on the following three conditions:

- Precipitation conditions (such as rain, snow, ice).
- Road surface conditions (such as snow-packed, icy, clear).
- Visibility conditions (such as foggy, clear).

Pikalert advises users of the presence of these three conditions and will make pavement treatment recommendations for snow and ice removal. Pikalert guidance is made available through web-based technology that supports browser-based displays and smartphones.

Pikalert currently provides three different interfaces for users:

- **Pikalert EMDSS** — NCAR’s Pikalert EMDSS is a web-based display that provides road weather and road condition forecasts out to 72 hours. The EMDSS display is typically configured to cover a network of state interstates and highways in an individual state. EMDSS is geared toward maintenance personnel since it provides road treatment recommendations in addition to weather and road condition information.

- **Pikalert MAW** — NCAR’s Pikalert MAW display is oriented toward the public. Like EMDSS, it provides road weather and condition guidance but restricts the time coverage out to 24 hours. It does not provide road treatment information, nor in-depth plots of weather variables.
• **Pikalert MAW phone application** — The MAW phone app is also oriented toward the public. It supports hands-off audio alerts of hazardous road conditions up ahead. The phone app will also inform the user of clearing conditions when exiting hazardous areas.

During the IMO 3.0 project, MnDOT supported NCAR’s efforts by providing field data and feedback on the accuracy of applications and models.

**Enhanced Maintenance Decision Support System (EMDSS)**

EMDSS provides road maintenance personnel with the capability to obtain road advisories, warnings, and treatment information for road maintenance purposes. The EMDSS display application covers a 72-hour forecast period and is useful for both strategic maintenance planning as well as for tactical decision-making. EMDSS has a map-based display including radar coverage as shown in Figure 5 (Pikalert map of Minnesota and Plains States, showing Minnesota highways and weather radar). EMDSS also allows the user to drill down and investigate RWIS and road segment information. The drill-down capability includes RWIS camera images (Figure 6, a composite of four roadway camera views during stormy weather) and RWIS weather plots (Figure 7, hourly graphs of snow, precipitation probability, temperature and wind speed aligned with the alert status [green, yellow or red] for a weather event).

![Figure 5. EMDSS base map display over Minnesota](image-url)
Figure 6. Weather camera images at a selected RWIS

Figure 7. Weather plots at an RWIS station
Motorist Advisory Warning (MAW)

MAW provides motorists with the capability to obtain road advisories and warnings for pre-trip planning or for making tactical decisions when en route. The MAW display application is useful for pre-trip planning and lets the motorist investigate what weather impacts are expected along potential routes over the next 24 hours.

The MAW phone application is useful for en route travel as it warns the motorist of potential weather impacts up ahead. The MAW phone application can be used in a hands-off manner as the warnings and alerts are issued vocally.

The MAW display and phone applications require MAW server technology to provide the necessary input.

Pikalert Enhancements

A number of science and engineering enhancements and improvements were made to the Pikalert System to promote diagnosis and forecast accuracy as well as to improve the capability of the Pikalert display.

Traveler Information — Snowplow Cameras and MnDOT 511

Overview

Weather contributes to approximately 25 percent of vehicle crashes nationally every year. Minnesota motorists can attest to the danger of snowy or icy roads during the winter.

During inclement weather, drivers may know that conditions are generally worse than usual, but they still may make ill-advised decisions when presented with inaccurate, incomplete, or vague weather advisories. More information about current and specific dangers and roadway conditions can help drivers make better decisions about whether to travel.

MnDOT sought to bridge the information gap between MnDOT staff in the field and the traveling public with respect to adverse road conditions. The project aimed to augment existing weather advisories with images of road conditions taken from MnDOT snowplows in the field. MnDOT planned to use its existing 511 travel information system—namely, the travel information website (https://hb.511mn.org/) and 511 mobile app—to share this information with the public.

Prior to this project, MnDOT had deployed cameras on only 20 snowplows and with limited network infrastructure. Iowa Department of Transportation’s (DOT) success with a similar plow camera deployment informed MnDOT’s approach to this project, although MnDOT’s system used different equipment, an onboard mobile data computer/automated vehicle location (MDC/AVL) solution instead of Iowa DOT’s cellular phone–based solution.

A final project report and research summary may be found on MnDOT Research Services website at http://dotapp7.dot.state.mn.us/projectPages/pages/projectDetails.jsf?id=18470&type=CONTRACT.
Deployment

In 2015 and 2016, MnDOT installed network video dash cameras and ceiling-mounted cameras on 226 snowplows. This is approximately one-quarter of MnDOT’s total snowplow fleet. A ceiling-mounted camera is shown in Figure 8 (a camera mounted on the cab ceiling of a Minnesota DOT snowplow). The cameras were integrated with the onboard MDC/AVL equipment and automatically captured snapshots of road conditions during plowing. Images were sent to MnDOT’s server and then imported in near-real-time to the MnDOT travel information website and MnDOT 511 mobile app for up-to-the-minute use by the traveling public.

Figure 8. Ceiling-mounted snowplow camera

After careful consideration of the capabilities and limitations of the cameras, the MDC/AVL system, and MnDOT’s back-end server capabilities, the following key operational features were ultimately selected and implemented:

- The dash cameras automatically recorded images whenever the MDC/AVL system was on.
- A camera recorded an image of the road ahead of the plow.
- Images were taken once every 5 minutes and were only retained if the plow was moving at least 10 miles per hour.
- The cameras were capable of taking operator-initiated snapshots and video clips.
- Video clips were able to be marked as three categories: accident, general interest, or work zone.
Plow camera images and metadata (geolocation, plow, camera, and conditions) were sent to a MnDOT server, which was upgraded to accommodate the data. MnDOT set a data retention schedule on the MDC’s software, for mobile snapshots (two days) and video segments (four days for non-accidents, retain-until-downloaded for accidents) as well as for the data server (14 days for snapshots).

Plow images were incorporated into the several aspects of MnDOT’s 511 travel information system. These included the desktop website, the mobile website, and the 511 app. The images were also incorporated into MnDOT’s internal website called Condition Acquisition and Reporting System (CARS).

A custom filter was designed to specify whether the image qualified to be shared with the public. For example, images taken when a truck was not on a state highway or did not meet speed criteria would not appear on the 511 winter weather layer. Images were plotted on an interactive map in 10-minute intervals, as shown in a detail of the MnDOT 511 website (Figure 9, a composite screen with an interactive map indicating the current and recent locations of a snowplow operating along Minnesota Highway 60 near Windom, Minnesota, a photo of the road showing current snow and ice conditions, and three recent road photos taken 10, 20 and 30 minutes prior to the current photo). The 511 mobile apps for Android and iPhone functioned in a similar manner.
Driver and Supervisor Perspectives

MnDOT reached out to snowplow drivers and their immediate supervisors using online surveys to learn about their experiences and perspective with respect to the cameras.

The surveys centered on ease of teaching or learning how to use the plow cameras. The general consensus was that the cameras were found to be easy to operate. Most found the cameras to not be a distraction, but a minority of drivers and supervisors were concerned with the distraction posed by interrupted sightlines and a busier cab. One more prominent outcome was that it was found that the driver-initiated image and video clip recording were hardly used.
General opinions were also solicited through free response questions. Drivers’ reactions were a nearly even mix of positive, negative and neutral. Supervisors’ reactions were much more positive than negative.

MnDOT also interviewed MnDOT managers responsible for the project implementation and gathered perspectives and lessons learned. Key lessons appear in Chapter 4. Lessons Learned and Recommendations.

Records Automation

Overview

Originally planned efforts related to records automation for herbicide application were not further developed as part of this project due to competing priorities.

However, MnDOT used existing opportunities with snowplow instrumentation (see the previous section) to capture several data points related to plow operation and distribution of winter maintenance materials. On instrumented snowplows, the onboard AVL was instrumented to record on a periodic basis:

- Vehicle longitude and latitude.
- Controller information (vehicle speed, chemical application rate).
- Sensor data (road temperature, air temperature).
- Operator inputs, if any.
- Data recorded from the camera interface.

MnDOT plans to integrate these data with its Transportation Asset Management System, or TAMS. Conceptually, TAMS would generate a work order within the AVL, telling the system the anticipated work to be undertaken (what, when, where and how). Based on completion of the work, the data would automatically download to MnDOT’s Resource Consumption Application (RCA).

Such data are important to managers and planners. Reporting these are typically low-priority for drivers, who are often focused on clearing snow and ice while ensuring their own safety and that of motorists on the road.

Fleet Management Systems and Vehicle Maintenance Information

Overview

MnDOT implemented a system to collect vehicle data from the onboard Controller Area Network Bus (CANBus) bus. The data includes maintenance information, such as whether a vehicle’s dash lights indicate the need for immediate or near-term service, as well as other data about the vehicle.

Due to the proprietary nature of the CAN trouble codes for different vehicles, initial efforts by MnDOT to collect this information were met with limited success. Eventually MnDOT partnered with truck manufacturer Navistar, which was able to interpret the CAN codes of Navistar vehicles as well as other makes. Navistar also has a web-based dashboard system (Figure 10, screenshot of a dashboard with...
information on two vehicles, including identifying information, date-and-time, current location, and status notices and warnings) that allows for the display of all vehicles’ statuses and the transmission of daily reports to MnDOT maintenance supervisory staff. Vehicles may be filtered according to fault severity, including derate condition (“limp home”), stop now, service immediately, service soon, or maintenance-related.

![Navistar dashboard](image)

**Figure 10. Navistar dashboard**

Users may also drill down to an individual health report for a given vehicle (Figure 11, screenshot of a dashboard with detailed information, notices and alerts on a single vehicle).
The Navistar system collects vehicle data in two ways:

- Using a MnDOT-installed module (Figure 12, photo of a small piece of hardware with connectors on both ends) that connects the CANBus to the vehicle’s MDC.
- Using a vehicle’s built-in diagnostic computer via Wi-Fi.

There are approximately 300 to 400 vehicles in MnDOT’s fleet equipped with the CANBus-AVL connection. MnDOT plans to continue to equip new vehicles with the AVL connections, but at this time does not have plans to go back and retrofit existing vehicles.

Figure 12. CANBus interface module
Chapter 4. Lessons Learned and Recommendations

Lessons learned (including best practices and challenges) and recommendations are presented in the same order as technology deployments appear in Chapters 2 and 3 of this report:

- Implementation of DSRC.
- Enhanced MDSS.
- Motorist Advisory Warning.
- Traveler Information.
- Fleet Management Systems.

Implementation of DSRC

*Programmatic*

Recommendation—

A significant portion of DSRC’s payload is already predetermined for use with basic safety messages and for V2I and V2V communications. Only 30 percent is available for advanced mobile applications. An agency should consider whether this is enough to meet its needs.

Challenge—

DSRC may have limited application, particularly in a rural state. With a range of approximately 1,000 meters, there may be significant cost implications to placing required infrastructure on long rural routes.

Consideration—

Some of what an agency would want to collect for maintenance purposes needs to be recorded for later analysis. This project was more focused on the immediate (or near-term) needs related to immediate weather response.

*Technical*

Recommendation—

Agencies should create software engineering specifications for this type of project. This may be difficult to do for an initial deployment, as software and protocols are being developed mid-process, but it would be valuable for future deployments.
Consider security early and at each step. Data path and device security is of utmost importance, and must be planned-in from the earliest stages of software design.

**Recommendation**—

Secure detailed and usable documentation from DSRC equipment providers. This should include background information about the overall structure of the software and explanation about its organization.

**Recommendation**—

For very complex technical projects such as this DSRC integration, an agency should work closely with a vendor against a well-crafted set of technical requirements.

**Best Practice**—

An RSU test site was valuable. A suggested location so close to the investigators’ offices turned out to facilitate ease of development, field-testing and safety.

**Challenge**—

DSRC software testing took significant time with extensive back-and-forth between the manufacturers and investigators. Understand upfront the significant time and effort that rewriting software will likely take.

**Challenge**—

Preserve institutional knowledge and plan for staff succession. This project kicked off as the key MnDOT visionary team member was retiring. His replacement had the task of coming up to speed on many highly technical projects in a very short period of time, and this contributed to delays during the early period of this project.

### Enhanced MDSS

**Recommendation**—

Some of the suggestions the supervisors had for NCAR’s EMDSS were overlays for radar (since added) and weather observations at airport and RWIS stations; precipitation rates; and easier-to-read graphs or tables. They would like to see more specific maintenance recommendations. They felt that EMDSS would be more of a benefit if they didn’t have the Pooled Fund MDSS already.

### Motorist Advisory Warning

**Recommendation**—

Some of the suggestions/comments the supervisors had for MAW were that it tends to report worse conditions than actually exist. It was found that an improvement in the precipitation analysis was needed for both EMDSS and MAW. Some suggestions were given on how to possibly improve this, such as using dew point depression to get a better idea if precipitation that is showing up on radar is likely reaching the ground or not. These were since addressed.

Expanded options for actions needed should be developed for the MAW application, as it seemed to use “delay travel,” “seek alternate route,” or “drive slowly and use extreme caution” for light snow as
well as heavy snow (Figure 13, side-by-side images of mobile devices showing heavy snow and light snow with similar language).

![Figure 13. Example of MAW Android smartphone application for heavy snow (left) and light snow (right)](image)

**Challenge—**

MnDOT supervisors already have the Pooled Fund MDSS, which provides most of the same information or even more. Moreover, there was very limited time to evaluate the system due to the very busy winter that Minnesota had.

**Traveler Information — Snowplow Cameras and MnDOT 511**

**Recommendation—**

Additional outreach should be done with plow drivers to clearly communicate the system’s benefits and foster broader use. This can be coupled with training and follow-up instruction on use of the camera’s features to encourage drivers to use the manual snapshot and video features when warranted.

**Recommendation—**

An agency should address drivers’ concerns about privacy directly (i.e., “Big Brother is watching”) and understand that these concerns have lessened over time. Supervisors should be advised not to overreact to these concerns.

**Recommendation—**

Concerns about in-cab distraction issues can be addressed by adjusting the system configuration or hardware. This might include making dash camera screens dimmable at the driver’s option, or placing screens and cameras out of critical sightlines.
Fleet Management Systems and Vehicle Maintenance Information

Recommendation—

MnDOT spent significant time and effort trying to set up its own system for capturing CANBus codes before working with vehicle manufacturer Navistar. Other agencies should consider working with vehicle manufacturers early in the process.

Challenge—

It can be difficult finding the right person at a vehicle manufacturer who can provide assistance with interpreting CANBus codes.

Recommendation—

The online maintenance reporting is set up for and will benefit dispatchers with large and diverse fleets.

Recommendation—

Clearly define the goal from the beginning and make sure all vendor partners are clear about the data the agency wants to collect and how it will be displayed.
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<td>Clarification of questions. Added vehicle installation photos.</td>
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Internet Protocols

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Abbreviations, Organizations

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<tr>
<td>RTMC</td>
<td>Regional Transportation Management Center.</td>
<td>MnDOT</td>
</tr>
<tr>
<td>SAE</td>
<td>Society of Automotive Engineers.</td>
<td></td>
</tr>
<tr>
<td>SDO</td>
<td>Standards Development Organizations.</td>
<td></td>
</tr>
</tbody>
</table>

---

1 A “Request for Comments” (RFC) is a type of publication from the Internet Engineering Task Force (IETF) and the Internet Society (ISOC), the principal technical development and standards-setting bodies for the Internet.
## Abbreviations, Technical Terms

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
<th>Origin</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACK</td>
<td>“Acknowledge” ... A positive response to a message or other stimulus.</td>
<td></td>
</tr>
<tr>
<td>AVL</td>
<td>Automated Vehicle Location.</td>
<td></td>
</tr>
<tr>
<td>BSM</td>
<td>DSRC “Basic Safety Message.”</td>
<td>FHWA</td>
</tr>
<tr>
<td>CAN</td>
<td>Controller Area Network.</td>
<td></td>
</tr>
<tr>
<td>DAQ</td>
<td>Data Acquisition.</td>
<td></td>
</tr>
<tr>
<td>DSRC</td>
<td>Dedicated Short Range Communication. Also known as IEEE 802.11p.</td>
<td>FCC, IEEE</td>
</tr>
<tr>
<td>ILCS</td>
<td>Intelligent Lane Control Structure.</td>
<td></td>
</tr>
<tr>
<td>IMO</td>
<td>Integrated Mobile Observations.</td>
<td>FHWA</td>
</tr>
<tr>
<td>IOT</td>
<td>Internet of Things.</td>
<td></td>
</tr>
<tr>
<td>JPGP</td>
<td>An AmeriTrak-designed message-passing protocol.</td>
<td>AmeriTrak</td>
</tr>
<tr>
<td>NAK</td>
<td>“Not-Acknowledge” ... A negative response to a message or other stimulus.</td>
<td></td>
</tr>
<tr>
<td>OBD-2</td>
<td>On-Board Diagnostics, version 2. Also known as OBD-II.</td>
<td></td>
</tr>
<tr>
<td>OBU</td>
<td>On-Board Unit. A mobile DSRC transceiver.</td>
<td>Arada</td>
</tr>
<tr>
<td>OTR</td>
<td>Over-the-Road.</td>
<td></td>
</tr>
<tr>
<td>RFC</td>
<td>Request for Comment. See footnote 1.</td>
<td></td>
</tr>
<tr>
<td>RSU</td>
<td>Roadside unit. Fixed-infrastructure DSRC transceiver. Also known as RSE.</td>
<td>Arada</td>
</tr>
<tr>
<td>SNF</td>
<td>Store-and-Forward.</td>
<td></td>
</tr>
<tr>
<td>V2I</td>
<td>Vehicle-to-Infrastructure.</td>
<td>FHWA</td>
</tr>
<tr>
<td>V2V</td>
<td>Vehicle-to-Vehicle.</td>
<td>FHWA</td>
</tr>
</tbody>
</table>
**Introduction**

This Technical Report begins by restating MnDOT’s project goals from its document “Dedicated Short Range Communication (DSRC) Project, Scope of Work.” MnDOT desired to accomplish the following infrastructure and technical goals:

In its draft statement of work for Integrated Mobile Observations (IMO) 3.0, the Federal Highway Administration (FHWA) office of Road Weather Management wishes to continue refining previous IMO work and expand its goals to include development, installation and operation of a hybrid communication method which includes using DSRC on an active corridor during the next 18 months. Additionally, FHWA desires State Departments of Transportation (DOTs) to design a sustainable system which demonstrates interoperability and leads to statewide deployment.

During IMO 1.0 and IMO 2.0, MnDOT installed Automated Vehicle Location (AVL) equipment along with many mobile sensors, conducted extensive testing and systems development, and moved well into the statewide deployment stage. Currently, MnDOT has about 75% of its snowplow fleet outfitted with AVL equipment. Permanent MnDOT positions have been created and filled to handle the planning, installation, support and training accompanying a deployment of this scale. There is strong support for this effort throughout the organization.

In addition to the listed objectives of actively using DSRC on a corridor that utilizes weather applications developed in IMO 2.0, MnDOT believes this project demonstrated its prior and continued commitment to FHWA’s goals and objectives, a desire to help FHWA achieve its goals and objectives, and the ability to accomplish each task in a timely and successful manner.

**Data Acquisition Strategy**

- MnDOT will utilize the 550 AmeriTrak AT500 telematics units they now have installed in snowplows and expand this number by installing approximately 100 additional AT500s on new snowplows during the project period, from January 2015 to October 2017.
- MnDOT selected a demonstration corridor; purchased, tested, installed and operated DSRC roadside and in-vehicle units; and integrated information collected using this system with data collected using current cellular wireless data transmission. Each demonstration vehicle operating on this corridor is to be capable of using both communication methods. DSRC is to be the preferred method whenever available, but vehicles will automatically revert to cellular communication in areas where DSRC coverage is interrupted or unavailable.

Each DSRC roadside receiver is connected to a fiber-optic communication network to provide efficient backhaul of received information and serve as a model for future connected-vehicle demonstration projects.

**Existing DSRC Applications**

DSRC is well established as an effective mobile communication technology for many safety-critical applications. A general list of some established Vehicle-to-Vehicle (V2V) applications include the following (acronyms, where used, are also noted):

---

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMA</td>
<td>Intersection Movement Assist.</td>
</tr>
<tr>
<td>LTA</td>
<td>Left Turn Assist.</td>
</tr>
<tr>
<td>EEBL</td>
<td>Emergency Electronic Brake Light.</td>
</tr>
<tr>
<td>FCW</td>
<td>Forward Collision Warning.</td>
</tr>
<tr>
<td>BSW/LCW</td>
<td>Blind Spot Warning/Lane Change Warning</td>
</tr>
<tr>
<td></td>
<td>High-Speed Platooning.</td>
</tr>
</tbody>
</table>

A general list of some established Vehicle-to-Infrastructure (V2I) applications include the following (acronyms, where used, are also noted):

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Red Light Violation Warning.</td>
</tr>
<tr>
<td></td>
<td>Reduced Speed/Work Zone Warning.</td>
</tr>
<tr>
<td>CSW</td>
<td>Curve Speed Warning.</td>
</tr>
<tr>
<td>BHI</td>
<td>Bridge Height Information.</td>
</tr>
<tr>
<td>SPaT</td>
<td>Signal Phase &amp; Timing.</td>
</tr>
</tbody>
</table>

**J2735**

A new Controller Area Network (CAN-bus) message standard, J2735, has been developed by the Society of Automotive Engineers (SAE). This new CAN-bus message facility allows in-vehicle DSRC equipment to interface with the vehicle’s high-speed data bus, receiving information necessary to communicate critical spatial and operating information about a vehicle to the DSRC communication fabric. Importantly, it provides effective isolation from the rest of the mission-critical operation of the vehicle’s data bus. J2735 is intended to provide a uniform method of obtaining information for DSRC and other bolt-on technologies without requiring each vendor to implement its own idea of what data items need to be acquired. By eliminating ad hoc data acquisition (DAQ) implementations, operational consistency and safety is enforced; interfering with a vehicle’s CAN-bus due to a software defect, unintentionally introduced as part of a custom DAQ function, could be catastrophic to the safe operation of the vehicle. See Appendix 1 for a brief description of J2735.

**J2735 versus Heavy Equipment**

Unfortunately, J2735 has only been implemented as an enhancement to the on-board diagnostics, version 2 (OBD-2) CAN-bus protocol found on light-duty trucks and passenger cars. Heavy equipment, such as trucks, construction equipment, over-the-road (OTR) tractors and trailers, etc., uses a different CAN-bus protocol known as J1939. J1939 does not offer an integrated J2735 extension. However, various independent projects, such as the “Connected Commercial Vehicle—Integrated Trucks” project (CCV-IT) are available, using commercially available bolt-on equipment that acquires J1939 CAN-bus data and emits a synthesized J2735 message.
Research and development is active and ongoing with respect to the implementation of the J2735 protocol for heavy trucks. See the recent presentation “Development of a Basic Safety Message for Heavy Truck Tractor-Trailers” by Alrik L. Svenson as an excellent example of the challenges and benefits of a heavy-truck safety message integration.

MnDOT’s Goals
With these challenges in mind, many questions arose as a DSRC project design was considered. These questions included:

- What would a DSRC integration with MnDOT winter maintenance fleet vehicles look like?
- How would it operate?
- How well would it work; that is, how much bandwidth would be available to pass all the collected data acquired between roadside unit (RSU) encounters?
- What types of data would be useful to pass through the DSRC communication fabric?
- How can the effectiveness and capacity of the DSRC communication channels be measured?

This report addresses the technical details that came into focus as MnDOT and technical consultant AmeriTrak collaborated to design a meaningful DSRC integration with operational winter maintenance vehicles. It addresses how the DSRC-passed data was isolated for post-project analysis, as well as mutual lessons learned during implementation, testing, and exercise of these solutions.

Infrastructure Planning
Overall infrastructure planning for this project included the following goals:

- Identify a corridor on which to deploy the DSRC RSUs.
- Select a DSRC vendor.
- Identify and select an RSU test site.
- Identify and select the remaining RSU production sites.

DSRC Corridor Selection
MnDOT chose a 3-mile stretch along I-35W starting at 66th Street, south of Minneapolis in Richfield, heading north to downtown Minneapolis and I-94. See Figure 1 for a map of the selected test corridor.

DSRC Vendor and Equipment Selection
MnDOT chose to use Arada Systems’ DSRC equipment for both the roadside RSUs and in-vehicle on-board units (OBUs). Six RSUs and five OBUs were purchased from Arada.

MnDOT Maintenance relied on expertise from MnDOT Traffic Management section in selecting the DSRC equipment, as MnDOT Maintenance had no experience with this type of equipment. MnDOT Traffic Management section chose the Arada/Lear equipment for the DSRC deployment.

<table>
<thead>
<tr>
<th>RSU</th>
<th>6</th>
<th>LocoMate RSU-201 Commando Roadside Unit. Figure 3 shows the selected Arada RSU.</th>
</tr>
</thead>
<tbody>
<tr>
<td>OBU</td>
<td>5</td>
<td>LocoMate ASD OBU-205 On-Board Unit. Figure 4 shows the selected Arada OBU.</td>
</tr>
</tbody>
</table>

**RSU Test Location Selection**

An RSU test location, implemented with RSU-1, was selected. It is located at the intersection of I-35W and the southbound 98th Street ramp, approaching from the west. This location is about 4 miles south of the “main” demonstration corridor; it is shown in Figure 2.

The 98th Street test site was chosen because it is close to AmeriTrak’s offices and software design team. With considerably less traffic, this location allowed AmeriTrak staff to iteratively test the AVL/DSRC integration in a somewhat safer environment. Because the software was in a constant state of flux during development, it allowed developers to field-test new ideas without having to drive north into the typically heavier traffic of I-35W.

*Figure 1. The DSRC demonstration corridor. Copyright © Google, Google Maps, 2017.*
Identification and Installation of RSU Locations

MnDOT Maintenance and Regional Transportation Management Center (RTMC) staff identified the number and locations of RSUs needed for this project. Six Arada RSUs were purchased. RTMC staff installed the six RSUs at half-mile intervals on Intelligent Lane Control Structures (ILCS) and equipment cabinets along the demonstration corridor. One of these RSUs, designated RSU-1 below, was used as the test site as described above and was also used for data backhaul. The selected ILCS span the entire highway, six lanes in each direction, providing relatively easy access for RSU installation.

The decision to use half-mile intervals was arbitrary. After observing the performance of the deployed system, it is recommended that the RSU intervals should be increased to about 1 mile for the next phase of this project.

All cabinet-mounted RSUs are located on the side of the highway, except for RSU-4, which is located in the center median.

<table>
<thead>
<tr>
<th>RSU</th>
<th>Location</th>
<th>Mounting</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>35-W at 98th St, SB Ramp.</td>
<td>Cabinet</td>
</tr>
<tr>
<td>2</td>
<td>35-W SB south of 50th St at Minnehaha Pkwy.</td>
<td>ILCS</td>
</tr>
<tr>
<td>3</td>
<td>35-W at Crosstown Commons.</td>
<td>Cabinet</td>
</tr>
<tr>
<td>4</td>
<td>35-W SB at 60th St exit, center median.</td>
<td>Cabinet</td>
</tr>
<tr>
<td>5</td>
<td>35-W NB between 47th St and 48th St.</td>
<td>ILCS</td>
</tr>
<tr>
<td>6</td>
<td>35-W SB at 66th St exit.</td>
<td>Cabinet</td>
</tr>
</tbody>
</table>
Figure 3. LocoMate RSU-201 Commando Roadside Unit.

Figure 4: LocoMate ASD OBU-205 On-Board Unit.
All installed RSU antennae deliver maximum power of 34 dBm, have a gain of 12 dBi, are omni-directional and have a 360° beam width. In the table below, “Site Elevation” is measured as “altitude above sea level.” The “Height” column is the mounted RSU height as measured at its location, above the stated elevation. See Appendix 2 for photographs and maps of each RSU installation.

<table>
<thead>
<tr>
<th>RSU</th>
<th>Location</th>
<th>Site Elevation (feet)</th>
<th>Height (feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>35-W at 98th St, SB Ramp.</td>
<td>852</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>35-W SB south of 50th St at Minnehaha Pkwy.</td>
<td>861</td>
<td>20</td>
</tr>
<tr>
<td>3</td>
<td>35-W at Crosstown Commons.</td>
<td>876</td>
<td>10</td>
</tr>
<tr>
<td>4</td>
<td>35-W SB at 60th St exit, center median.</td>
<td>859</td>
<td>10</td>
</tr>
<tr>
<td>5</td>
<td>35-W NB between 47th St and 48th St.</td>
<td>849</td>
<td>20</td>
</tr>
<tr>
<td>6</td>
<td>35-W SB at 66th St exit.</td>
<td>852</td>
<td>10</td>
</tr>
</tbody>
</table>

**Mobile Planning**

Mobile device deployment planning included the following goals:

- Select plow trucks and supervisor vehicles from the truck stations that maintain the DSRC demonstration corridor.
- Install OBUs into the selected vehicles.

**DSRC Demonstration Vehicles**

The following vehicles were chosen as DSRC demonstration vehicles for the five purchased OBUs.

<table>
<thead>
<tr>
<th>Truck ID</th>
<th>204507</th>
<th>210143</th>
<th>213393</th>
<th>214525</th>
<th>215551</th>
</tr>
</thead>
<tbody>
<tr>
<td>Make</td>
<td>Sterling</td>
<td>Ford</td>
<td>Ford</td>
<td>International Navistar</td>
<td>International Navistar</td>
</tr>
<tr>
<td>Model</td>
<td>L8511 Single Axle</td>
<td>F-150</td>
<td>F-150</td>
<td>7500 Single Axle</td>
<td>7600 Tandem Axle</td>
</tr>
<tr>
<td>GPS Receiver</td>
<td>GlobalSat</td>
<td>GlobalSat</td>
<td>GlobalSat</td>
<td>Fangtec</td>
<td>GlobalSat</td>
</tr>
<tr>
<td>ATE-SA10⁵</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Spreader</td>
<td>Dickey-John</td>
<td>None</td>
<td>None</td>
<td>Force 6100</td>
<td>Force 6100</td>
</tr>
<tr>
<td>CAN-bus</td>
<td>J1939</td>
<td>None</td>
<td>None</td>
<td>J1939</td>
<td>J1939</td>
</tr>
<tr>
<td>Vaisala⁶</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>Non-HD</td>
<td>Non-HD</td>
</tr>
<tr>
<td>Camera</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

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⁵ The ATE-SA10 is an AmeriTrak-produced, add-on sensor box.
OBU Installation Procedure

After performing extensive bench testing in the lab and in-vehicle testing in the field, AmeriTrak compiled a short instruction guide for MnDOT OBU equipment installers. These instructions are included in this section.

**Power**

- The OBU requires +12-Volts to operate.
- Use the AmeriTrak-supplied power cord with the molded coaxial barrel connector on one end.
- The "plus" side of the power cord is marked with a small piece of red shrink-wrap.
- Connect the "plus" side of the power cord to a switched +12-Volt circuit through a fuse link.
- Use a 3-Amp fuse in the fuse link.
- This ensures that both devices, the AT500 and OBU, boot with vehicle ignition.

!!! DO NOT connect the OBU power cable to AmeriTrak’s Power Distribution Board !!!

The Power Distribution Board is part of the AmeriTrak AT500 installation kit. It is not rated for the additional current required by the OBU.

**Mounting Location**

The two Wi-Fi antennae should peek through a window in the cab. This will depend somewhat on where the RSUs are located along the highway.

- If RSUs are located on highway overhead structures, then mount the OBUs on the center of the dash looking out the windshield.
- If RSUs are located along the right side of the highway, then the OBUs should be located on the passenger side of the vehicle, allowing the antennae to peek out through the passenger-side window.

**GPS Antenna**

- Each OBU has its own GPS “pancake”-style antenna.
- Using double-stick mastic tape, place the antenna on the dash, allowing the antenna to “look out” the front window.
- Attach the blue SubMiniature A (SMA) quick-disconnect connector on the OBU’s blue bulkhead connector marked “GPS.”

**Wi-Fi Antennae**

- Attach each green SMA quick-disconnect connector on the OBU’s green bulkhead connectors marked “DSRC ANT1” and “DSRC ANT2.”
- The actual antennae are interchangeable. Either antenna can be attached to either green bulkhead connector.

**Ethernet Cable**

- Connect one end of the AmeriTrak-supplied Ethernet cable to the OBU’s RJ-45 connector marked “LAN-3.”
- Connect the other end of the Ethernet cable to AmeriTrak’s AT500 RJ-45 connector.

An OBU installation is depicted in Figures 5 and 6. This installation features external antennae. The photos show the coax jumper cables used to connect the OBU to the external antenna coax cables. The black cable is an OBU-dedicated GPS antenna cable.

Antenna mountings are depicted in Figures 7 and 8. Figure 7 shows an external mounting of the antennae. Figure 8 shows a dashboard-mounted OBU with two different antenna orientations. It is preferred that the two OBU antennae be oriented vertically, as in the left photo. However, once the truck starts moving, vibration causes the two antennae to “flop,” as seen in the right photo. It is noteworthy that OBUs with “flopped” antennae continued to work.
Figure 5. The AT500 and its associated Arada OBU installed on the back wall of the cabin of an International snowplow.

Figure 6. A close-up of the OBU.
Figure 7. One vehicle used two external antennae, which cleaned up the OBU installation. This allowed the OBU to be mounted on the back wall of the vehicle, rather than the dashboard.

Figure 8. An example of a dashboard-mounted OBU with different antenna orientations.
Software Engineering Technical Goals

Given the challenges that a heavy-truck DSRC integration project presents and the questions that arise from these issues, three goals were identified that would characterize this project and its results:

- **Demonstrate a complete DSRC integration with AmeriTrak’s production AVL system acting as a host.**

  This goal was the most challenging to achieve. In most cases, DSRC implementations are stand-alone, closed systems. In the case of Arada, a Bluetooth OBD-2 module connects to its OBU, which generates the Basic Safety Message (BSM). The OBU then communicates with the RSU, passing along the BSM and other Arada-specific messages. The MnDOT DSRC project breaks this “closed circuit” model.

  For this project, the OBU functioned as a “client” to the AmeriTrak AT500 telematics device. Instead of passing only DSRC-specific, closed circuit messages, the OBU was now expected to pass AT500-generated messages along with the OBU/RSU-specific, “closed loop” messages within the context of the AT500’s client/server computing model. In the same way, the RSU was now expected to receive these “custom” AT500 messages, passing them to the designated AmeriTrak server.

  In order to accomplish this, custom software on the mobile-side was required, developed by both AmeriTrak and Arada. Getting this software to work together within the strict security models of both computing environments (Arada and AmeriTrak) was challenging.

- **Demonstrate and quantify robust DSRC-to-V2I information exchange.**

  In order to accomplish this goal, separate data transfer pathways were implemented, as well as separate persistence (storage) targets. This design allowed duplication of each AT500-generated message, marking it as a “DSRC Transfer Message” and storing it on the telematics device in special “Intended for DSRC Transfer” cache tables.

  This approach required AmeriTrak to design and implement a new, DSRC-dedicated server. Rather than send the DSRC-received information to running instances of existing logical servers, a new server species was created, thus simplifying the task of sorting out whether a received message arrived by way of DSRC communication channels or by “standard” cellular communication channels.

  Rather than create a new database instance dedicated to DSRC-received messages, AmeriTrak extended its existing production database by creating new tables designed to persist and characterize DSRC-received messages. The new DSRC-dedicated server then targeted these DSRC-specific tables, creating a new, custom communication and persistence pathway, isolated from other “standard” communication traffic.

- **Demonstrate and quantify full two-way communication between the in-vehicle AVL system and data center using DSRC.**

  Because DSRC V2I concepts require a central authority to broadcast different types of status and conditions information, it was decided that the demonstration system would simulate this by acknowledging (ACK) every message received through the DSRC infrastructure.

  To accomplish this, every AT500 message that arrives at the dedicated DSRC server immediately generates an acknowledgment (ACK) message. The server sends each ACK message to the RSU connection that received the original message, and that RSU immediately broadcasts the ACK. If the AT500 is still in-range, it will hear the ACK; the message corresponding to the received ACK will then be marked as “sent-and-ACKed,” removing it from the list of “send at the next DSRC connection.”

---

Note that AmeriTrak telematics devices implement a full-featured relational database. This views stored data not as files and file-based, but as tables within a database instance.
Overall Software Architecture

Figure 9 shows how the Arada DSRC components have been integrated with AmeriTrak’s AT500 AVL system. The mobile side shows an OBU connecting to a host AT500, while the infrastructure side shows an RSU connecting to a logical server running at AmeriTrak’s data center. Notice that the DSRC equipment is connecting using TCP/IP over IPV-4, a departure from standard Arada communication methods. Note that even though cameras may be attached to the AT500, no image or video data was transported using DSRC communication.

Multiple RSUs

While Figure 9 shows a single OBU connecting to a single RSU, in reality there can be multiple connections made to a deployed collection of RSUs. Figure 10 shows how an OBU-equipped vehicle can connect to multiple RSUs located along its route. When an in-vehicle OBU comes into range of an RSU, it will connect and communicate. When an in-

Figure 9. Overall DSRC integration architecture, including the mobile side and data center.
vehicle OBU travels beyond the range of its current RSU, it will disconnect. This sequence repeats for subsequent RSUs it encounters along its route.

Figure 10. Diagram of how a single vehicle can connect to one or more RSUs encountered along its route.
Message Store-and-Forward, Theory of Operation

A robust “Store-and-Forward” (SNF) process allows a mobile device to maintain captured data continuity in difficult wireless coverage conditions. In fact, it may be argued that any wireless connection technology can be considered unreliable and therefore discontinuous.

Two assumptions are made by the SNF data processing model:

- Assume an unreliable or absent connection.

  Because of the assumption that there is never a decent connection to a data center, every message that the AT500 generates is immediately cloned and saved in special cache tables within the mobile database. Upon insertion into these tables, the message is marked as “unacknowledged.” Therefore, there is a completely asynchronous mechanism that can wait until (1) an ACK returns from the server or (2) the SNF process runs.

  Although this approach means the loss of a real-time nature for the end-for-end push technology, which assumes message delivery to connected data center clients within 2 seconds, the contiguous record of acquired data is still preserved. Balancing bandwidth constraints and local processor load, the SNF process is run every 10 minutes. SNF process timing may be easily altered, as it is set by a configurable parameter.

- Expect every message to be acknowledged (ACKed) upon receipt at the target data center.

  The ACK message is not expected at any prescribed time interval; it can arrive at any time. However, in most cases, the ACK message arrives in well under a second after its corresponding message is received by the data center. Upon receipt, the returning information contained in the ACK message is used to update the SNF cache tables.

  When the bell rings and the SNF process is run, any message contained in the SNF table structures marked as “unacknowledged” is collected and sent to the data center, without any prior knowledge of a connection to the data center being present. This is because the data center connection details are managed by a completely separate application. Well-defined Application Programming Interfaces (APIs) exist between all the applications that implement the behavior of the AT500, but asking about the health of data center connections is assumed to be nobody’s business except the application that controls and maintains it. This is because these details are complex and need to be properly encapsulated, and therefore isolated, from other parts of the system.

  Note that the SNF process, for both standard message delivery and the newly added DSRC message delivery, operates continuously. If an SNF message was sent, but not ACKed, it will be sent again during the next cycle. This condition can arise if the AT500 or the OBU loses connection just before or during message transmission.

In this embodiment, all AT500 messages are sent continuously via a cellular connection, and the same messages are sent via DSRC when a DSRC connection is established. Note that the DSRC transmission method is, by necessity, a batch process due to the make-then-break nature of DSRC.

Adapting SNF for DSRC

Because the nature of a deployed V2I DSRC implementation is precisely that of a deliberately intermittent connection, it was proposed that SNF technology could be applied, with some modification. The biggest change involves the trigger which informs the SNF process to run; this trigger is currently implemented with a complex timer algorithm that takes into account many other factors beyond the current time.

Rather than replace the timer function for this project, the timer framework was extended, allowing other types of triggers to fire the SNF process. In this case, the newly added trigger mechanism turned out to be the instant that the AT500 comes into range of an RSU. This does break a stringent rule of functional isolation: knowledge of a connection status.
The second change to the SNF framework, allowing its adaptation to an integrated DSRC application, was to add DSRC-dedicated cache tables to the mobile database. This extension allows the AT500 to clone and isolate all generated messages intended for transmission over an acquired DSRC link. Because the DSRC message cache is now separate from the standard message stream, DSRC-specific metric messages can be easily added.

**Arada Firmware Design Changes**

Because of the nature of AmeriTrak’s AT500 software architecture, Arada was asked if modifications could be made to its software. This would accommodate the differences between Arada’s requirements and AmeriTrak’s implementation, listed below.

<table>
<thead>
<tr>
<th><strong>Issue</strong></th>
<th><strong>Arada OBU / RSU Requires:</strong></th>
<th><strong>AmeriTrak AT500 Uses:</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Internet Protocol Version</td>
<td>IPV-6</td>
<td>IPV-4</td>
</tr>
<tr>
<td>Data-Delivery Protocol</td>
<td>UDP</td>
<td>TCP</td>
</tr>
</tbody>
</table>

Although AmeriTrak has developed client and server software extensions that support the User Datagram Protocol (UDP), it would have been a challenge to sort out received UDP message traffic, essentially reassembling packets into their original message formats, creating appropriate ACK messages and re-broadcasting over UDP. Since this is what the Transmission Control Protocol (TCP) does, Arada was asked if it would be willing to extend its firmware to accommodate TCP.

Another problem to overcome was the lack of IPV-6 protocol support on the AT500. Although IPV-6 support is solidly in AmeriTrak’s development plans, there was insufficient bandwidth, within the urgent time frame and deadlines of this project, to successfully convert and test the AT500 software to support both IPV-4 and IPV-6. IPV-4 could not simply be discarded for IPV-6; both had to coexist due to previous integrations requiring ongoing support.

Arada agreed to extend its OBU and RSU software to accommodate TCP/IP over IPV-4. This took longer than expected with difficulties along the way. However, the important result was that the Arada software was rendered compatible with AmeriTrak’s AT500 deployment.

**Arada Connection Details**

As implemented for security reasons, the Arada DSRC devices control the sequence of connections. That is, security concerns specify that both the Arada OBU and RSU do not allow any non-DSRC incoming connections to their software. Therefore, both the AT500 and data center logical DSRC server must wait for all the Arada devices to contact and connect to AmeriTrak software. AmeriTrak-designed software is unable to “take charge” and control the sequence of communication events, processes that AmeriTrak is accustomed to managing. This means that connection success or failure is completely dependent upon Arada’s firmware and, by extension, how it handles communication problems, which (through no fault of Arada) are common.

Because both systems were now connected and functional, the Arada deployment model changed from that of a stand-alone, after-market addition to that of an integrated, more traditional client/server application. Some interesting problems arose as integration testing proceeded. These problems involved:

- Messaging needs between the two systems.

  Although the two systems were now finally compatible, with great effort on both sides, there was not time to collaborate on a robust two-way messaging Application Programming Interface (API) between the two systems. A certain amount of information needs to be exchanged, allowing both systems to be acutely aware of each other’s issues and status. Some examples of a more robust exchange of information might include general system status, connection status, connection/disconnection event notification, number of messages sent and received, etc.
• In-range notification.

   One of the most important pieces of information needed by AmeriTrak from Arada concerns the DSRC connection status. As the integration is now implemented, there is no way of knowing when the OBU wanders into range of an RSU. Clearly, the OBU knows the exact millisecond a connection to an RSU is made, but, at the moment, it keeps this information to itself.

• Local connection maintenance.

   As implemented, the Arada equipment is relying on the “Keep Alive” option that is built into the TCP. Although effective, it has caused problems in AmeriTrak’s mobile computing environment. A better approach is to implement a mutual heartbeat message between the two systems (detailed in the following section), taking the connection status monitoring away from the much lower protocol level and moving it further up into the application levels. This would allow greater flexibility in dealing with the volatile circumstances of the mobile environment, especially in heavy-truck applications.

New Heartbeat Messages

In order to determine who is connected to whom, two new DSRC heartbeat messages have been designed and implemented:

<table>
<thead>
<tr>
<th>Mobile-to-Server</th>
<th>Every second</th>
<th>The AT500 emits a heartbeat message to the DSRC OBU.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Server-to-Mobile</td>
<td>Every 2 seconds</td>
<td>The DSRC server emits a heartbeat to all connected RSUs.</td>
</tr>
</tbody>
</table>

Mobile-to-Server

The mobile-to-server message is used as a metric to measure the success of each OBU’s encounter with an RSU. AmeriTrak had to create a way to accomplish this. A mobile-to-server message is emitted by the AT500 every second. Therefore, the <count> argument becomes a reasonably accurate seconds counter.

   >DsrcTest: <msgId>,<count>;

This message is emitted to the OBU with no assumption that the OBU is connected to an RSU. If no connection exists, the >DsrcTest: message will be lost. If a connection does exist, the OBU will forward it to the dedicated server at AmeriTrak’s data center through the RSU to which it is connected. Therefore, the missing >DsrcTest: messages might serve as an interesting metric for measuring the effectiveness of the DSRC connections.

Server-to-Mobile

A server-to-mobile heartbeat message is emitted every two seconds by the logical DSRC server instance running at AmeriTrak’s data center.

   >Dsrc:;

This message is intentionally designed to be very short, and is sent to every connected RSU. Each RSU broadcasts the >Dsrc: message upon its receipt, allowing connected OBUs to receive it. It is this mechanism that allows each AT500 to know when it has encountered an RSU. In fact, it is this very feature that allows the described integration to work.

AmeriTrak’s In-Range Notification Process

As mentioned earlier, the integrated Arada equipment now looks more like a client/server application rather than a stand-alone product. Because the OBU has no way to inform the AT500 when it is in range of an RSU, it was necessary to build a notification process.

The AmeriTrak notification process, implemented through the receipt and processing of the >Dsrc: message, informs the AT500, in real time, of both connection conditions: in-range and out-of-range. This became necessary because of the implemented design. The basic assumption is that there is no DSRC connectivity most of the time. Because the DSRC should be used when it becomes available, the design specifies saving up all messages to pass over the DSRC link when it appears. Since all these accumulated messages are sitting in a number of tables in the mobile
database, a trigger is needed to launch a process that will run a database query, process the returned information and begin dumping data, as fast as possible, over the established link. There are several variables that affect this: how long the AT500 is in range of the RSU; the amount of data stored that needs to be transferred; the strength of the connection to the RSU; etc. In some cases, all of the data cannot be transferred, so the AT500 must know when to stop the transfer process.

The following console excerpt shows the >Dsrc: heartbeat message being emitted to each connected RSU by AmeriTrak’s dedicated DSRC server running at the data center. Note that there were only three RSUs deployed when this console output was captured.

```
13:19:12  MsgRtr: [1 d 16:54:49] (psv.3 act.0) (t.3 a.3 r.0 d.0) rb: 0/4000
13:19:14  NetConn: [RSU-4.1002] Sent: <9> >Dsrc:
13:19:14  NetConn: [RSU-1.1004] Sent: <9> >Dsrc:
13:19:14  MsgRtr: [1 d 16:54:51] (psv.3 act.0) (t.3 a.3 r.0 d.0) rb: 0/4000
13:19:16  NetConn: [RSU-4.1002] Sent: <9> >Dsrc:
13:19:16  NetConn: [RSU-3.1003] Sent: <9> >Dsrc:
13:19:16  NetConn: [RSU-1.1004] Sent: <9> >Dsrc:
```

**Message Acknowledgment**

The server acknowledges (ACKs) all messages received over a DSRC link by sending an ACK message back to the AT500 through the RSUs:

```
>OkDsrc: <msgId>
```

It’s important to note that the AT500 never ACKs any received >Dsrc: heartbeat messages.

**AmeriTrak’s Dedicated DSRC Server**

A new endpoint server, named SvrDsrc, was written and deployed at AmeriTrak’s data center. This gives the installed RSUs a secure connection target against which they can transfer data. This new server implements three important functions:

- **Run very fast.**
  
  By running each passive TCP connection thread as fast as possible, it was possible to catch all DSRC messages ending up at each endpoint, with time to spare.

- **Provide a heartbeat.**

  The provided >Dsrc: heartbeat message to each connected RSU allows each AT500 with an OBU to implement its in-range/out-of-range detection algorithm.

- **Manage database tables.**

  Each DSRC-received message is inserted into a series of DSRC-specific archive and control tables, allowing the system to archive all the data passed across the various DSRC links.
An excerpt from the server’s .ini file (redacted as necessary for security purposes) specifies an initial nine passive TCP connection points. Any number of TCP listeners can be specified, but nine were chosen, three more than the number of purchased RSUs.

<table>
<thead>
<tr>
<th>Conn Name</th>
<th>Server IP Address</th>
<th>Port</th>
<th>RSU Static IP Address</th>
</tr>
</thead>
<tbody>
<tr>
<td>RSU-1</td>
<td>123.xx.xx.xx</td>
<td>prt1</td>
<td>192.yy.yy.zz1</td>
</tr>
<tr>
<td>RSU-2</td>
<td>123.xx.xx.xx</td>
<td>prt2</td>
<td>192.yy.yy.zz2</td>
</tr>
<tr>
<td>RSU-3</td>
<td>123.xx.xx.xx</td>
<td>prt3</td>
<td>192.yy.yy.zz3</td>
</tr>
<tr>
<td>RSU-4</td>
<td>123.xx.xx.xx</td>
<td>prt4</td>
<td>192.yy.yy.zz4</td>
</tr>
<tr>
<td>RSU-5</td>
<td>123.xx.xx.xx</td>
<td>prt5</td>
<td>192.yy.yy.zz5</td>
</tr>
<tr>
<td>RSU-6</td>
<td>123.xx.xx.xx</td>
<td>prt6</td>
<td>192.yy.yy.zz6</td>
</tr>
<tr>
<td>RSU-7</td>
<td>123.xx.xx.xx</td>
<td>prt7</td>
<td>192.yy.yy.zz7</td>
</tr>
<tr>
<td>RSU-8</td>
<td>123.xx.xx.xx</td>
<td>prt8</td>
<td>192.yy.yy.zz8</td>
</tr>
<tr>
<td>RSU-9</td>
<td>123.xx.xx.xx</td>
<td>prt9</td>
<td>192.yy.yy.zz9</td>
</tr>
</tbody>
</table>

Each RSU was assigned a different static IP address corresponding in sequence to the enumeration used throughout this report. All deployed RSUs were configured to remotely connect to a logical server instance running at AmeriTrak’s data center, located at 123.xx.xx.xx. Each RSU was assigned a different sequential TCP port number (“port”), starting at prt1. Again, the port number sequence follows this report’s RSU enumeration. Each assigned connection name, used internally by the server software, corresponds exactly with the RSU descriptions and sequence already described.

Each passive TCP connection runs asynchronously in its own thread, ensuring excellent real-time response to incoming messages. The following table summarizes the expected passive connections and includes the static IP addresses of each RSU. The declarations found in the server .ini file, shown above, are derived from the following table (redacted as necessary for security purposes), excerpted from AmeriTrak’s software design documents.
The new dedicated DSRC server was designed to have access privileges to the production database. A new message history archive table was created to hold all messages received across the DSRC links. Some of the columns in this new table follow:

<table>
<thead>
<tr>
<th>Column Name</th>
<th>Data Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>msgId</td>
<td>bigint</td>
<td>A unique, AT500-assigned message ID.</td>
</tr>
<tr>
<td>updSw</td>
<td>tinyint</td>
<td>Post-processing: 1 = ready for processing, 2 = error, 0 = processed.</td>
</tr>
<tr>
<td>source</td>
<td>varchar(20)</td>
<td>The name of the RSU this message was received from.</td>
</tr>
<tr>
<td>esn</td>
<td>bigint</td>
<td>The AT500’s unique electronic serial number (ESN).</td>
</tr>
<tr>
<td>vName</td>
<td>varchar(20)</td>
<td>The AT500’s assigned vehicle name.</td>
</tr>
<tr>
<td>acqTime</td>
<td>timestamp</td>
<td>The AT500 GPS time at which this message was created.</td>
</tr>
<tr>
<td>msg</td>
<td>text</td>
<td>This is the original ASCII JPGP message.</td>
</tr>
</tbody>
</table>

The connection sequence—from OBU to AT500 and then to the RSU connecting to SvrDsrc at AmeriTrak’s data center—is diagrammed in Figure 11. The assigned IP addresses and TCP port numbers are also shown in this diagram. The AmeriTrak-designed message tracking protocol JPGP is detailed further in Appendix 3.
AmeriTrak AT500

192.168.xx.xx
Local port 567 allowed

Arada OBU

192.168.xx.xx
Connect on local port 567

Arada RSU-1

192.168.xx.xx
Connect to 123.xx.xx.xx : prt1

Router and Cable Modem Bridge

192.168.xx.xx
Bridge to 123.xx.xx.xx

AmeriTrak Data Center DSRC Server

123.xx.xx.xx
Ports prt1 ... prt9 open

Arrow direction shows who connects to whom

Figure 11. Typical AT500/OBU to RSU-1 connection flow.
**DSRC Production Configuration**

**Infrastructure Environment**

Figure 12 diagrams the installation details of the RSU test site, RSU-1, located at the intersection of I-35W and 98th Street on the southbound entrance ramp. RSU-1 connects to AmeriTrak’s data center using a Comcast cable modem and router.

![Diagram](image)

*Figure 12. RSU-1 Test site installation, 98th Street southbound ramp on I-35 west.*

The remaining RSUs also connect to the AmeriTrak data center through the equipment located at 98th Street. This is because, for security reasons, MnDOT’s RTMC did not want new connections to or from other vendors to be added to its high-speed fiber-optic network. RTMC’s custom, fiber network is used exclusively to connect and transport real-time video from hundreds of traffic-monitoring cameras that it manages. Because thousands of consumers across the Twin Cities use and rely upon this real-time video every day, all parties involved with this project agreed to *not* disrupt this network in any way.

The solution to the data transport issue was easy to implement. RTMC created a secure tunnel on its fiber network, routing all DSRC messages from the other installed RSUs to the 98th Street location. By configuring firewalls on both the Linksys router and the Comcast modem, additional security after the RTMC tunnel was enabled. These combined security measures ensured that the DSRC data would be transported at very high speeds, but would remain isolated from the rest of the RTMC network.

**Mobile Environment**

Before all the reconfigured DSRC equipment was turned over to MnDOT, extensive field-testing was conducted. The following configuration was installed in a passenger test vehicle:

- An AmeriTrak AT500 with modified software, featuring changes that allowed it to connect with an Arada LocoMate OBU.
- An Arada LocoMate OBU with modified firmware running Arada’s new IPV-4 TCP/IP client.

The OBU was installed on the dashboard of the vehicle. The “rubber duck” DSRC antennae were attached to the OBU, aligned vertically, positioned to “look through” the vehicle’s windshield. The AT500 was installed in the backseat area of the vehicle.

---

8 A rubber ducky antenna (or rubber duck aerial) is an electrically short monopole antenna that functions somewhat like a base-loaded whip antenna. It consists of a springy wire in the shape of a narrow helix, sealed in a rubber or plastic jacket to protect the antenna. Rubber ducky antenna is a form of normal-mode helical antenna. (Richard B. Johnson, "Rubber Ducky Antenna," 2006, [http://www.abominablefirebug.com/RDuckey.html](http://www.abominablefirebug.com/RDuckey.html))
Next, a “test corridor” was established between 106th Street to the south and 82nd Street to the north, just south of I-494. Figure 13 is a map of this local test corridor. A test vehicle drove through this corridor several times for each OBU. All five OBUs were exercised through this “test corridor,” all connecting to RSU-1 at 98th Street.

![Figure 13. Local test corridor south of the selected demonstration corridor.](image)

Results

Excellent results were obtained. Testing demonstrated that all cached messages were able to be passed and acknowledged through the DSRC link. Several tests were conducted in which the vehicle was operated for several hours, accumulating almost 2,000 DSRC-cached messages. Upon the vehicle’s entering the local test corridor, all messages were offloaded through the established DSRC link in less than 5 seconds. Examination of the archived data at the data center confirmed this performance.
### Route and Range

<table>
<thead>
<tr>
<th>Route and Range</th>
<th>Approximate Connect Location</th>
<th>Approximate Loss Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northbound travel</td>
<td>About 100 feet past the 106th Street entrance ramp, on the highway.</td>
<td>¼ of the distance past the 94th Street exit, between the 94th and 90th Street exits.</td>
</tr>
<tr>
<td>Southbound travel</td>
<td>Just past the 94th Street bridge, after emerging from under the bridge.</td>
<td>About 100 feet from the start of the 106th Street exit.</td>
</tr>
</tbody>
</table>

### Handover

AmeriTrak’s reconfiguration and complete testing of all Arada equipment was completed on February 25, 2017. Since RSU-1 was already installed for testing, the remaining five RSUs and all five OBUs were handed over to MnDOT the following week. MnDOT coordinated with RTMC to get the RSUs installed along the demonstration corridor, while members of the MnDOT AVL team installed the OBUs in the five candidate vehicles.

### Issues with the Current Implementation

#### AmeriTrak’s Open Issues

- There was only time to implement a data acquisition (DAQ) system.
  
  A report facility must be built around the implemented DAQ system. Because of the complexity of integrating the Arada and AmeriTrak systems, the implementation schedule slipped and no time was available to add web-based interfaces that would conveniently allow investigators to examine and analyze the collected data.

- More specificity is required for ACK messages.
  
  The ACK message generated by `SvrDsrc` must include the electronic serial number (ESN) of the AT500 that generated the message. This is necessary because multiple OBUs may hear the same ACK message. The included ESN will disambiguate the delivered ACK message.

- A DSRC “killer app” should be designed as soon as possible against the acquired data.
  
  During several conference calls with MnDOT and FHWA, it became clear that one or more DSRC applications should be implemented. These new applications would demonstrate how acquired DSRC data can be applied to real-world highway maintenance operations. Since it was shown that data can efficiently flow both ways, RTMC should be included, perhaps interfacing with some of its requirements and data.

#### Arada’s Open Issues

- A better Application Programming Interface (API) must be designed between the two systems.
  
  Since there is now an interesting client/server application with the successful integration of Arada and AmeriTrak equipment, collaboration with Arada is important to determine how crucial status and problem information can be efficiently exchanged between the two systems.

- In-range and out-of-range messages must be added to the OBU.
  
  AmeriTrak is currently synthesizing an in-range notification using server operations. It would be very helpful and much more efficient if the OBU would notify the AT500 immediately upon making contact with an RSU.

- Better documentation would be very helpful.
  
  AmeriTrak would like to work with Arada to help improve its documentation.

- Remote update of firmware is needed.
At this time, AmeriTrak does not understand how to update the RSU firmware from a remote location. All that is known is how to update the RSU firmware and configurations across a wireline connection.

**AmeriTrak’s Lessons Learned**

- A specification was necessary but absent.
  
  Unfortunately, AmeriTrak did not have, nor did it create, a software engineering specification early in this project. This statement actually presents a serious Catch-22. The catch is: When discussions started with MnDOT about a DSRC integration into heavy trucks, “we didn’t know what we didn’t know.” Although a spec was really needed at the start of this project, likely a meaningful or useful document could not have been produced at that point. Later in the project, when there was an understanding of how DSRC worked within the Arada context, AmeriTrak did in fact produce a detailed technical spec that allowed the completion of this project.

- An RSU test site was very important.
  
  AmeriTrak commends MnDOT for suggesting an RSU test site along I-35W. It was fortunate that the suggested location was so close to AmeriTrak’s offices as it significantly reduced travel time. It turned out to be a great idea for ease of development, field-testing and safety. If travel to the demonstration corridor were necessary for every field test, a minimum of one hour would have been consumed, given the traffic present most of the time. The test site also presented the opportunity to test the software without traveling on I-35W; all that was needed was to drive east or west along 98th Street over the highway, or north and south along the west-side service road.

- Security considerations must be considered early and at each step.
  
  Data path and device security is of utmost importance, and must be planned-in from the earliest stages of software design. All stakeholders must be present when security is discussed and planned.

- DSRC software testing took lots of time.
  
  After Arada agreed to alter its software, it took many months and lots of back-and-forth between Arada and AmeriTrak. AmeriTrak was unfamiliar with some of the customized tools that Arada deploys within its custom Linux operating systems, and so required lots of “hand-holding” from Arada. The lesson learned here is that wholesale software rewrites should not be taken lightly or done informally. DSRC is extremely complex, and AmeriTrak was adding additional complexity with its integration. To Arada’s credit, and with great effort on the part of both parties, a very successful, reliable and high-performance integrated telematics product was achieved.

- Better documentation from DSRC equipment providers is necessary.
  
  Although all of Arada’s software is documented in several (thick) user manuals, these could be a more useful set of documents if their production values were better. That is, better typesetting and clearer prose. Finally, more background information about the overall structure of Arada’s software and some explanation about its organization would be helpful. At the moment, Arada’s documentation is less like a handbook and more like a long list of implemented commands.

- Initial interaction between MnDOT and AmeriTrak was lacking.
  
  This project started to get serious just as a key MnDOT visionary team member was retiring without having transferred enough background and technical knowledge. His replacement had the Herculean task of coming up to speed on at least 387 highly technical projects in a very short period of time, which he accomplished in rapid succession. The “organized chaos” of this transition caused some delays during the early period of this project. An important lesson learned is that, for very complex technical projects such as this DSRC integration, it is important that an agency work closely with a vendor against a well-crafted set of technical requirements. Another important lesson is that no one person should have all the knowledge: Always train a backup.
Appendix 1

A Brief Introduction to J2735

The following description is an excerpted and edited citation from the “ITS Standards Fact Sheets” of the U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology, Intelligent Transportation Systems Joint Program Office. The following URL will take the reader to the complete Fact Sheet which contains active links to related documents:

https://www.standards.its.dot.gov/Factsheets/Factsheet/71

Overview

Standards for dedicated short range communication (DSRC) are intended to meet the requirements of applications that depend upon transferring information between vehicles and roadside devices as well as between vehicles themselves. Typically, this type of communication occurs between moving vehicles entering a communications zone with fixed roadside communication equipment or directly between moving vehicles. DSRC provides the foundation for a variety of applications including vehicle safety, emergency vehicle notification, automated tolling, enhanced navigation, traffic management and many others.

How are the standards used?

This standard—Society of Automotive Engineers (SAE) J2735: Dedicated Short Range Communications (DSRC) Message Set Dictionary— supports interoperability among DSRC applications. The message sets specified in this standard depend upon the lower layers of the DSRC protocol stack to deliver the messages from applications at one end of the communication system (for example, in a vehicle) to the other end (for example, a roadside equipment device). These lower layers of the DSRC protocol stack are defined and specified in standards developed by other Standards Development Organizations (SDOs). In particular, the lower layers are addressed by Institute of Electrical and Electronics Engineers (IEEE) standard P802.11p, and the upper-layer protocols are covered in the IEEE P1609 series of standards. The DSRC families of standards developed by the various SDOs are meant to operate together in a harmonious fashion. The message sets specified in this standard define the message content delivered by the communication system at the application layer. This standard therefore defines the message payload at the physical layer.

Scope

This standard—SAE J2735: Dedicated Short Range Communications (DSRC) Message Set Dictionary— specifies standard message sets, data frames and data elements for use by applications intended to utilize the 5.9 GHz Dedicated Short Range Communications for Wireless Access in Vehicular Environments (DSRC/WAVE) communications systems, referenced in this document simply as “DSRC.” The scope is limited to specifying initial representative message structures and data elements and providing sufficient background information to allow readers to properly interpret the DSRC standards and message definitions from the point of view of an application developer.

The standard defines the following message formats:

<table>
<thead>
<tr>
<th>Message Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A la Carte message</td>
<td>The A la Carte message is composed entirely of message elements determined by the sender, allowing for flexible data exchange.</td>
</tr>
<tr>
<td>Basic Safety message</td>
<td>The basic safety message (BSM) contains vehicle safety-related information that is periodically broadcast to surrounding vehicles.</td>
</tr>
<tr>
<td>Emergency Vehicle Alert message</td>
<td>The Emergency Vehicle Alert message is used for broadcasting warnings to surrounding vehicles that an emergency vehicle is operating in the vicinity.</td>
</tr>
<tr>
<td>Generic Transfer message</td>
<td>The Generic Transfer message provides a basic means to exchange data across the vehicle/roadside interface.</td>
</tr>
</tbody>
</table>
The Probe Vehicle Data message contains status information about the vehicle to enable applications that examine traveling conditions on road segments.

The Common Safety Request message is used when a vehicle participating in the exchange of the basic safety message can make specific requests to other vehicles for additional information required by safety applications.

The standard provides several informative annexes (appendices) that give background on message framework, the use of various fields within the messages, expected latency and priority for various message types. These appendices illustrate the use of the messages and are not intended to be prescriptive.

- The first appendix covers operation with the vehicle safety message including intersection collision warning, emergency electronic brake lights, pre-crash sensing, cooperative forward collision warning, left-turn assistant, stop sight movement assistance and lane-change warning.
- The second appendix covers traffic probe message use and operation including probe snapshot information, probe data message sets, sending probe data message sets to an RSE (roadside equipment, equivalently RSU), probe data message sets received by an RSE, vehicle anonymity, probe data security, vehicle-based data lifecycle and probe data message management.
- The third appendix covers the emergency-vehicle-approaching warning scenario which provides warning to drivers in the vicinity of a public safety vehicle that there may be potential interference between the vehicles.
- The last appendix covers the use of the message dispatcher which allows the flexibility of reducing, extending and reconfiguring message contents.
Appendix 2

RSU Installation Photos and Location Maps
All maps are courtesy of Google. Copyright © Google, Google Maps, 2017

**RSU-1**

RSU-1 is illustrated in composite Figure 14 (top image is of the RSU mounted on roadside hardware; lower-left image is a map with an indicator arrow; lower-right image is the satellite image map with an indicator arrow).

*Figure 14. RSU-1: This is the test RSU, located at 35-W at 98th Street, SB ramp, approaching from the west.*
RSU-2

RSU-2 is illustrated in composite Figure 15 (top two images are views of the RSU mounted on an overhead structure that crosses the lanes of traffic; lower-left image is a map with an indicator arrow; lower-right image is the satellite image map with an indicator arrow).

Figure 15. RSU-2: 35-W SB south of 50th Street at Minnehaha.
RSU-3

RSU-3 is illustrated in composite Figure 16 (top image is of the RSU mounted on roadside hardware; lower-left image is a map with an indicator arrow; lower-right image is the satellite image map with an indicator arrow).

Figure 16. RSU-3: 35-W at Crosstown Commons.
RSU-4

RSU-4 is illustrated in composite Figure 17 (top image is of the RSU mounted on roadside hardware; lower-left image is a map with an indicator arrow; lower-right image is the satellite image map with an indicator arrow).

Figure 17. RSU-4: 35-W SB at 60th Street exit, center median.
**RSU-5**

RSU-5 is illustrated in composite Figure 18 (top two images are views of the RSU mounted on an overhead structure that crosses the lanes of traffic; lower-left image is a map with an indicator arrow; lower-right image is the satellite image map with an indicator arrow).

![RSU-5 Illustration](image)

*Figure 18. RSU-5: 35-W NB between 47th and 48th Street.*
RSU-6

RSU-6 is illustrated in composite Figure 19 (top image is of the RSU mounted on roadside hardware; lower-left image is a map with an indicator arrow; lower-right image is the satellite image map with an indicator arrow).

Figure 19. RSU-6: 35-W SB at 66th Street exit.

Appendix A. DSRC V2I Telematics Integration: Implementation and Deployment Details
Appendix 3

JPGP Message Format

Syntax

AmeriTrak’s JPGP ASCII message syntax is described in the following table:

| Commands | • The message command is always the first field (field 0).  
| • All commands are prefixed with a “greater than” sign (>).  
| • All commands begin with an upper-case alpha (except where specifically noted).  
| • All commands end with a colon (:) postfix. |
| Fields | • Comma-delimited operands (fields) follow the command.  
| • In some cases, pure text is enclosed in double quote marks (“ ”) to preserve white space.  
| • White space surrounding comma delimiters is ignored.  
| • Refer to the definition of each message for individual field details. |
| Terminations | • All messages are semicolon (;) and “carriage-return” and “line-feed” terminated.  
| • Message termination in the documentation is assumed. However, when present, the notation is either <cr><lf> or \r\n |

Examples

Some message examples are:

| Syntax | >Command: <operands>; <cr><lf> |
| Example 1 | >Fire;::<cr><lf>  
| Example 2 | >Add:16;<cr><lf>  
| Example 3 | >Set:Upd,1,10;<cr><lf> |

General Time Format

The time fields present in each message are named <rxTime> or <acqTime>. It captures either the current GPS time if GPS lock is present, or the current system time of the mobile computing platform if GPS lock cannot be obtained.

This field will represent the time that data was acquired. The acquired data is represented by the subsequent fields that compose the remainder of the message. <rxTime> or <acqTime> are composite fields whose general format is either:

[date time] or [yy-mm-dd-hh-mm-ss]

The [date] and [time] portions are separated by a space. The [date] portion is delimited with dashes, while the [time] portion is delimited with colons. [time] is always presented in a 24-hour format. The overall time format is then:

[year-month-day hour:minute:second]

Finally, the time zone is always set to local time, adjusted for Daylight Saving Time (DST). This policy exists because each AmeriTrak mobile device is responsible for time stamping its own outbound information. In the case of Minnesota DOT, time will be presented in Central Standard Time (CST: UTC -6 hours), while New York DOT will show Eastern Standard Time (EST: UTC -5 hours). UTC (Universal Time) is not used in AmeriTrak’s system; all time is converted to local time by the mobile telematics device.