Weather-Savvy Roads Pilot Program

Final Report

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1 INTRODUCTION

New Jersey Department of Transportation (NJDOT) owns and operates just over 2,316 miles of roadway in the State of New Jersey. As part of its mission, NJDOT is responsible for maintaining these roadways during adverse weather conditions for safe travel, which often demands around-the-clock coverage by the maintenance and operations personnel and assets that could continue for many days.

New Jersey has been impacted in recent years by severe storms, such as Hurricanes Irene (2011) and Ida (2021), Superstorm Sandy (2012), Tropical Storms Lee (2011) and Fey (2020), as well as several Nor'easters and snow storms every winter season. NJDOT management understands the importance of having accurate, reliable, and timely information about road weather conditions and the impact this information can have on NJDOT's ability to efficiently deploy its resources and effectively manage the roadways in adverse weather conditions, especially when those conditions change rapidly across the region. For the visual awareness of the traffic and roadway conditions, NJDOT currently relies on 460 fixed cameras installed along its rights-of-way, which are primary source of visual situational awareness. The agency also owns 52 Road Weather Information System (RWIS) stations that collect road weather data and inform the operations and maintenance personnel of road conditions across the State's highway system. Finally, NJDOT has a fleet of close to 1400 vehicles that operate on the State's highways on a daily basis as part of Department's business practices. The NJDOT vehicle fleet is currently operated from over 60 facilities around the State. When in operation, drivers of NJDOT fleet vehicles provide 'at-a-glance' situational awareness of road conditions, incident detection and verification.

As it is fiscally inconceivable to install and maintain fixed cameras and RWIS stations along every State operated road, NJDOT is developing its capabilities in mobile video and roadway-sensing data collection as cost-effective alternatives. To improve the winter road maintenance (WRM) capabilities and leverage the latest advancements in Intelligent Transportation Systems (ITS) and connected vehicle (CV) technology, NJDOT launched an initiative in 2017 for the deployment of Integrated Mobile Observations (IMO) for road weather and traffic management. As part of the initiative, NJDOT applied for and received New Jersey's first Accelerated Innovation Deployment (AID) Demonstration Program grant from the United States Department of Transportation (USDOT) to instrument NJDOT fleet vehicles with IMO systems. The IMO pilot deployment project was launched in Spring 2019 and included the acquisition, installation, testing, deployment, and evaluation of an IMO system that would provide remote video streaming and road weather sensing capabilities from NJDOT fleet vehicles to the web-based data management and visualization portal. This pilot deployment project supports the implementation of the Federal Highway Administration's (FHWA) Weather-Savvy Roads concept, which was recognized as one of the proven, market-ready innovations in the fourth round of the FHWA Every Day Counts Program (EDC 4). It also supports deployment of Weather Responsive Transportation Management (WRTM) strategies that were identified in April 2019 as part of the NJDOT Capability Maturity Model (CMM) self-assessment.

Instrumentation of the Department's fleet vehicles began in March 2020 and, by the conclusion of the AID grant at the end of December 2021, was completed on twenty-four fleet vehicles. The instrumented vehicles included:

- Six Safety Service Patrol (SSP) trucks and two Incident Management Response Team (IMRT) trucks deployed on a daily basis as part of the Traffic Management (TM) and Traffic Incident Management (TIM) practice at NJDOT.
- Eight pick-up trucks operated by Operations Maintenance supervisors and one SUV operated by an Operations Maintenance manager, all of which are deployed during various roadway maintenance activities, including road weather management.
- Seven plow-trucks deployed during WRM activities.

Besides the vehicle instrumentation, the activities completed as part of the AID grant included system monitoring and maintenance, as well as development and continuous improvements of the backend data management system and internet-based data visualization portal.

2 GOALS AND OBJECTIVES OF THE PILOT PROGRAM

The primary goal of the pilot program has been to advance the application of innovative technology in support of weather-responsive roadway management through limited, targeted technology deployment, testing, evaluation, and technology transfer. This has been achieved through the deployment of real-time vehicle-based road weather sensors and video cameras, vastly improving NJDOT's ability to detect and forecast adverse road weather and pavement conditions, and determine the most effective roadway and traffic management response. These technologies have enabled the communication of critical road-weather data between vehicles, infrastructure, and Department personnel across the State. The collected data has been used to assess the impacts of weather on roads, vehicles, and travelers, and has also been used to inform the decision making process by the Department leadership as part of the weather-responsive transportation system management, including the selection and timing of operations strategies and tactics for effective road weather management.

The Weather-Savvy Roads Pilot Program has helped NJDOT assess how the mobile sensing and communication technology can enhance the road weather management decision making process, as well as technical aspects related to technology deployment, integration, operation, and maintenance. This has been accomplished by addressing two critical objectives:

1. **Promote and support Intelligent Transportation System (ITS) sensor deployment and performance monitoring.**

2. **Improve maintenance operations.**

The IMO pilot deployment project has contributed to the following qualitative and quantitative improvements in traffic and road weather management practices at NJDOT:

- **Proactive Management** – The video feed from on-board video cameras and road weather data from weather sensors has provided information needed to proactively support the Department's road maintenance and mobility management activities, as well as management of vehicle fleet resources. Efficient deployment of both personnel and vehicle fleet, as well as winter contract vehicles to locations affected by adverse weather is critical to improving the mobility and safety of the transportation system.

- **Improved Data Collection and Accuracy** – The mobile observations of road weather conditions obtained from in-vehicle sensors have expanded the coverage of the roadway network beyond stationary RWIS sensors.

- **Stronger Collaboration Across Agencies** – The access to real-time video monitoring and road weather sensor data has been provided to mobility operations, roadway maintenance, and emergency response and management units. This additional, shared layer of situational awareness of the current road weather conditions enhanced collaboration among different NJDOT units in developing and executing appropriate response to road weather emergencies. Working together strengthens the relationship between various entities within NJDOT that are often needed on day-to-day activities.

- **Improved Safety** – The data collected from vehicle-sensors was stored and made available for review and analysis of significant events as part of post-event analysis and evaluation.

- **Enhanced Pre- and Post-Event Pavement Treatment Strategy** – The real-time observations provided the information needed to dynamically determine the effectiveness of treatment strategies and proactively select and deploy the most appropriate pavement treatment options.

3 SYSTEM DESIGN

A functional diagram of the Weather-Responsive Traffic Management System (WRTMS) deployed as part of the Weather-Savvy Roads Pilot Program is presented in Figure 1. The system is composed of two key components: (1) the Vehicle System (VS), and (2) the Road Weather Data Management System (RWDMS). The VS is located within the instrumented vehicles and consists of hardware components and the software that collects and transmits video, road weather condition, and vehicle location data. The RWDMS is hosted at the New Jersey Institute of Technology (NJIT) and serves as the back-office system responsible for validating, ingesting, and processing all data received from the instrumented vehicles and external data sources.

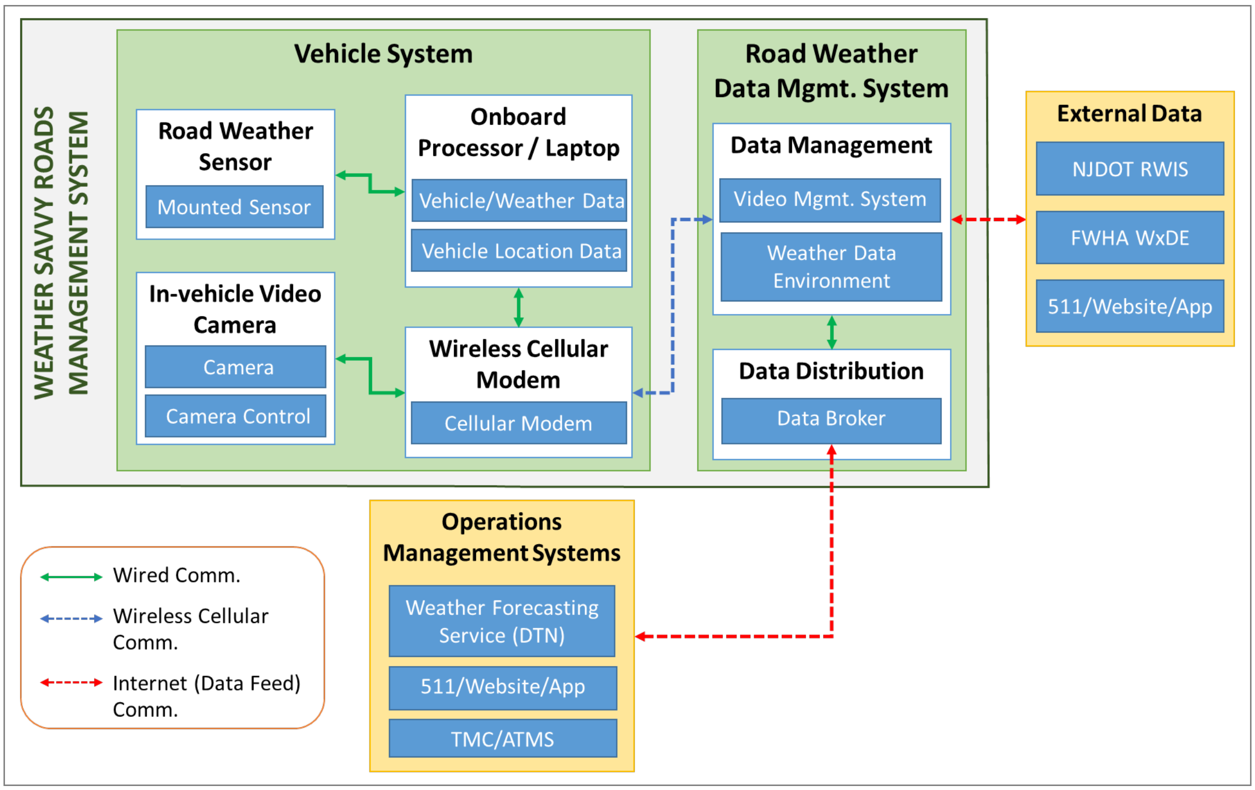


Figure 1. Functional Diagram of the Pilot WRTMS Deployment (Source: NJIT)

This functional representation inherently leads to a flexible, scalable, and maintainable design. The WRTMS implemented as part of the Weather-Savvy Roads Pilot Program has accomplished the following components of system integration:

- NJDOT's Road Weather Information Systems (RWIS); and mobile environmental data (including video) from equipped vehicles.
- Streaming video of roadway conditions through an onboard video processing module. The video feed is transmitted to the video management system hosted at NJIT in real time using wireless communication. Each in-vehicle camera is accessed via static IP and is accessible

to authorized personnel through a client software with username and password authentication.

- The road weather sensor data is transmitted from the mobile weather sensor to the onboard computer using serial communication (connectivity is accomplished via USB cable). After the data translation and processing, the road weather data is transmitted using wireless communication in real time to the back-office data management system hosted at NJIT and managed by the ITS Resource Center.

- All vehicles are equipped with a GPS module[1], which allows the data collected on the vehicles to be geotagged and time-stamped for localization, spatial and temporal analysis.

- The system is designed to receive a variety of weather-related observations including: data from NJDOT RWIS and/or data from the USDOT Weather Data Environment (WxDE), traffic incident data and NJDOT CCTV video feed from 511NJ/Transportation Regional Event Exchange (T-REX) system.

- It is envisioned that in the future the RWDMS would exchange data with external systems such as the NJDOT's weather data provider and the NJDOT statewide Traffic Management Center (TMC) and/or Advanced Traffic Management System (ATMS) data management system. This data exchange may include continuous data feeds, as well as alerts and notifications.

The following subsections detail the different systems that comprise the deployed WRTMS.

3.1 Vehicle System (VS)

The VS streams encoded video, and geotagged and time-stamped road weather condition data through wireless cellular communication to the RWDMS. The VS consists of four distinct subsystems to achieve this:

1. **In-Vehicle Video Camera** – a high-definition digital in-vehicle video camera with technology that increases the ability to view the scene in extremely high (bright) and low (dark) light conditions.

2. **Road Weather Sensor** – a vehicle-mounted sensor that collects data on road surface and air temperature, relative humidity, frost and dew point, grip, road surface state (or condition), and layer thicknesses of water/ice/snow.

3. **Onboard Processor (OBP)** – a laptop/tablet computer that ingests the weather and vehicle location data and executes a client software that generates and transmits the data packets to the RWDMS. The OBP is also used to locally control and adjust settings of the on-board camera, as well as to calibrate, monitor and adjust settings on the road weather sensor and

[1] In the current system design, the GPS modules and antenna are integrated with the cellular router. Only the road weather data collected from the mobile road weather sensor is geotagged and time-stamped. The video is not recorded or stored, and is not geotagged.

the wireless router. In the future, the OBP will have a client software that will display the road weather and vehicle position data on the screen of the laptop/tablet.

4. **Wireless Cellular Modem** – a rugged Long Term Evolution (LTE) cellular modem for in-vehicle applications. The modem connects to the FirstNet cellular service, a high-performance nationwide cellular communications platform dedicated to public safety and emergency response users. The modem can be managed locally from the OBP, as well as remotely through a cloud-based device management platform.

3.2 Road Weather Data Management System (RWDMS)

The RWDMS receives data streamed from the VS, along with data from other sources, and processes them for analysis. The system is composed of two main subsystems:

1. **Data Management –** a subsystem that houses the components necessary to receive and analyze all internal and external data.

    - **Video Management System** – a custom-developed Java application that connects to the on-board cameras in participating vehicles via static IP and receives the video stream in MJPEG format using HTML or RTSP protocol. The streaming video is shown in a web-based graphical user interface for an individual vehicle, or on a virtual "video wall" within the user interface, where each camera feed occupies a single display tile. In the pilot deployment the video recording, storage, and playback are not enabled.

    - **Weather Data Environment (WDE)** – in charge of aggregating, processing (fusion), and storing all the data collected from the vehicles, as well as internal and external sources. The WDE communicates with vehicles using a custom-made API (developed by NJIT in C#), which ingests the road weather and vehicle position data (Integrated Mobile Observations, or IMO) from each participating vehicle and stores the data in an Oracle database. It also ingests data from external sources such as USDOT WxDE, which contains near-real-time data from the RWIS stations nationwide (NJIT is retrieving an XML data feed from WxDE that contains data reported from active NJDOT-owned RWIS stations, provided they are connected to the WxDE system). The WDE also has been configured to receive the video feed from the NJDOT CCTV through 511NJ system, as well as read and display the traffic incident data from the T-REX system provided by TRANSCOM. The main objective of the WDE is to output (through data analytics and visualization) actionable road weather and IMO data to be shared with internal and external entities, allowing them to enhance their decision making process.

2. **Data Broker** – a subsystem that receives the outputs from the WDE for dissemination across external interfaces through a pre-specified data feed (e.g., XML or JSON format). This component of the system is not yet developed, but it is envisioned and planned for deployment in one of the future phases of the project. The outputs can be shared through the Data Broker with various external systems, such as:

    - Weather Data Provider/Forecasting Service that NJDOT is using (DTN),
    - Traveler information systems (e.g., 511) via TRANSCOM,
    - TMC operators (e.g., export to the T-REX system or future ATMS), and others.

4 STAKEHOLDERS

4.1 Stakeholders

This section lists the major stakeholders of the NJDOT Weather-Savvy Roads Pilot Program, as well as their roles and responsibilities (i.e., “who does what”).

- **NJDOT Transportation Operations Systems & Support (TOS&S) Management Staff** – Includes the leadership from the Division of Transportation Mobility and the Operations Division. They are responsible for the overall management of the project, evaluation of the project benefits, directing the application of the project outcomes, and determining NJDOT’s strategic direction with respect to using the integrated mobile observations (IMO) as a Weather-Savvy Roads strategy and as a part of the WRTMS. They are also charged with the acquisition of the equipment and contracting the services for system implementation, including vehicle instrumentation, maintenance, and operation.

- **NJDOT Fleet Vehicle Operators** – The vehicle operators are the primary direct enablers of the technology. They are exposed to this technology on a daily basis in their normal work activities. They are also responsible for reporting any issues with the equipment/system installed on their vehicles to their respective supervisor or manager. The fleet vehicle operators include Safety Service Patrol (SSP), Incident Management Response Team (IMRT) personnel, snow plow drivers, and operations supervisors who operate the vehicles instrumented as part of this project.

- **NJDOT Operations Division and Mobility Division Staff** – These stakeholders encompass supervisors, section managers, Assistant Division Directors and Directors responsible for the efficient management and operations of winter maintenance, mobility and traffic operation across the State. They have access to the web-based data portal that provides live video feed from the vehicle dashcams, as well as vehicle location and road weather condition data transmitted from the vehicles, and they use this information at their discretion. The supervisors and managers are ultimately responsible for reporting system maintenance problems and seeing that they get remedied during the period of the field test.

- **NJDOT Equipment Repair Supervisors/Managers** – These stakeholders are responsible for the day-to-day maintenance of the installed road weather sensors, including regular inspection of the equipment and periodic cleaning, especially after severe storms. They are also responsible for reporting any damage or defect on the equipment installed externally or inside the cab of the maintenance vehicles, i.e., plow trucks, to the designated point-of-contact (POC) for the Transportation Operations Systems & Support Division Management Staff.

- **NJIT Project Team** – The NJIT project team contributed technical expertise during the design of the Weather-Savvy Roads Pilot Project and worked closely with the TOS&S Management Staff on the development and implementation of the Weather-Savvy web-based data portal. The NJIT was also responsible for overseeing the fleet-vehicle instrumentation, monitoring and documenting the overall system performance.

4.2 User Needs

This subsection presents a list of high-level needs for each stakeholder. This list of needs provides an insight into the system's key capabilities that the users of the system require in order to perform their responsibilities in an efficient manner. The needs are as follows:

1. **General Operational Needs**
    - Receive information in (near) real time.
    - Receive accurate and actionable information.
2. **NJDOT Transportation Operations Systems & Support Management Staff**
    - Use WRTMS to enhance situational awareness.
    - Monitor the WRTMS's performance.
    - Determine future equipment and system needs.
3. **NJDOT Fleet Vehicle Operators**
    - Minimum inputs required by the operator, with preferably no log on required. The system should start up automatically when vehicle is started and remain operational as long as the vehicle is running.
    - Vehicle equipment should not hamper or impede normal operation of the fleet vehicle.
    - Use existing in-vehicle display to provide information on road conditions to operations centers.
    - Allow the drivers to report issues with sensors, equipment, or software.
4. **NJDOT Operations Division and Mobility Division Staff**
    - Observe the fleet vehicle's routes through AVL/GPS applications.
    - Review video/images to assess ongoing winter maintenance operations for maximum effectiveness.
    - Observe the road weather data reported by the mobile RWIS sensor installed on-board the vehicle.
5. **NJDOT Equipment Repair Supervisors/Managers**
    - Oversee and coordinate the maintenance of the Weather-Savvy vehicle equipment to ensure that equipment remains in good operating condition.
    - Regular inspections of the road weather sensors, especially after severe storms.
    - Report issues with road weather sensors and other Weather-Savvy equipment and coordinate the repairs as needed.

6. NJIT Project Team

- Oversee and coordinate the installation of the Weather-Savvy project equipment on selected NJDOT vehicles.
- Integrate the Weather-Savvy IMO (real-time) data feeds into the web-based data visualization and analysis systems.
- Remotely access the Weather-Savvy client software to verify system availability and operability.
- Provide evaluation, analysis, and reporting of the Weather-Savvy system to NJDOT and other stakeholders.

5 VEHICLE INSTRUMENTATION

5.1 Description of the Equipment

As illustrated in Figure 2, each vehicle included in the Weather-Savvy pilot project was equipped with the following devices:

1. Mobile road weather sensor VAISALA MD30.

2. Video camera system, either the AXIS F Series camera system (including AXIS F1005e bullet camera sensor and F41 video processing unit) or AXIS P Series dome camera (P3925 or P3935 camera with integrated video processing module).

3. Tablet computer Panasonic Toughpad FZ-G1 series, which also served as the main data processing unit and the local system console.

4. High performance LTE-Advanced vehicle router Sierra Wireless MP70 with a 6-in-1 SharkFin Antenna (2xLTE, GNSS, 3xWiFi, 2.4/5GHz).

5. Power distribution unit, including fuse box with ground side, 100AMP manual circuit breaker, and programmable auto shut-off timer, as well as all the required cabling. In a revised setup applied in three vehicles, the auto shut-off timer was replaced with a relay, which was energized by the router using the router's built-in programmable timer.

6. Sierra Wireless AirLink MP70 OBD2 Y Cable, connecting the vehicle's OBD2 port to the OBD2 port on the router for future use in extracting vehicle telemetry data. It should be noted that the OBD2 cable is installed in each vehicle but has not been actively used, i.e., the vehicle telemetry data is not collected from the vehicle. Nevertheless, the capability of doing so does exist and may be considered in a later phase of the project.

7. Each vehicle was also equipped with auxiliary devices, including mounting brackets, laptop mount, docking station and the keyboard for the tablet PC.

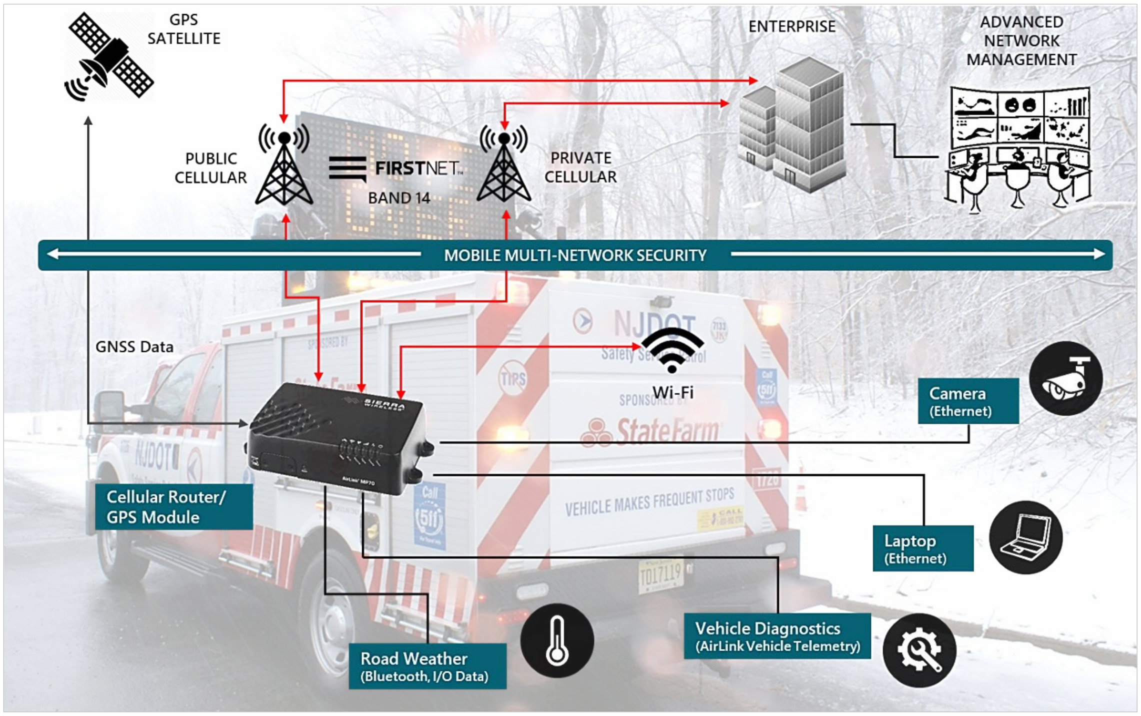


Figure 2. NJDOT Weather-Savvy Pilot System Design (Source: NJIT)

The schematic wiring diagram of the equipment installed in each vehicle is shown in Figure 3. This diagram illustrates the initial setup with a bullet camera model Axis F1005e, which required external video processing unit (Axis F41). The alternative setup with dome cameras (models Axis F3925-R and Axis P3935-LR) was somewhat simplified as these cameras had built-in video processing module and did not require separate video processing box (Figure 4). Instead, the dome camera is directly connected to the PoE injector using RJ-45 connection. The setup with the dome camera was advantageous as it required less space on the instrument board and had a smaller footprint for installation in the vehicle (e.g., it could easily fit under a seat).

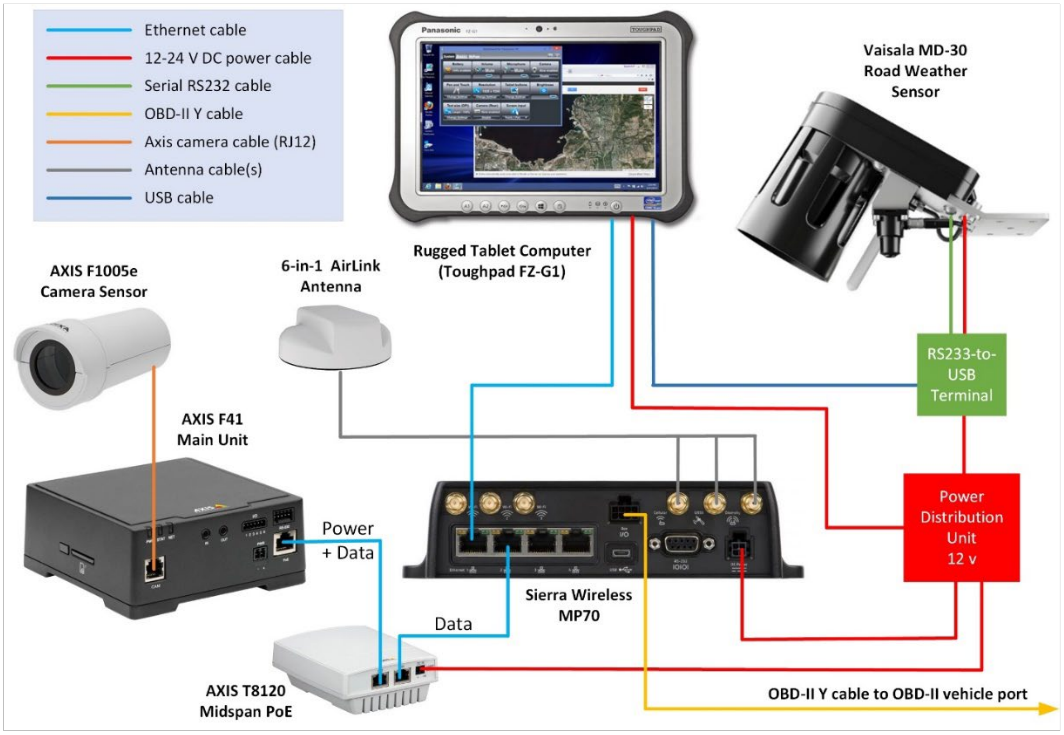


Figure 3. Weather-Savvy instrumentation wiring diagram schematics, bullet camera (Source: NJIT)

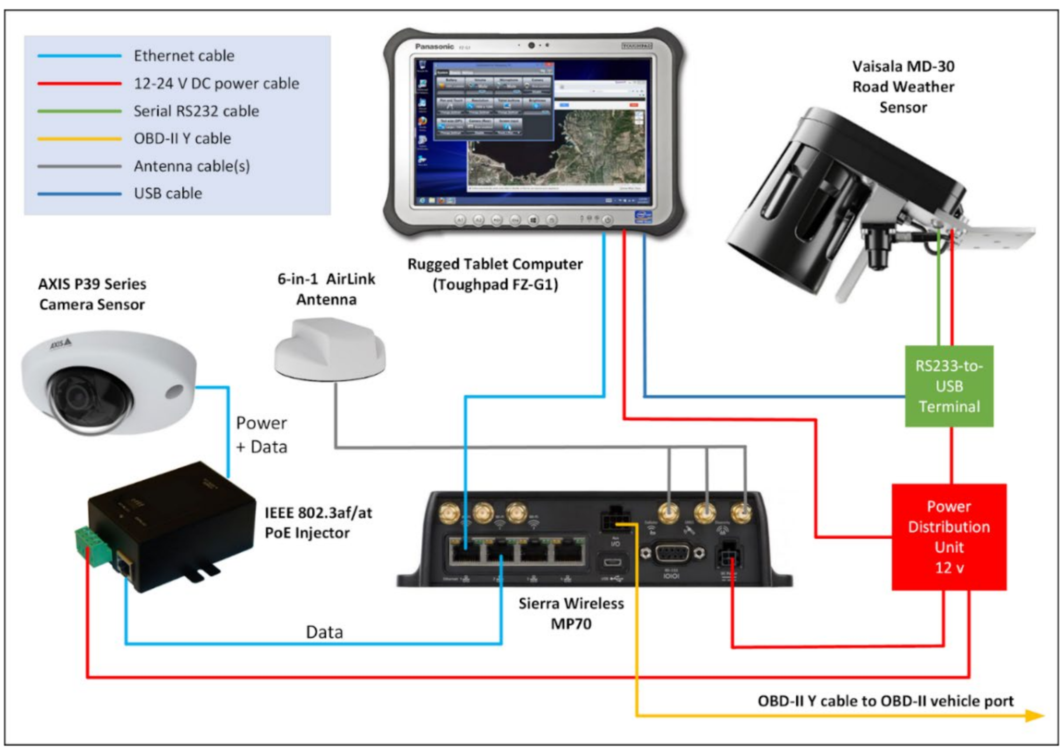


Figure 4. Weather-Savvy instrumentation wiring diagram schematics, dome camera (Source: NJIT)

The following is a more detailed description of the key devices installed as part of the vehicle instrumentation in the Weather-Savvy Roads Pilot Program, and their installed disposition on the vehicles. A detailed list of instrumented vehicles with the device models and serial numbers is provided in Appendix A.

5.1.1 Mobile Road Weather Sensor

The initial scope of work for the project proposed the use of Vaisala DSP100 (Surface Patrol) sensor for the vehicle installation, which NJDOT already has on 50+ vehicles with an in-cab display. However, by the time the project was initiated, Vaisala brought to market a more sophisticated and advanced sensor model MD30, so the decision was made to procure those sensors for this pilot project instead.

The MD30 consists of three sensor components (see Figure 5):

1. Laser-based surface state and water/ice/snow layer thickness sensor,
2. Infrared road surface temperature sensor, and
3. Air temperature and humidity sensor probe.

The parameters measured by Vaisala MD30 are summarized in Table 1. The sensor provides an option to select the temperature and thickness units: degrees Celsius or Fahrenheit for temperature, and millimeters or inches for layer thickness. The MD30 units installed in this project were programmed to report temperature in degrees Fahrenheit, and layer thickness in inches. The details of MD30 configuration are provided in MD30 Setup Guide and Interface Client Technical Reference.

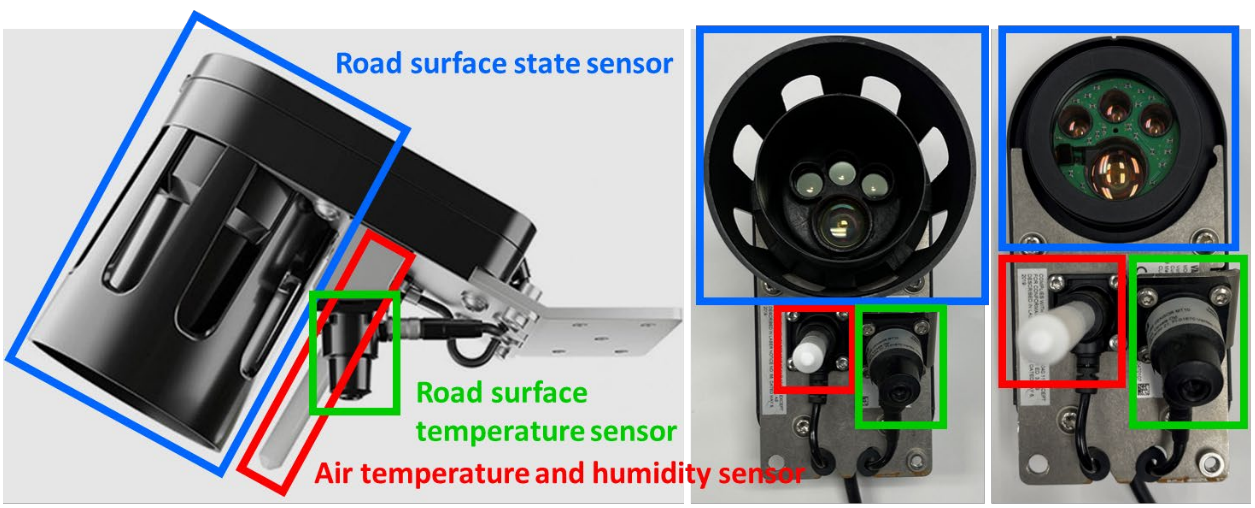


Figure 5. Components of the Vaisala MD30 sensor (Source: NJIT)

Table 1. Vaisala MD 30 Measured Parameters (Source: Vaisala)

Grip and Surface State	
Reported level of grip	0.09 ... 0.82
Reported surface states	Dry, Moist, Wet, Ice, Snow, Slush
Measurement interval	40 times/s
Surface Layer Thickness	
Water	0 ... 5 mm (0 ... 0.20 in)
Ice	0 ... 2 mm (0 ... 0.08 in
Snow (water equivalent)	0 ... 1 mm (0 ...0.039 in)
Surface Temperature	
Measurement range	−40 ... +60 °C (−40 ...+140 °F)
Air Temperature and Relative Humidity	
Humidity range	0 ... 100 %RH
Temperature range	−40 ... +60 °C (−40 ... +140 °F)
Dew point/Frost point range	−40 ... +60 °C (−40 ... +140 °F)

The installation of the sensor differed between the three types of vehicles included in the pilot deployment:

- On the SSP trucks (modified Ford F-350) the sensor was installed on the vehicle undercarriage on the driver's side using a specialized bracket and facing downward in the wheel track. The air temperature and humidity sensor was detached and installed on the frame of the overhead DMS sign mounted on the vehicle's rooftop. The air temperature and humidity sensor was mounted on a magnetic bracket and was connected to the MD30 sensor base with an appropriate cable. See Figure 6 and Figure 7 for illustration.

- On the IMRT trucks (modified Ford F-250) the sensor was installed in a similar fashion as on the SSP trucks. Initially the air temperature and humidity sensor remained attached to the sensor base because the vehicle had no surfaces on the cab or cap where the magnetic bracket could be mounted (neither the cab nor the cap has steel surfaces). Therefore, as an alternative, the mounting bracket for the air temperature and humidity sensor was bolted to the vehicle cap instead of using a magnetic pad to "stick" to the mounting surface. A silicon sealant was used to seal the bolts.

- On the plow dump trucks, the MD30 sensor base was installed in the front of the vehicle using a specialized bracket and facing downward in the wheel track. On the International trucks the sensor was installed just behind the front bumper, and on the Volvo trucks it was installed on the plow lift frame in front of the front bumper. The air temperature and humidity sensor was detached and installed at the back of the cab, mounted on a magnetic bracket. As in the case of the SSP trucks, the air temperature and humidity sensor was connected to the MD30 sensor base using the appropriate cable provided by the vendor. See Figure 8 and Figure 9 for illustration.

Figure 6. Vaisala MD30 base sensor installed on the SSP truck (Source: NJIT)

Figure 7. Air temperature and humidity sensor installed on the SSP truck (Source: NJIT)

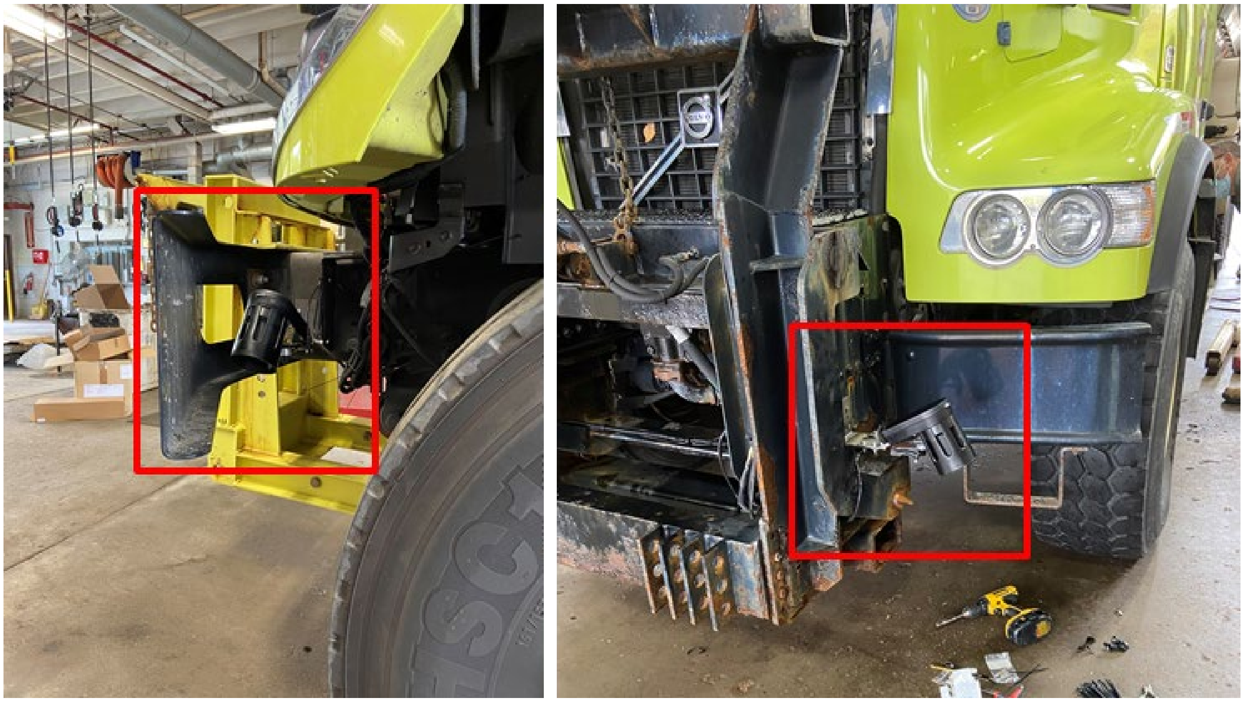


Figure 8. Vaisala MD30 base sensor installed on the plow dump trucks (Source: NJIT)

Figure 9. Air temperature and humidity sensor installed on a plow dump truck (Source: NJIT)

The data from the MD30 sensor was collected using serial communication. Since the MD30 communication cable had a RS232 pinout, and the onboard computer and the docking station only had USB ports, it was necessary to install a RS232-to-USB conversion cable. It connected to the MD30 RS232 pinout on one end, and to the USB port on the computer docking station installed in the vehicle cab on the other end. Each sensor unit was calibrated following the installation according to the manufacturer's guidelines. The calibration was done in two stages: (1) reference plate calibration, and (2) road adaptation calibration. Both stages can be completed in about 10-15 minutes, and whenever possible they were completed right after the sensor installation. However, the road adaptation calibration requires driving on a completely dry asphalt pavement, so on several occasions the road adaptation had to be postponed due to wet roads and rainy weather.

5.1.2 Windshield Video Camera System

The initial proposal for the installation of the "dashcam" was to use the same camera system utilized in the New Jersey State Police vehicles. The vendor for this camera system was on the State contract, which would greatly reduce the time and effort for the procurement. However, at the outset of the project it became apparent that the proposed camera system would be much harder to integrate and operate as envisioned. This was mainly due to the requirement to integrate the video with the road weather data in a data management platform and have the ability to stream the video into a generic multicast video server system as opposed to the vendor-provided video integration system. Thus, the project team researched the alternative IP camera systems available on the market and selected an AXIS camera system designed for custom installation in vehicles, which was easier to integrate and setup for the purposes of this project.

The initial camera system consisted of three components:

- Camera sensor (bullet-type design) AXIS F1005e (with an integrated 12-meter cable).
- AXIS F41 Main Unit, which performs video encoding and transmission, and provides power to the camera sensor unit.
- Power-over-Ethernet (PoE) injector (AXIS T81B22 PoE midspan or Tycon TP-DCDC-1248-M). The PoE injector must be for 12-24 VDC input and comply with IEEE 802.3af. The PoE injector receives power from vehicle battery via power distribution unit, and supplies power supply to the F41 main unit.

The main characteristics of the installed camera system are the following:

- The camera sensor is fixed, it does not have an automatic or electronic pan/tilt/zoom capability.
- The sensor is outfitted in a “bullet” housing and positioned against the vehicle windshield facing the front of the vehicle (see Figure 10 and Figure 11 for illustration).
- The camera system main unit and the PoE injector are installed on the main electronic board positioned under the back set in F-250 and F-350 vehicles, or vertically on the back wall of the cab interior in the plow dump trucks (see Figure 12 and Figure 13 for illustration).
- The camera is set up to stream the video at the rate of 5 frames per second, with the capture resolution 1080p and streaming resolution 640x360.
- The video recording and storage on the F41 unit is disabled. Thus, no video or still images are automatically recorded or stored.
- The video stream is set up to display an overlay with the vehicle ID, license plate number, date and time (See Figure 14 for illustration).
- The access to camera settings and the video stream was controlled through the router’s LAN and required user authentication (username and password).

Figure 10. The camera and the computer system installed in an SSP (F-350) truck (Source: NJIT)

Figure 11. The camera and the computer system installed in a plow dump truck (Source: NJIT)

Figure 12. The camera main unit (Axis F41), PoE injector, cellular LTE modem, and the power distribution unit installed under the back seat of an IMRT (F-250) and SSP (F-350) trucks (Source: NJIT)

Figure 13. The camera main unit (Axis F41), PoE injector, cellular LTE modem, and the power distribution unit installed against the back wall of the cab interior in a plow dump truck (Source: NJIT)

Figure 14. The video snapshot from one of the vehicle cameras showing the video overlay with the vehicle ID, license plate number, date and time of the screen capture (Source: NJIT)

5.1.2.1 Bullet Camera Performance Issues

Following the initial installations of the bullet-type cameras, it was observed that in some vehicles the cameras would tilt out of position during vehicle operation. It was reported by some vehicle operators that this was happening due to vehicle vibration. The operators were asked to manually adjust the camera position and tighten the two nuts that hold the camera housing attached to the camera mount (see Figure 15). However, this was thought to be quite inefficient, and over time it could lead to permanent damage of the camera mount requiring the replacement of the mount. NJIT had researched and identified two potential solutions for this problem: (1) use a glue, such as Loctite, to fix the bolts in place after putting the camera in the optimal position – this solution would likely require a new mount and camera housing in case the camera must be moved out of the position for any reason; or (2) replace the bullet cameras with dome cameras.

5.1.2.2 Dome Camera Alternative

After careful considerations, it was decided to acquire dome cameras for the additional vehicle instrumentations (i.e., the bullet cameras in 19 vehicles that were initially installed would not be replaced). Two models of dome cameras were acquired and tested for potential replacement of the existing bullet cameras: AXIS P3925-R and Axis F4005. After testing and evaluating the candidate camera systems at NJIT lab and in a test vehicle, it was determined that the vertical viewing angle of the model Axis F4005 was too low and subject to vibration. The model P3925-R had a very stable image and the appropriate viewing angle. The P3925-R camera was installed on one of the fleet IMO vehicles (Operations Supervisor Crew #047, 2019 Ford F-250 pickup). The camera was mounted against the cab ceiling (attached to the headliner), facing the vehicle windshield. The horizontal viewing angle of the camera lens was 110°, and it did not have pan-tilt-zoom (PTZ) capability (except the electronic zoom). Neither the camera lens nor the housing can be repositioned without dismantling the camera housing. Thus, the camera only provides the windshield view, no view of the inside of the cab or the driver.

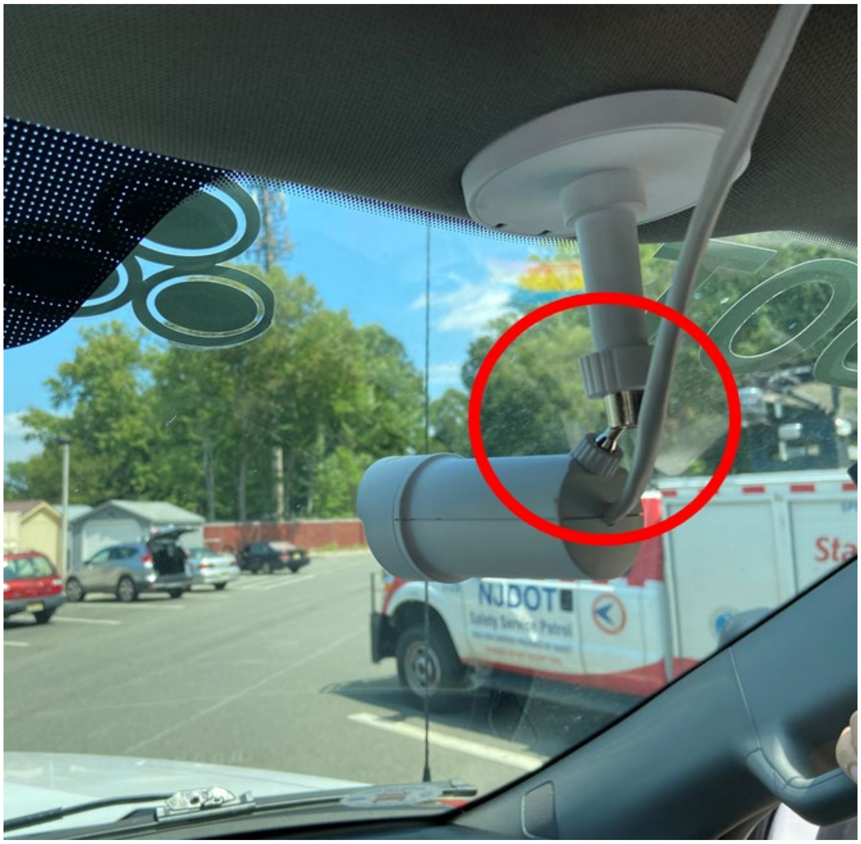


Figure 15. Position of the camera and the camera mount with the tightening bolts circled (Source: NJIT)

The performance of the dome camera had been monitored and it had proven to be stable and providing image of high quality. The dome camera model provided two critical advantages over the bullet-camera model, including:

- it did not suffer from tilting out-of-position due to vehicle vibrations while driving, so it did not require frequent manual adjustment; and
- it had a built-in video processing capability, so it did not require additional video processing hardware (such as F41 Main Unit, which was necessary with the bullet-camera model F1005e).

As already noted, the setup with the dome camera required a smaller footprint on the electronics board for Weather-Savvy instrumentation as it eliminated a need for the video processing unit. The setup of the electronics board for the system with dome camera Axis P3925-R is shown in Figure 16. The illustrations of the installation of Axis P3925-R dome camera in NJDOT vehicle are shown in Figure 17 and Figure 18. A snapshot of the video image broadcasted from the camera via cellular communication is shown in Figure 19.

Figure 16. The electronics board without the video processing unit (not required for the dome camera models), installed under the passenger seat in F350 SSP vehicle (Source: NJIT)

Figure 17. Dome camera (Axis P39 Series) installed in an NJDOT fleet pick-up truck – front view (Source: NJIT)

Figure 18. Dome camera (Axis P39 Series) installed in an NJDOT fleet pick-up truck – side view (Source: NJIT)

Figure 19. A video image broadcasted from the dome-type dashboard camera via cellular communication (Source: NJIT)

The dome camera model Axis P3935-LR was installed in one of the vehicles instrumented as part of this project using the wiring setup shown in Figure 4. Based on the evaluation of the camera performance, it is recommended to adopt the dome camera configuration as a permanent replacement for the bullet-camera type in the future vehicle instrumentation sets. The dome camera system installed in the pilot deployment consists of two components:

- Camera sensor such as AXIS P39 series (e.g., P3925-R or P3935-LR, with RJ-45 connector); and
- Power-over-Ethernet (PoE) Class 2 injector. The PoE injector must comply with IEEE 802.3af/at and be rated for 12-24 VDC input. The PoE injector selected for the IMO in-vehicle application is Tycon Systems TP-DCDC-1248GD-M (Gigabit 9-36VDC input, 48VDC output, 17W DC to DC converter and 802.3af POE inserter, with metal enclosure for greater durability and industrial applications).

One aspect to be careful about is the camera positioning relative to the ceramic frit in the rearview mirror area of the front windshield. As shown in Figure 20, the windshield frit can present an occlusion in the camera view, and once the dome camera is mounted the viewing angle is fixed. Thus, it is important to check the camera view prior to affixing it to the vehicle headliner.

Figure 20. Screenshot of a video stream from windshield camera showing the partial occlusion from the windshield frit (Source: NJIT)

5.1.3 On-board Tablet Computer

At the outset of the project conception, it was decided to equip the vehicles with a laptop computer that could be used for both the pilot deployment project as well as other potential future applications, as opposed to procuring a data processing unit that would be solely dedicated to this project. Similar to the camera system, initially this was supposed to be a laptop computer included in the package for State Police vehicles. However, after some research it was decided to procure a Windows-based tablet computer, which had specifications and versatility better suited for the project and potential future applications. Panasonic Toughpad FZ-G1 was selected based on the size, specifications, performance characteristics, and the delivery timeline.

The computer was installed in a docking station with power supply, as previously shown in Figure 10 and Figure 11. The docking station has a lock with a key, which allows the user to lock the tablet in the docking station. The following are the most critical settings that were made on the computer as part of the system setup:

- The computer is configured to start up automatically when vehicle is started (i.e., boots up or wakes up on ignition), does not require user login, and remains powered up as long as the vehicle is running.

- The power shut-off timer is set up to shut off the power to the computer docking station one hour after the vehicle shut-off, giving enough time to the system administrators to perform computer maintenance and updates when vehicle is not in operation. In an earlier set-up a power shut-off timer switch was integrated in the power supply circuit to execute the power shut-off. In a later setup, implemented in the last three vehicles instrumented in this project, the shut off control was handled by the timer integrated on the cellular router and the relay energized/deenergized by the router.

- The computer mount is configured in a way that allows the operator to move the tablet and the keyboard away from the driver's position, so it does not impede or distract the vehicle operator. The computer screen is configured to shut down after 2 minutes of inactivity.

- The remote access to the computer is accomplished using TeamViewer application with a black screen feature, which shows a static screen saver when the remote session is active and disables local input.

- A custom Python application was developed that communicates with the Vaisala MD30 and the router to retrieve the road weather data and vehicle position data, and then send it to the RWDMS. The application is configured to launch at startup and continue running, even when the computer "wakes up" from the sleep mode.

- A user interface application, designed to display the road weather data on the computer screen, was also developed and installed on the tablet PC. The application was developed in Java and Node.js runtime as a desktop Graphical User Interface (GUI) application, using the Electron software framework as a development platform. The user interface of the desktop GUI application is shown in Figure 21.

Figure 21. Screenshot of the in-vehicle tablet PC with application GUI showing the live readings from the MRWIS sensor (Source: NJIT)

5.1.4 In-vehicle Cellular Router with the FirstNet Service Plan

Wireless data service was required in each vehicle to provide a continuous stream of data from the vehicle to the data center (including the video and MRWIS data) in real time. For this purpose, the cellular data communication service was provided through FirstNet network, which is dedicated to critical users including public safety, emergency management, and other first-response emergency services. The project deployment qualified for the FirstNet cellular and data service as it supports critical public safety function related to traffic and incident management, as well as roadway operations in adverse weather conditions. Thus, the router for the vehicle instrumentation had to be "FirstNet-ready" and it had to be designed for mobile (vehicle) applications. With an assistance from the FirstNet provider, the Sierra Wireless MP70 LTE-Advanced Pro cellular router was selected for the vehicle instrumentation. The MP70 is a high-performance, LTE-Advanced vehicle router developed specifically for mobile mission critical applications in public safety, transit and field services. The FirstNet service is configured with a static public IP. The detailed configuration of the routers deployed in this pilot project is provided in a separate document.

5.2 Instrumented Vehicles

Vehicle instrumentation was completed on twenty-four NJDOT fleet vehicles between March 2020 and October 2021. The list of vehicles with installation dates is shown in Table 2. All installations of the cellular router, dashboard camera system, and the tablet computer were completed by the Emergency Accessories and Installation, Inc. (EAI) at their facility in Cherry Hill, NJ. The installations of the Vaisala MD30 mobile road weather sensor were completed by the manufacturer's technician at the NJDOT's garages: Fernwood complex garage in Ewing

(South and Central Region), Cherry Hill Yard (South Region), Flemington Yard (Central Region), Lafayette Yard and Netcong Yard (North Region).

All the equipment was successfully tested following the installation and was monitored on a regular basis. The MD30 MRWIS sensors were calibrated according to the vendor instructions using the calibration plate followed by the road adaptation calibration. In case a dry roadway was not available at the time of installation (e.g., rainy or snow day), the road adaptation calibration was performed at a later date when road conditions were favorable and met the manufacturer calibration guidelines. According to these guidelines, the road adaptation calibration must be performed on dry roadway and preferably "old" asphalt (concrete and recently laid asphalt should be avoided). The calibration parameters were noted and documented for future reference.

Table 2. List of Instrumented Vehicles with Installation Dates

Region	Crew (Yard)	Vehicle Year/Make/Model	Install Dates	
			Cab(1)	MRWIS(2)
South	IMRT vehicle	2017 Ford F250 Ext. Cab	3/23/2020	4/22/2020
South	SSP Crew #7529 (Cherry Hill)	2019 Ford F350	4/8/2020	6/4/2020
South	SSP Crew #7513 (Cherry Hill) (3)	2017 Ford F350	5/7/2020	6/4/2020
North	IMRT vehicle	2017 Ford F250 Ext. Cab	5/12/2020	4/22/2020
North	SSP Crew #1711 (Harding)	2018 Ford F350	5/14/2020	5/22/2020
North	SSP Crew #1716 (Harding)	2017 Ford F350	5/19/2020	5/22/2020
South	Maintenance Operations Crew #411 (Cherry Hill)	2018 International 6T Plow	9/4/2020	10/1/2020
South	Maintenance Operations Crew #456 (Mays Landing)	2018 International 6T Plow	9/8/2020	10/1/2020
Central	Maintenance Operations Crew #330 (West Amwell)	2018 International 6T Plow	9/11/2020	10/22/2020
Central	Maintenance Operations Crew #331 (Flemington)	2018 Volvo 10T Tandem Plow	9/17/2020	10/22/2020
North	Maintenance Operations Crew #231 (Sussex)	2019 International 7T Plow	9/29/2020	10/21/2020
North	Maintenance Operations Crew #227 (Rockaway)	2016 Volvo 10T Tandem Plow	10/2/2020	10/21/2020
North	Operations Supervisor, Crew # 026 (Roxbury)	2018 Ford F250 Ext. Cab	10/28/2020	10/21/2020
Central	Operations Supervisor, Crew # 335 (Metuchen)	2017 Ford F250 pickup	1/28/2021	4/22/2021
South	Operations Supervisor, Crew #414 (Cherry Hill)	2017 Ford F250 pickup	1/21/2021	2/4/2021

Region	Crew (Yard)	Vehicle Year/Make/Model	Install Dates	
			Cab(1)	MRWIS(2)
South	Operations Supervisor, Crew #045 (Cherry Hill)	2018 Ford F250 Ext. Cab P/U	1/22/2021	2/4/2021
HQ	Statewide Maintenance Supervisor (Ewing HQ)	2018 Dodge Durango	1/29/2021	1/29/2021
North	Maintenance Operations Crew #220 (Hanover)	2020 Ford F250 pickup	10/20/2021	2/18/2022
North	Maintenance Operations Crew #216 (Columbia)	2017 Ford F250 pickup	7/15/2021	8/13/2021
North	Maintenance Operations Crew #215 (West Orange)	2020 Ford F250 pickup	7/16/2021	9/24/2021
South	SSP Crew #7512 (Cherry Hill)	2019 Ford F350	7/27/2021	8/24/2021
Central	Maintenance Operations Crew #336 (Bloomsbury)	2020 Ford F250 pickup	7/22/2021	9/24/2021
North	Maintenance Operations Crew #216 (Columbia)	2018 International 6T Dump	7/28/2021	8/13/2021
North	SSP Crew #1713 (Harding)	2020 Ford F350	10/21/2021	8/13/2021
South	SSP Crew #7513 (Cherry Hill) (3)	2021 Ford F350	3/2/2022	3/2/2022

(1) Cab – Dates of installation of the in-cabin hardware and wiring. Sorted in the ascending order (earliest to latest).

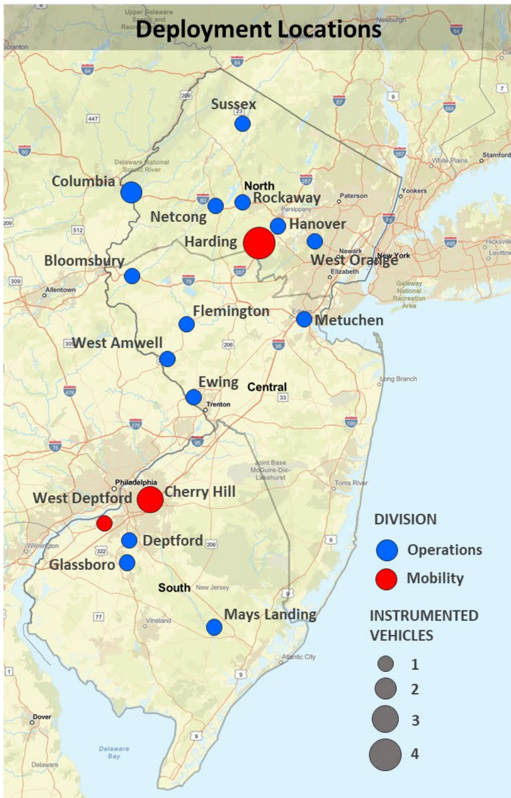
(2) MRWIS – Dates of installations of the mobile road weather information sensor (MRWIS).

(3) SSP Crew #1713 vehicle was decommissioned as it reached the end of service life in March 2022. It was replaced by a new vehicle (with the same crew #), and the complete Weather-Savvy instrumentation was successfully transferred between the two vehicles.

The vehicles were strategically selected considering the following criteria:

- Provide relatively uniform coverage of the roadway network between the NJDOT Operations Regions (North, Central, South).
- Provide relatively uniform coverage of the roadway network between the NJDOT SSP/IMRT regions (North/South).
- Instrument SSP and Maintenance Operations vehicles assigned to the maintenance yards that cover the "incline packages" for the winter operations (i.e., the roadways with steep inclines that historically presented greater operations challenges during winter storms).

The map in Figure 22 shows the locations and number of vehicles that have been instrumented as part of the Weather-Savvy Roads Pilot Program. The locations are color coded based on the NJDOT Division that operates the vehicles: Operations, which operates the operations maintenance fleet and plow trucks, and Mobility, which operates the Safety Service Patrol (SSP) and Incident Management Response Team (IMRT) trucks. Each location is labeled and represents an NJDOT operations maintenance yard or SSP yard where vehicles are based.



Vehicle Instrumentation Status

Total Instrumented Vehicles in Operation: 24

- Operations Plow Trucks: 6
- Operations Supervisor Pickups: 9
- Operations Managers SUV: 1
- SSP Trucks: 6
- IMRT Trucks: 2

Operations			Mobility	
North	Central	South	North	South
2 plows 4 pickups	2 plows 2 pickups 1 SUV	2 plows 3 pickups	3 SSP 1 IMRT	3 SSP 1 IMRT

Strategic instrumentation of vehicles:

- Cover the yards assigned to “incline packages”
- Cover the North/Central/South regions
- Cover SSP North/South routes

Figure 22. Locations of the yards (bases) of the instrumented IMO vehicles by region and NJDOT Division/Unit (Source: NJIT)

6 DATA COLLECTION

As noted earlier in the report, the Weather-Savvy Roads IMO system implemented in this pilot project currently collects the data from the Vaisala MD30 sensors and Sierra Wireless MP70 routers. The data is collected using a Python application installed on the tablet computer. The application extracts the data from the two devices every 5 seconds. It uses serial communication protocol to request and receive the sensor readings from MD30, and User Datagram Protocol (UDP) communication to receive the current GPS location of the vehicle from MP70 (the data is provided in NMEA GGA+VTG format). The list of data items collected from MD30 and MP70 devices is shown in Table 3.

Table 3. The Data Items Collected From the Vehicles (in 5-second Intervals)

Attribute	Source	Unit/format	Example
Collection Timestamp	Localhost (computer) time	Date/time	11/19/2020 10:45:06
ROUTERID (IMEI)	Sierra Wireless MP70	integer	357715090990641
Latitude	Sierra Wireless MP70	decimal degrees	40.79938617
Longitude	Sierra Wireless MP70	decimal degrees	-74.27363733
GPS Fix Quality	Sierra Wireless MP70	integer code	1
Tracked Satellites	Sierra Wireless MP70	integer	15
Altitude	Sierra Wireless MP70	meters, decimal	168.68
Altitude Unit	Sierra Wireless MP70	string	M
Geoid Height	Sierra Wireless MP70	meters, decimal	-34.2
Geoid Height Unit	Sierra Wireless MP70	string	M
MD30 Sensor ID	Vaisala MD30	string	R2220037
Air Temperature	Vaisala MD30	degrees F, decimal	46.4720
Surface Temperature	Vaisala MD30	degrees F, decimal	41.7380
Relative Humidity	Vaisala MD30	%	36.17
Dew Point	Vaisala MD30	degrees F, decimal	21.0778
Frost Point	Vaisala MD30	degrees F, decimal	22.3302
Data Count	Vaisala MD30	integer	20749
Data Warning Flag	Vaisala MD30	integer	0
Data Error Flag	Vaisala MD30	integer	0
Surface State (US)	Vaisala MD30	integer code	1
Surface State (EN15518)	Vaisala MD30	integer code	1
Grip (coefficient)	Vaisala MD30	relative, decimal	0.81998
Water layer thickness	Vaisala MD30	inches, decimal	0.00003

Attribute	Source	Unit/format	Example
Ice layer thickness	Vaisala MD30	inches, decimal	0.00000
Snow layer thickness	Vaisala MD30	inches, decimal	0.00000
Unit Status Flag	Vaisala MD30	integer code	768
Error Bits Flag	Vaisala MD30	integer code	0

The data received from MD30 and MP70 devices is merged in a single data packet every 5 seconds and transmitted to the central server hosted at NJIT using the cellular FirstNet communication (through the router MP70). On the server side, the data from the vehicles is received through an Application Programming Interface (API), custom-built for this project. The API ingests the data from each vehicle and stores it in a working database on the server.

7 DATA PORTAL (WEBSITE)

7.1 Description of the Web-based Data Portal

The data collected from the vehicles is stored in a database hosted at NJIT and is displayed in a web-based data visualization portal. The prototype web-based application with limited functionality was launched in May 2020 and has been continuously updated and upgraded since then.

Sample screenshots of the web-based portal are shown in Figure 23 – Figure 28. Some of the key features deployed to date in the web-based visualization tool include:

- Secure user access using Secure Sockets Layer (SSL) certificate and credentialing with username and password.

- List of instrumented Weather-Savvy vehicles with an indication of their activity status.

- Vehicle dashboard, activated by clicking on the vehicle ID in the vehicle list. It combines readings from the mobile RWIS sensor (MD30) and the video stream from the vehicle camera. The dashboard also indicates vehicle ID, date, and timestamp of displayed data, as well as the video camera clock.

- The full-screen video viewing feature, activated by clicking on the full screen overlay toggle in the lower right corner of the video tile. This feature is very useful for displaying video feed in TMC during weather events.

- Vehicle trace with mobile road weather observations is shown on the map in real time. The trace highlights the trajectories of all IMO vehicles active in the past 30 minutes and it is color-coded based on detected roadway condition or road surface temperature (the user selects one of these two roadway attributes to be shown in the vehicle trace).

- The RWIS map layer, showing the location and live readings from the NJDOT RWIS stations. Currently this data is obtained from the FHWA Weather Data Environment (WxDE). This map layer is optional and can be turned on or off by the user.

- NJDOT Operations Regions and Subregions map layer, an optional map layer that can be turned on or off by the user.

- The TRANSCOM T-REX (formerly OpenReach) New Jersey map layer, showing the location of reported and active traffic events from New Jersey 511 system. On-click pop-up tooltip provides description of each event.

- Estimated Road Surface Temperature, showing the estimated road surface temperature across the entire network, based on the readings from RWIS and MRWIS sensors. The estimates are calculated in near-real-time (in 15-minute increments) in a separate application using a machine learning algorithm.

- The virtual video wall module, providing simultaneous display of multiple vehicle dashboards with live video streams as tiles on the screen. This module also provides an optional sidebar display of the map with the current vehicle locations.

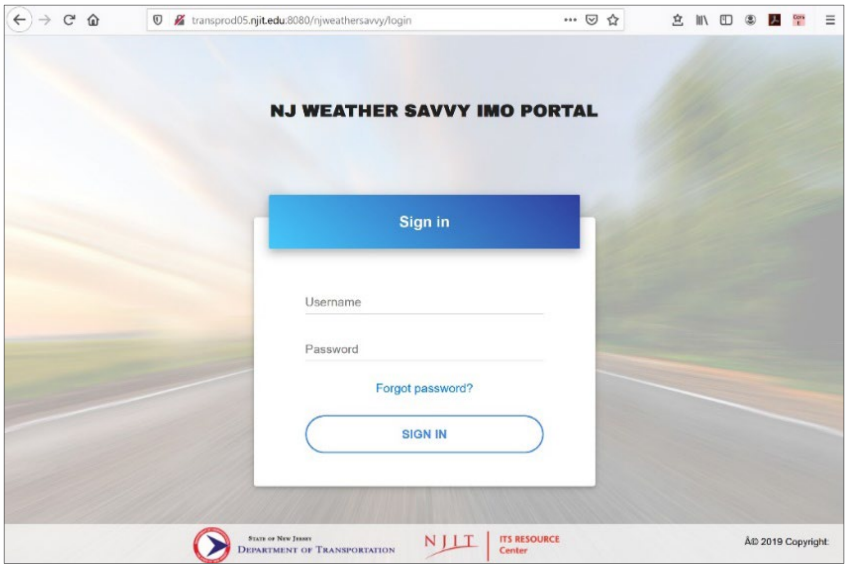


Figure 23. NJ Weather-Savvy IMO Portal Login Screen (Source: NJIT)

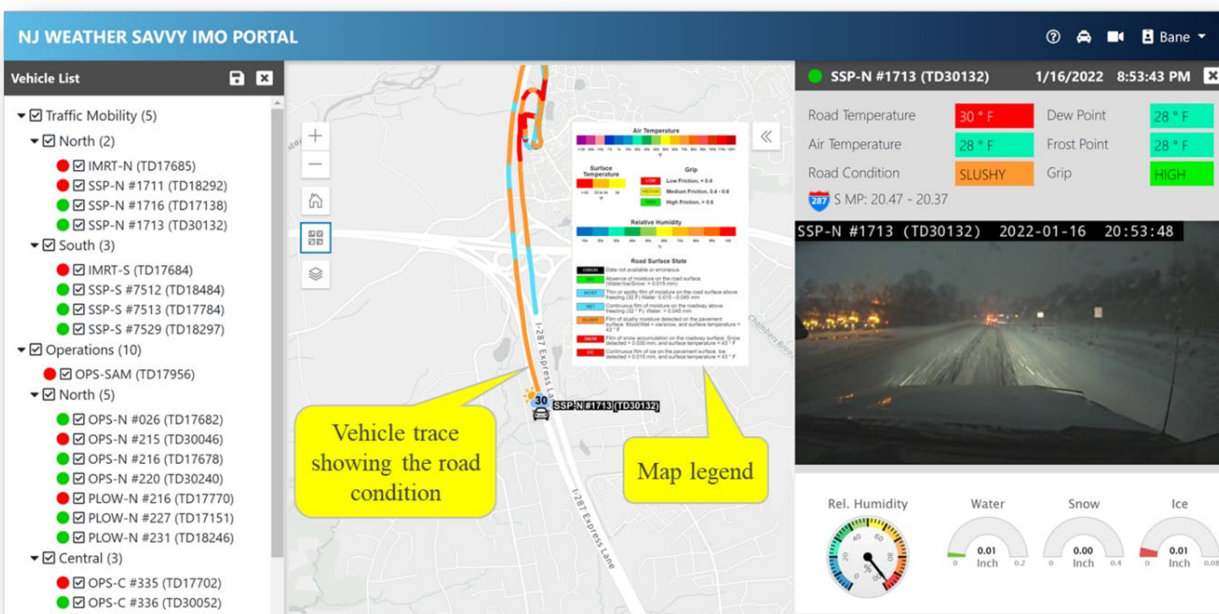


Figure 24. Main page showing the situational map, list of vehicles with active/inactive indicators, and vehicle dashboard for the selected vehicle (Source: NJIT)

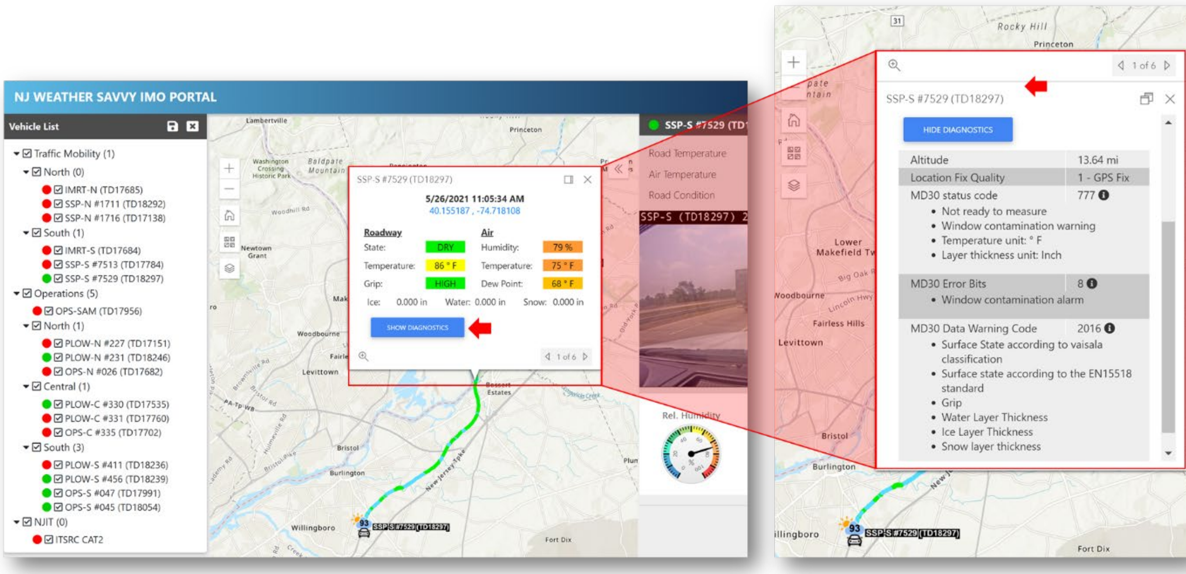


Figure 25. Main page the situational map, vehicle trace, and a data and diagnostics pop-up tooltip (Source: NJIT)

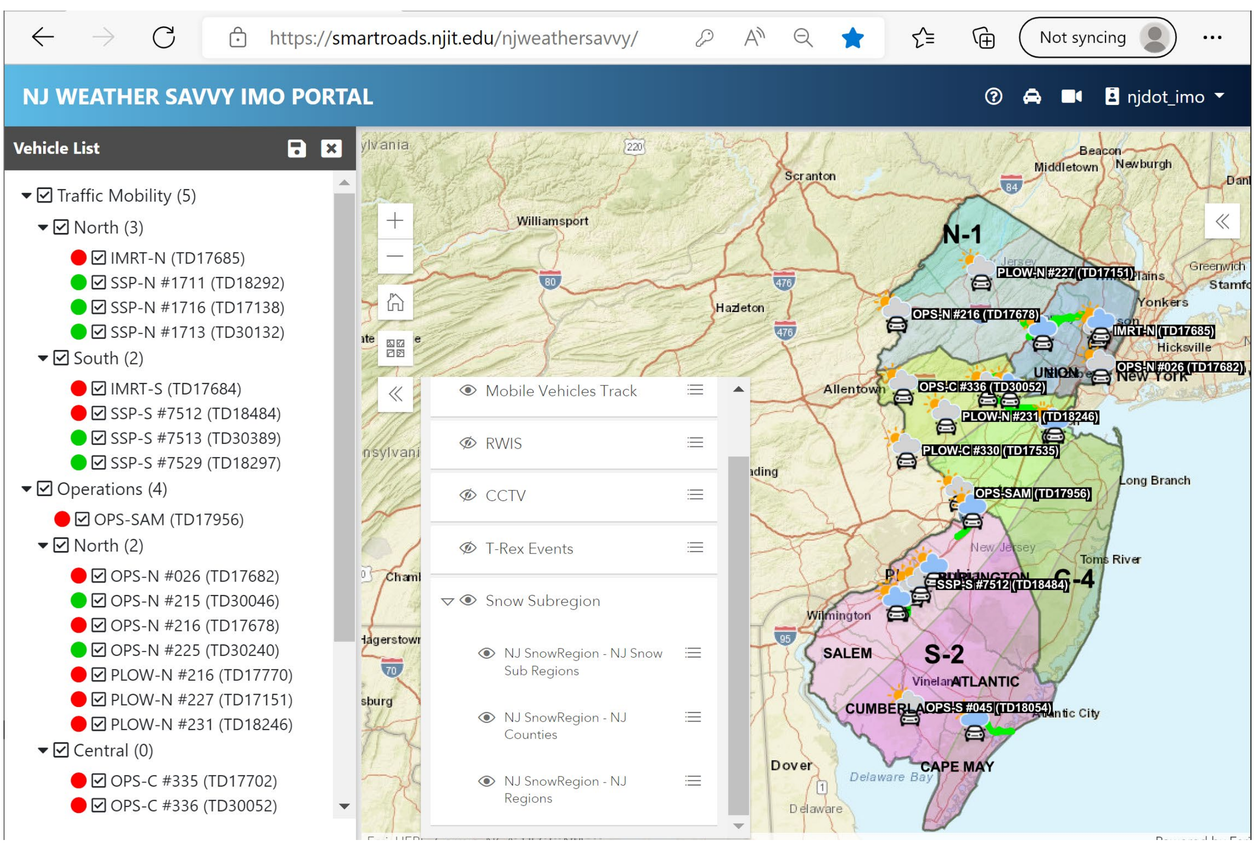


Figure 26. Main page with a list of map layers that can be turned on and off, showing the layer of NJDOT Operations (Snow) regions and subregions (Source: NJIT)

Figure 27. Toggling between the dashboard view and full-screen view of the video using the toggle overlay button in the lower right corner of the view (Source: NJIT)

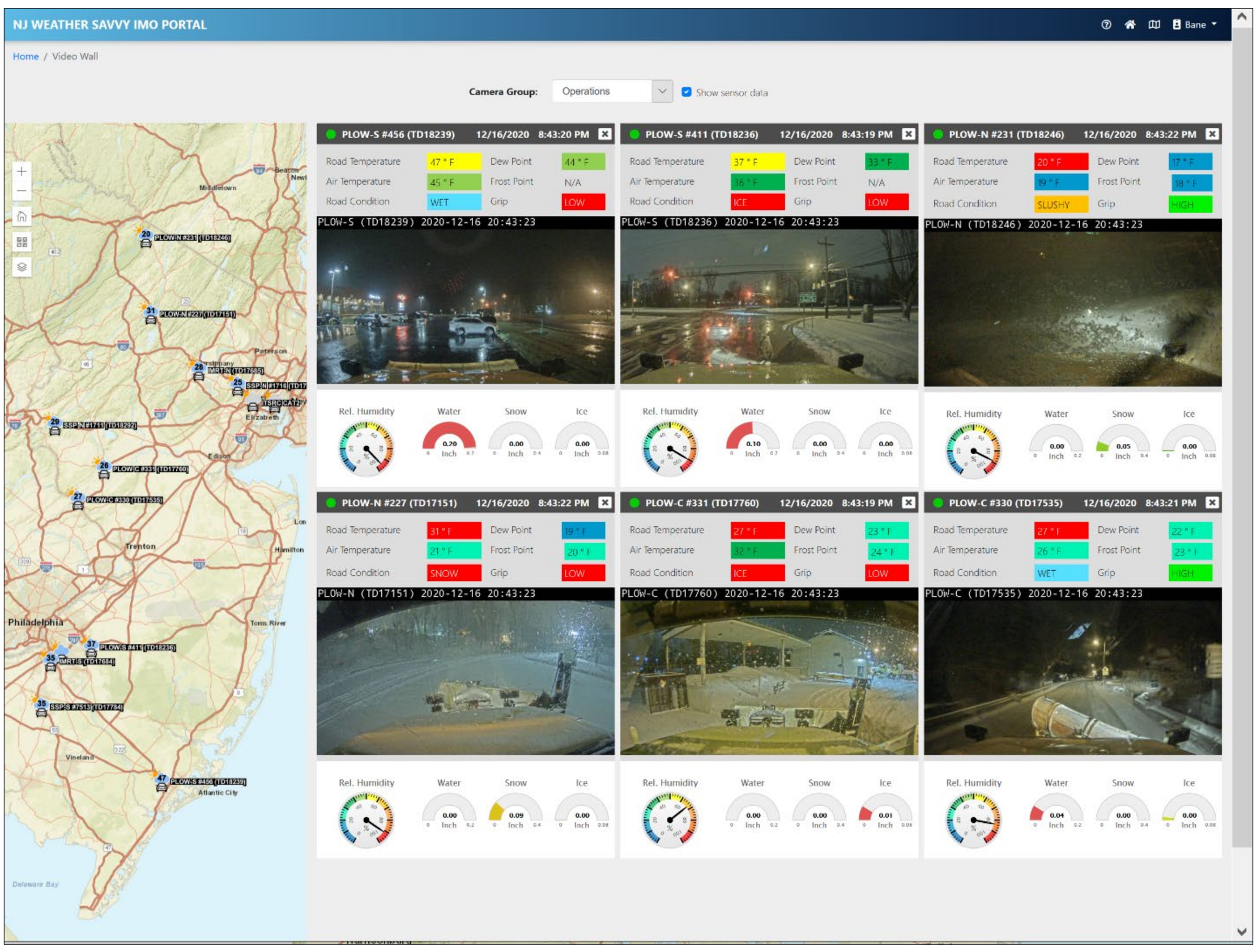


Figure 28. Virtual video wall (Source: NJIT)

7.2 Web Application Security Features

Given that the web-based application provides access to data collected from State vehicles, which is then used by State officials for traffic operations and management purposes, the security features of the application have been of great concern. Besides user authentication, another layer of security was added through implementation of Web Application Firewall (WAF), in response to the request from the State of New Jersey Office of Information Technology (OIT). WAF firewall boosts security and protects the web applications and servers from the cyber-attacks by applying a set of firewall rules. Following the OIT/NJDOT protocols, the Weather-Savvy server was configured to reroute all the traffic to the OIT's Imperva WAF server and only accept traffic coming from the Imperva's IP addresses. The NJIT network administrators applied the new firewall rules to forward any traffic for the Weather-Savvy server to the WAF server. NJIT also configured the firewall rules to only allow traffic coming from Imperva IP addresses.

Since the application and database servers are hosted at NJIT, they are also subject to NJIT firewall protection, anti-malware, anti-spyware, and other cybersecurity measures and protocols implemented and maintained by the NJIT Information Technology division. This provides additional layer(s) of security for the data and the application.

The application site was onboarded and tested to ensure that WAF was not blocking any features (functionalities) or legitimate activity in the Weather-Savvy application. Several configurations were changed to ensure compatibility. A password reset feature was also revised to comply with the WAF security requirements. It had been set up to send out an automatic email to the users who requested to reset their passwords; the email is sent from an e-mail account that was created specifically for the Weather-Savvy application.

8 OBSERVED PERFORMANCE IMPROVEMENTS

The performance improvements observed during the pilot project can be summarized as follows:

- **Proactive Management** – The video feed from on-board video cameras and road weather data from weather sensors has provided information needed to proactively support the Department's road maintenance and mobility management activities, as well as management of vehicle fleet resources. Efficient deployment of both personnel and vehicle fleet, as well as winter contract vehicles to locations affected by adverse weather is critical to improving mobility and safety of the transportation system.

- **Better Data Collection and Accuracy** – The mobile observations obtained from in-vehicle sensors expanded the coverage of the roadway network with road weather data beyond stationary RWIS sensors. The data collected from mobile sensors (MRWIS) was used to evaluate accuracy of RWIS sensors, and it could be used to calibrate the RWIS air temperature and pavement temperature sensors.

- **Stronger Collaboration Across Agencies** – The video monitoring and road weather sensor data were provided to traffic operations, roadway maintenance, and emergency response and management units, ensuring that they all have a common situational awareness of the current road weather conditions and collaborate in developing and executing appropriate response. Working together strengthens the relationship between various entities within the NJDOT that are often needed on day-to-day activities, and especially during weather-related and other emergencies. This was apparent during several winter storms, with positive feedback from Operations managers and TOC operators including one stating, "I wish we had these on every vehicle".

- **Improved Safety** – The geocoded and timestamped road weather data collected from the vehicle-sensors was stored in a database and is available for review and analysis for significant events as part of post-event analysis and evaluation.

- **Enhanced Pre- and Post-Event Pavement Treatment Strategy** – The real-time observations provide the information needed to dynamically determine the effectiveness of treatment strategies and proactively select and deploy the most appropriate pavement treatment options. While direct actionable feedback has not been implemented in this pilot deployment project, this is considered as the next step in system operations. Either through a decision support system, or by directly feeding the data into the salt spreader controller, the data collected from the MRWIS sensors can be used to calculate the parameters for determining the type, amount, and timing of roadway treatment during the winter weather events.

9 WEATHER-SAVVY VEHICLE USAGE AND ACTIVITY SUMMARY

The analysis of vehicle activity was conducted using the data collected from the instrumented NJDOT Weather-Savvy vehicles during the 2021-2022 winter season, between 25 September 2021 and 25 April 2022 (seven months). The analysis is based on the "status reports" transmitted by the mobile routers installed in each vehicle (referred to in this analysis as "vehicle systems"). The routers transmit the "status reports" in response to so-called "heartbeat" pings once every 15 minutes while the routers are active (i.e., powered and having communication signal). During the 7-month analysis period, a total of 110,888 records have been generated by 24 vehicle systems (Figure 29), with most individual activity recorded by the SSP-South vehicles. In addition to the "heartbeat" activity response, the status reports also include the current vehicle location (i.e., GPS coordinates) and cellular signal quality parameters. Thus, it is possible to plot on a map the locations of vehicle systems based on their status reports, as shown in Figure 29. Around 7% of analyzed records did not have valid latitude/longitude information (a total of 7,734), which may be due to a loss of GPS fix.

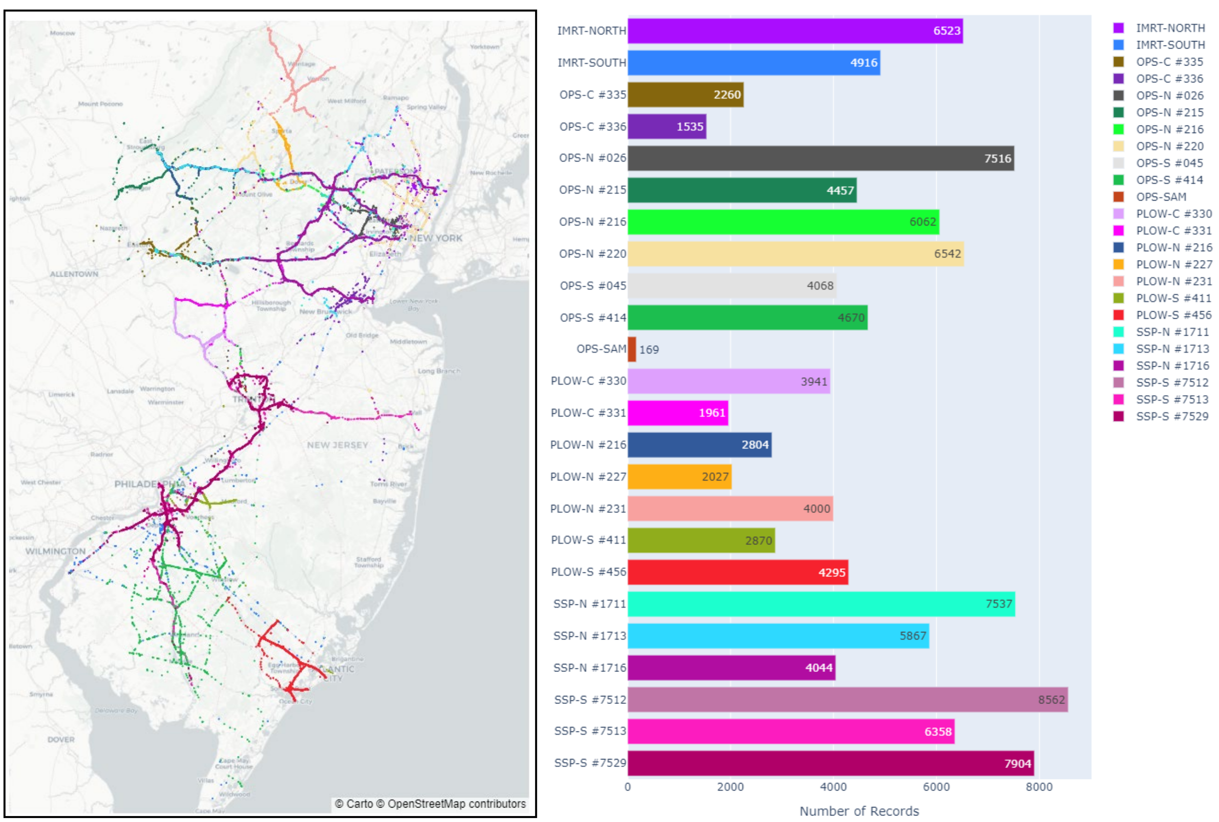


Figure 29. Records generated by each device during the analysis period, 25 September 2021 – 25 April 2022 (Source: NJIT)

Over the 7-month analysis period, the highest activity across the 24 vehicle systems was in the month of January, followed by March and February (Table 4). The higher level of activity in the month of January can be attributed to greater number of snowfall and freezing rain events than in other months of the 2021-2022 winter season (4 major snow events were recorded in January 2022, with an average of 5-inch snowfall accumulation per event). Typically, maintenance vehicles are in operation longer hours, including overtime service, during the winter weather emergencies.

Table 4. Vehicle activity records (15-minute status reports) generated per month

Month	SEP-2021 (5 days)	OCT-2021	NOV-2021	DEC-2021	JAN-2022	FEB-2022	MAR-2022	APR-2022 (25 days)
Records	2758	13373	14033	13758	21560	17164	18035	10207

The consistency of Weather-Savvy vehicles usage during the analysis period is illustrated in Figure 30 and Figure 31. In Figure 30, each dot in the graph represents a vehicle system with the total number of active days and active hours along the x-axis and y-axis respectively, while the size of the dots in the graph is scaled to reflect the total number of records generated by the vehicle systems during the analysis period. The total number of hours per vehicle is calculated by accounting for each hour in which the vehicle system reported at least one status record, while the total number of active days is calculated by summing up all days in which the vehicle systems reported at least one status record. Among all vehicle systems, OPS-N #215 had the most days of activity: 199 out of 213 days in the analysis period. Overall, 15 vehicle systems had been active for more than 110 days during the winter season (more than 50% of time).

The graphic in Figure 31 shows the month-to-month level of activity per vehicle system, considering the corresponding number of status report records per month. The figure reveals relatively higher activity of the SSP vehicles, which is to be expected given their daily service along the assigned beats. The figure also reveals that the vehicle system SSP-N #1711 was offline since early January (i.e., no status reports were recorded for this vehicle system since January 6th), which is consistent with the fact that the vehicle had downtime for repair due to a damage caused in a motor-vehicle crash in early January.

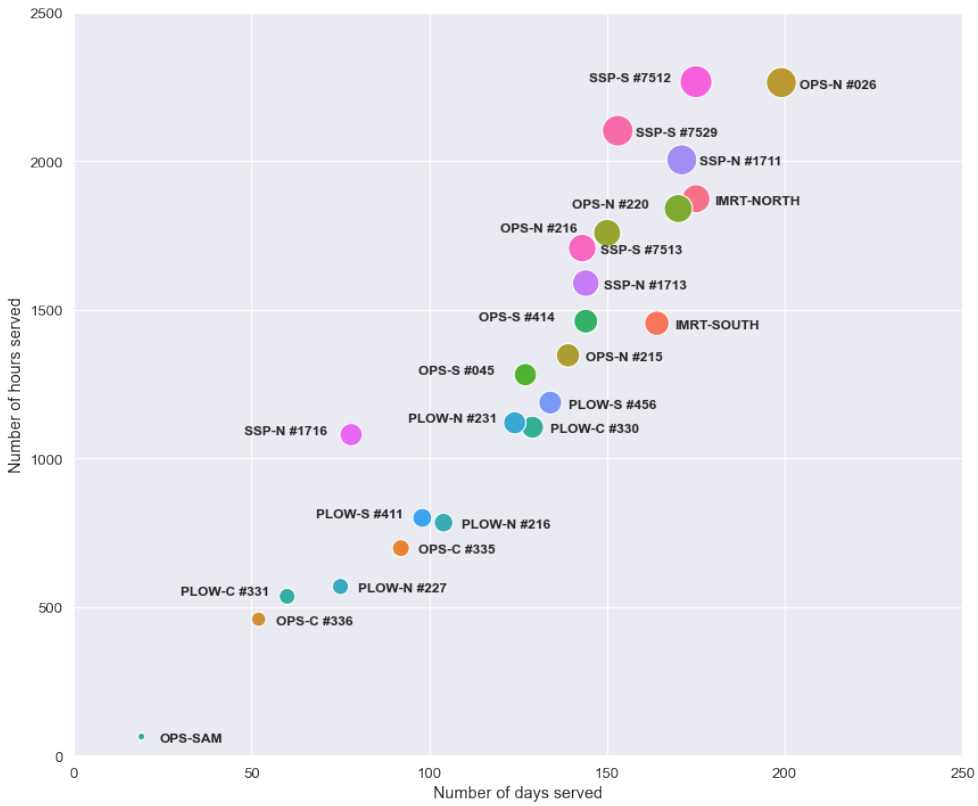


Figure 30. Number of days vs. number of hours served by each system (Source: NJIT)

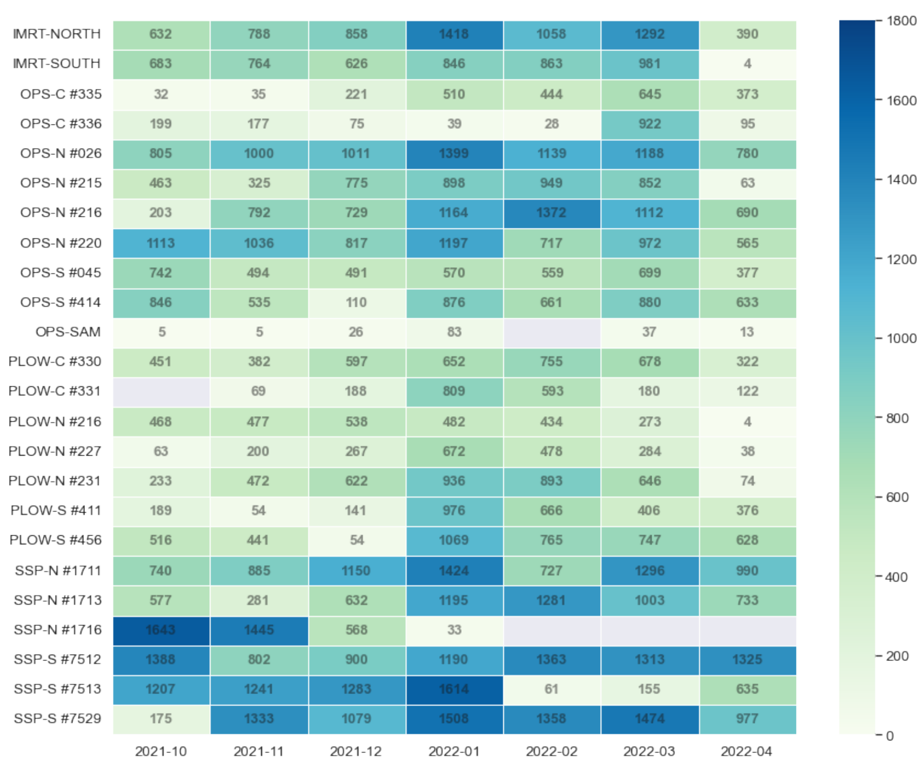


Figure 31. Number of records generated per system per month (Source: NJIT)

In terms of roadway coverage, the Weather-Savvy vehicle systems were active on almost all major highways across New Jersey. The most activity was recorded along I-80, closely followed by I-287, and the third route with the most "activity" was I-295 (as shown in Figure 32). Besides the interstate highways, other major highway arterials are also among the top 15 roadways with most status report records, including US 46, US 40, US 202, NJ 10, NJ 42, NJ 23, and NJ 47.

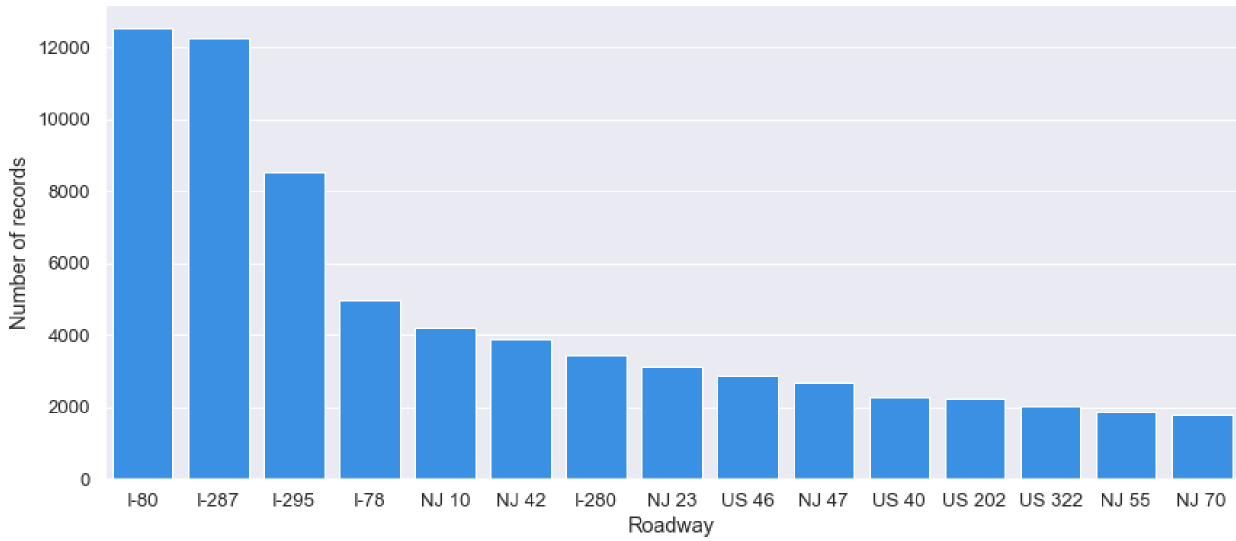


Figure 32. Top roadways with respect to vehicle system activity (Source: NJIT)

Another important aspect of the Weather-Savvy vehicle system effectiveness is their activity during the winter weather events. Specifically, time spent on the road during the weather emergencies. For the purposes of this analysis, three snow events with the greatest snow accumulation were identified during the 2021/2022 winter season. They all occurred in the month of January and lasted a total of five days (January 3, January 6-7, and January 28-29). A total of 5,000 status reports were recorded during these five days, making up 5% of all activity records for the 7-month analysis period. The summary of the five-day vehicle system activity during these winter storms in January 2022 is shown in Figure 33. As can be observed in the figure, all 24 vehicle systems were active, but they covered varying times of day. The heatmap graph in the lower part of the figure shows the number of records generated by vehicle systems per hour of the day. It should be noted that there can be at most 20 records per vehicle system generated for a given hour of the day over a five-day period[2]. Thus, as can be observed, half of the vehicles remained active from 6AM to 8PM for at least 3 days (i.e., 2 snow events). A few of them remained "on the road" throughout these three snow events. As expected, the most activity was recorded for the SSP and PLOW vehicle systems, as the corresponding vehicles are operated in shifts and can be in service 24 hours per day, if and when needed. The one exception is SSP-N #1711, which was out of service after January 6th, as previously explained.

[2] Considering there could be at most four reports in an hour (one every 15 minutes), over 5 days of storms that would add up to a maximum of 20 records per vehicle system.

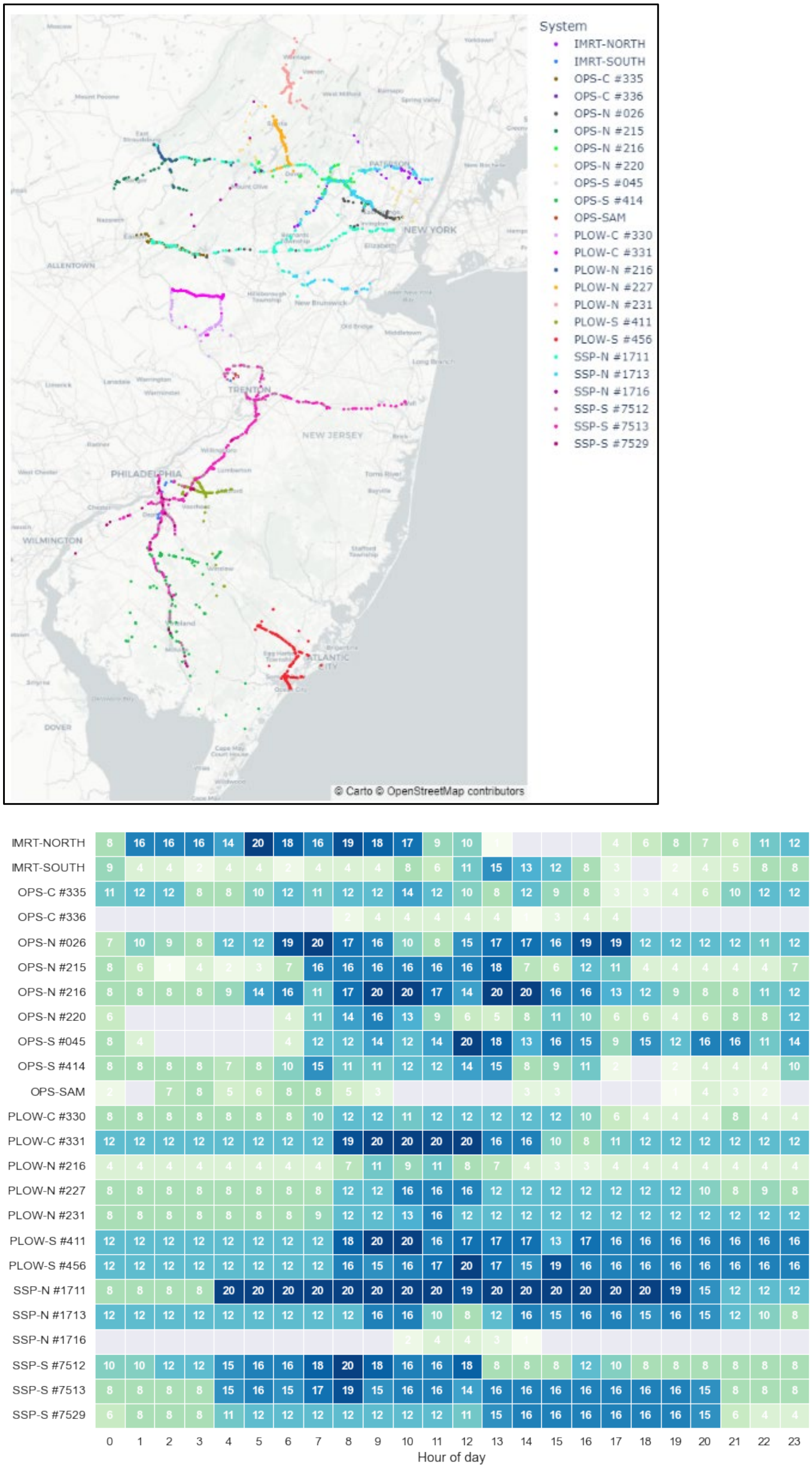


Figure 33. Service coverage during top three snow events (Source: NJIT)

10 EVALUATION OF THE CELLULAR SIGNAL STRENGTH AND QUALITY IN THE PROJECT SERVICE AREA

10.1 Signal Quality Performance in the Project Service Areas

Since the IMO data is broadcasted in real time from the vehicle systems to the back-office data repository[3] via cellular wireless communication, an uninterrupted cellular service in the vehicle systems' operating areas is critical to the system functionality. Thus, evaluation of the cellular signal strength and quality is needed to determine the adequacy and quality of cellular service used for the IMO data broadcast. The evaluation of the cellular signal strength and quality was conducted for the operating areas of the 24 vehicles instrumented to date as part of the Weather-Savvy Roads Pilot Program. The evaluation was based on the status reports received every 15-minutes from the in-vehicle cellular router in response to so-called "heartbeat" pings. As noted in the previous chapter of the report, a total of 110,888 status reports were recorded from 24 vehicle systems between September 25, 2021, and April 25, 2022. The performance of the cellular communication was evaluated based on the two parameters included in the status reports:

- Received Signal Strength Indicator (RSSI) in dB, and
- Network service type.

Based on the collected data, the majority of status records indicated acceptable signal quality, as shown in Figure 34, with 99.5% indicating EXCELLENT or GOOD RSSI levels (overall, 88% had EXCELLENT RSSI). Only about 0.6% of the recorded status reports had FAIR or POOR signal quality measured by RSSI. Plotting the RSSI values for each status report on a map (Figure 35), reveals areas where more attention should be given to signal quality, such as roadway sections along NJ 29 where POOR and FAIR signal quality has been consistently observed.

[3] Currently the IMO system is not storing any data locally on the in-vehicle computer. This will be revisited in the future project iterations and the local data storage may be introduced if needed.

RSSI Values	Signal Strength
> -71 dBm	EXCELLENT
-71 dBm to -85 dBm	GOOD
-86 dBm to -100 dBm	FAIR
< -100 dBm	POOR

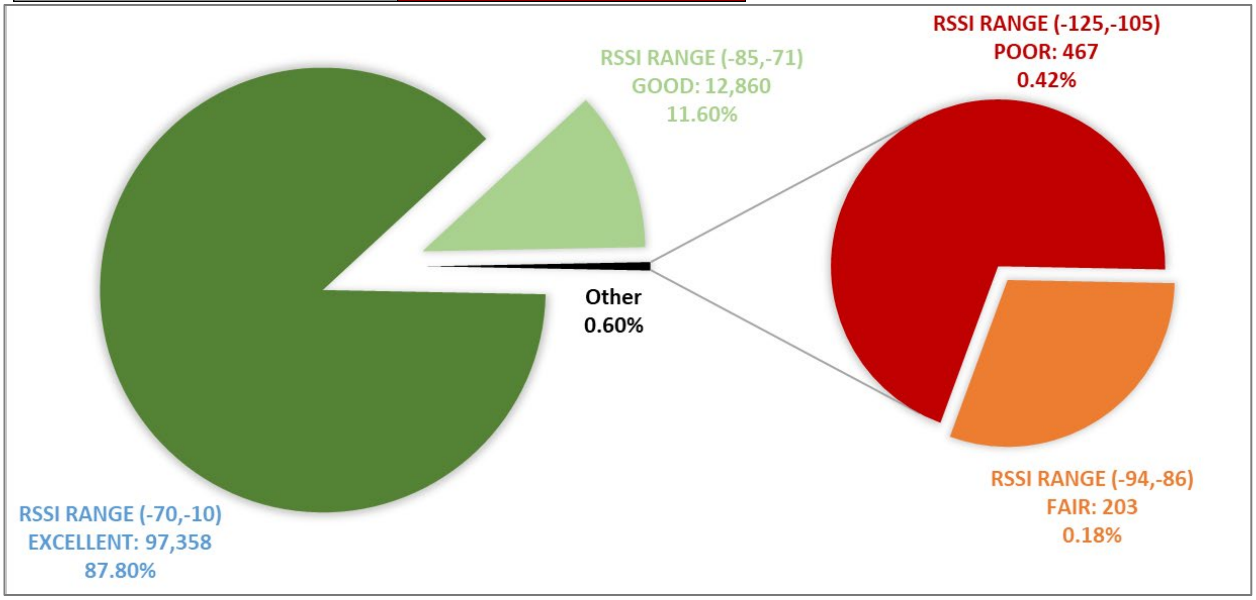


Figure 34. RSSI signal quality breakdown (Source: NJIT)

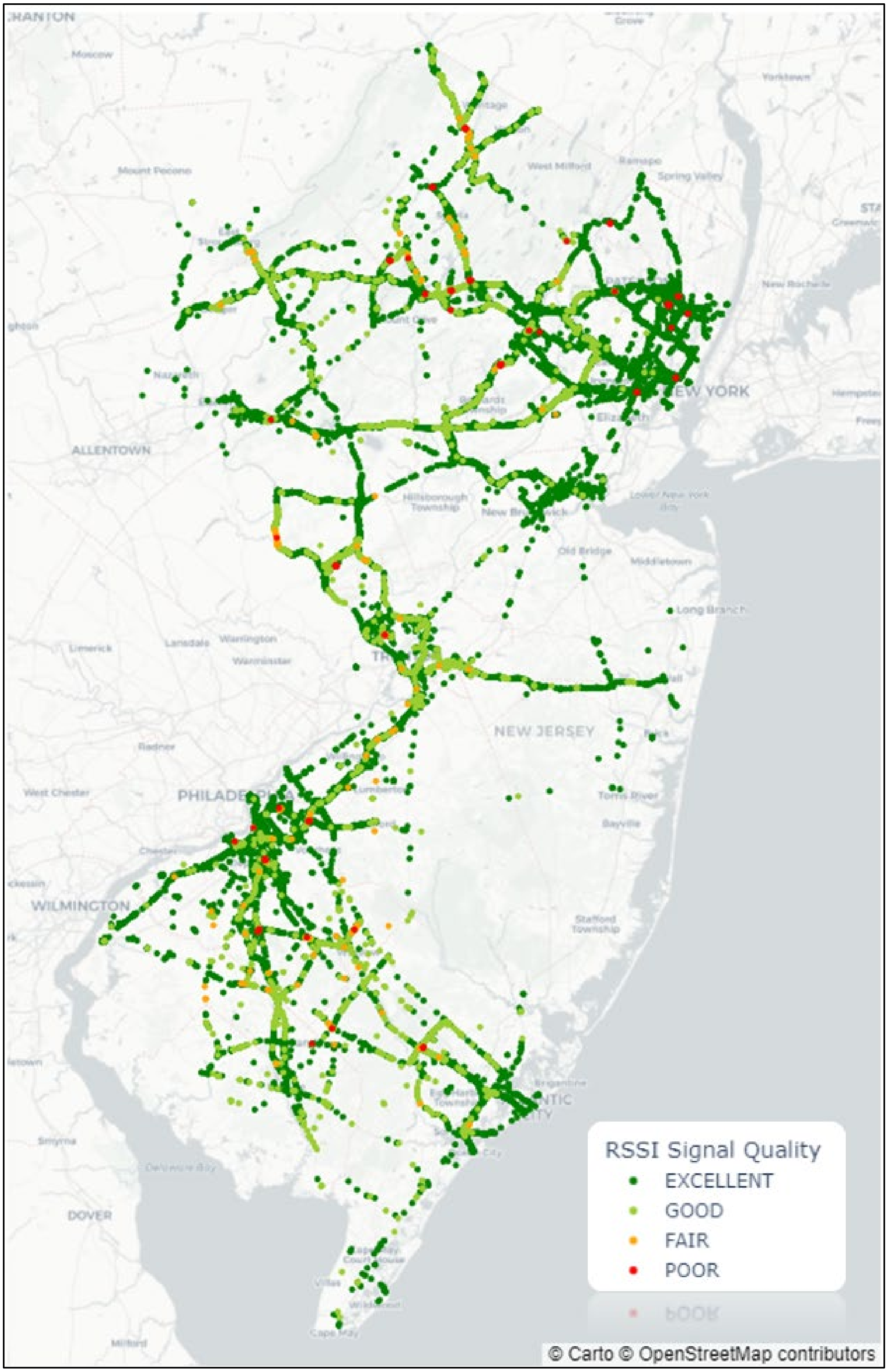


Figure 35. RSSI signal quality (Source: NJIT)

The summary of RSSI by vehicle system is shown in Figure 36. The data indicates that PLOW-N #227 experienced the highest percentage of POOR signal quality in the corresponding service area, followed by IMRT-NORTH. These two vehicle systems operate in the northern part of New Jersey in areas at relatively higher elevations and roadways on rolling terrain. Right behind these two vehicle systems is PLOW-C #330, which operates in a service area that includes sections of NJ 29 where POOR signal quality had been observed.

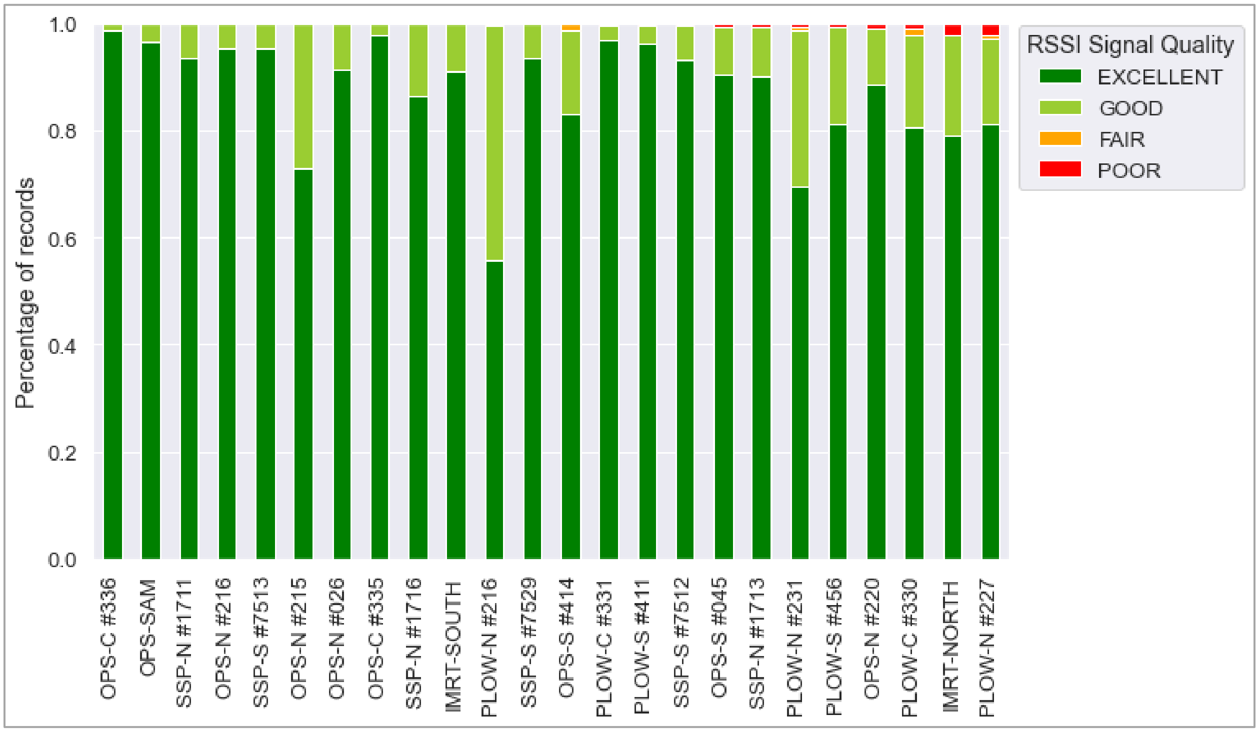


Figure 36. Percentages of RSSI signal quality per system (Source: NJIT)

A more detailed summary of signal quality by vehicle system is provided in Table 5. The table lists the number of status reports generated by each vehicle system for each RSSI level. It can be observed that IMRT-NORTH vehicle system had the most records of POOR signal quality (145), about 2.2% of all recorded reports from this vehicle system. The vehicle systems reporting the most records of FAIR signal quality were OPS-S #045 and PLOW-C #330, with 51 and 38 records respectively. It should be noted that the vehicle system PLOW-C #330 has 83 combined records of FAIR and POOR signal quality, which was about 2% of all records for this vehicle system.

Table 5. Records with different RSSI signal quality levels per system (Source: NJIT)

System	Excellent	Good	Fair	Poor	Total
IMRT-NORTH	5,156	1,221	1	145	6,523
OPS-N #220	5,801	676	9	56	6,542
PLOW-N #227	1,647	323	10	47	2,027
PLOW-C #330	3,174	684	38	45	3,941
SSP-S #7512	7,975	551	1	35	8,562
SSP-N #1713	5,282	550	1	34	5,867
PLOW-S #456	3,495	764	3	33	4,295
PLOW-N #231	2,786	1,156	34	24	4,000
OPS-S #045	3,682	358	5	23	4,068
PLOW-S #411	2,758	100	1	11	2,870
OPS-S #414	3,881	732	51	6	4,670
PLOW-C #331	1,901	52	2	6	1,961
SSP-S #7529	7,393	499	10	2	7,904
IMRT-SOUTH	4,481	428	7		4,916
PLOW-N #216	1,561	1,236	7		2,804
OPS-N #026	6,863	647	6		7,516
SSP-N #1716	3,492	548	4		4,044
SSP-S #7513	6,070	284	4		6,358
OPS-N #215	3,257	1,197	3		4,457
OPS-N #216	5,778	281	3		6,062
OPS-C #335	2,211	47	2		2,260
SSP-N #1711	7,036	500	1		7,537
OPS-C #336	1,515	20			1,535
OPS-SAM	163	6			169

To get a more aggregate view of recorded RSSI signal quality, a map was created with 5000ft-by-5000ft grid, with each grid cell color-coded based on the average RSSI[4] obtained from the vehicle systems (see Figure 37). The map reveals that the Philadelphia and New York City metropolitan areas have the best signal quality, whereas mountainous areas to the northwest, sections of NJ 29 along Delaware River, and to the southern part of New Jersey have areas with GOOD to FAIR signal quality.

[4] The average RSSI in each grid cell is calculated as an average of all RSSI values recorded by the vehicle systems while traversing the corresponding grid cell anytime during the 7-month evaluation period, from September 25 2021 to April 25 2022.

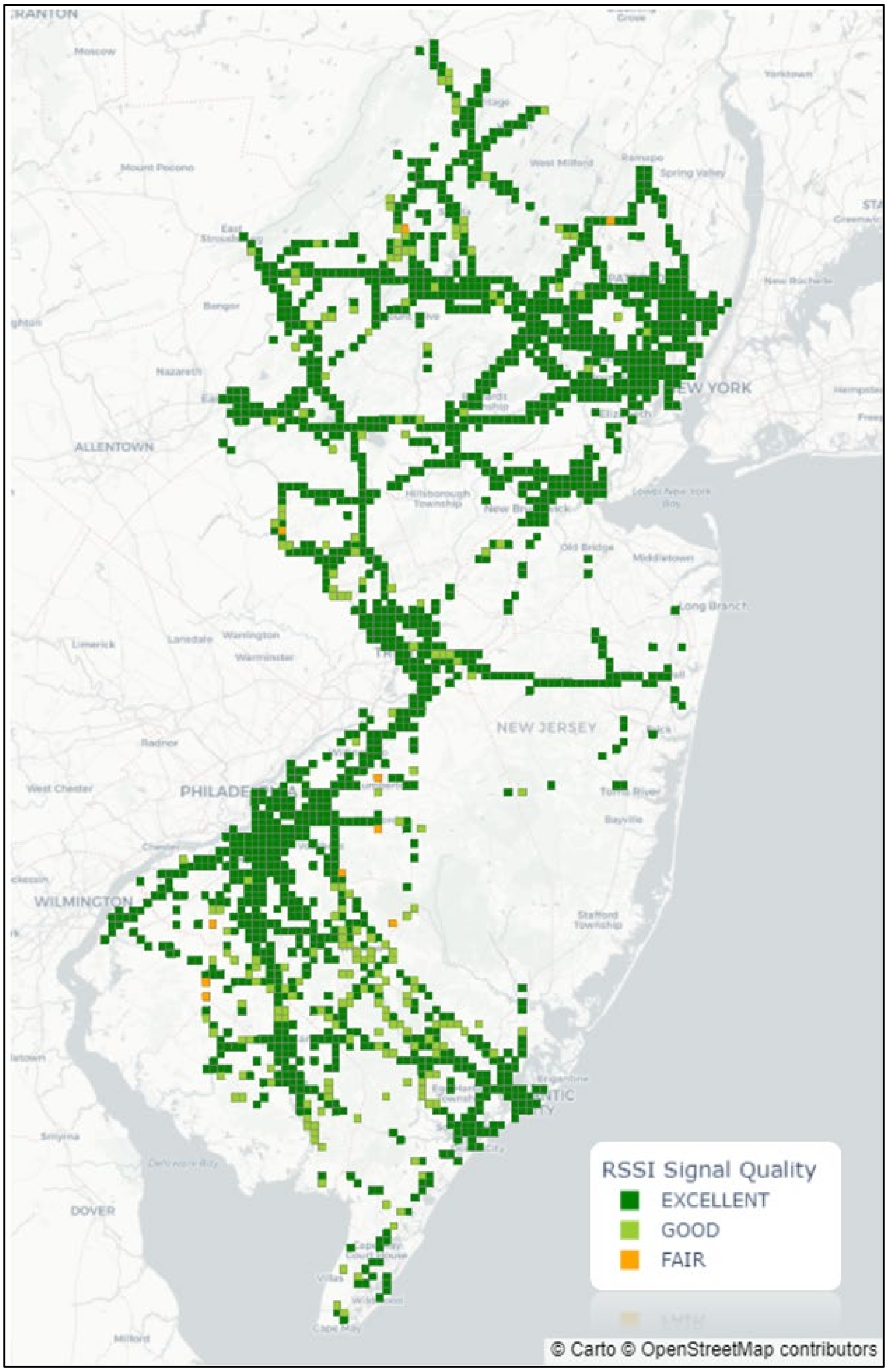


Figure 37. Averaged RSSI quality per 5000ft-by-5000ft grid (Source: NJIT)

The areas of underperforming signal quality are further analyzed by identifying all map grid cells with at least one POOR signal quality record. Each such cell is plotted on the map in Figure 38 along with the corresponding stacked bar-graph of signal quality levels, and the value representing the total number of records. The figure conveys similar spatial pattern of signal quality to the one seen in Figure 37: grid cells with at least one POOR signal quality record are mostly grouped in the northern and southern part of New Jersey, and along NJ 29. Most grids with a higher percentage of POOR signal quality records also have very few records in total, which could be an indication that those cells have areas with no signal at all.

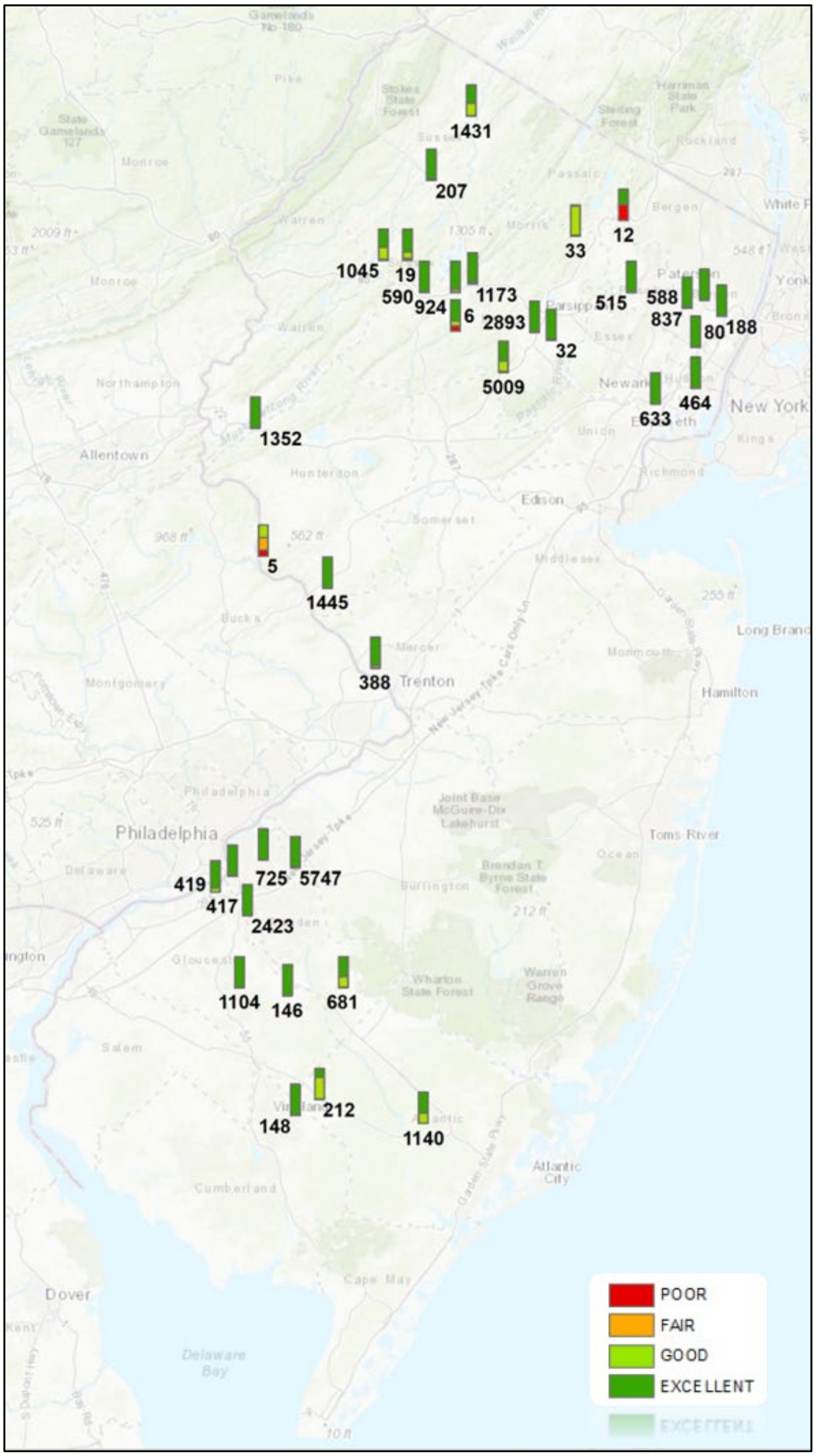


Figure 38. RSSI signal quality levels for grids experiencing POOR signals (Source: NJIT)

The locations with the greatest number of observed POOR signal quality records were mapped for further analysis. Close examination found that many of signal records were generated by vehicles in the parking lots of NJDOT yards, as shown in Figure 39. For instance, the highest number of POOR signal quality records is found in a parking lot of NJDOT SSP yard in Harding, near I-287. A large number of such records had the GPS location in NJDOT maintenance yards in Rockaway (near NJ 15), West Amwell (near NJ 179), and Cherry Hill (near I-295). Overall, the signal quality tends to be GOOD or EXCELLENT along the service routes of the vehicle systems stationed at these yards, so it is assumed that the POOR signal quality records may have been generated during the system startup (while establishing communication).

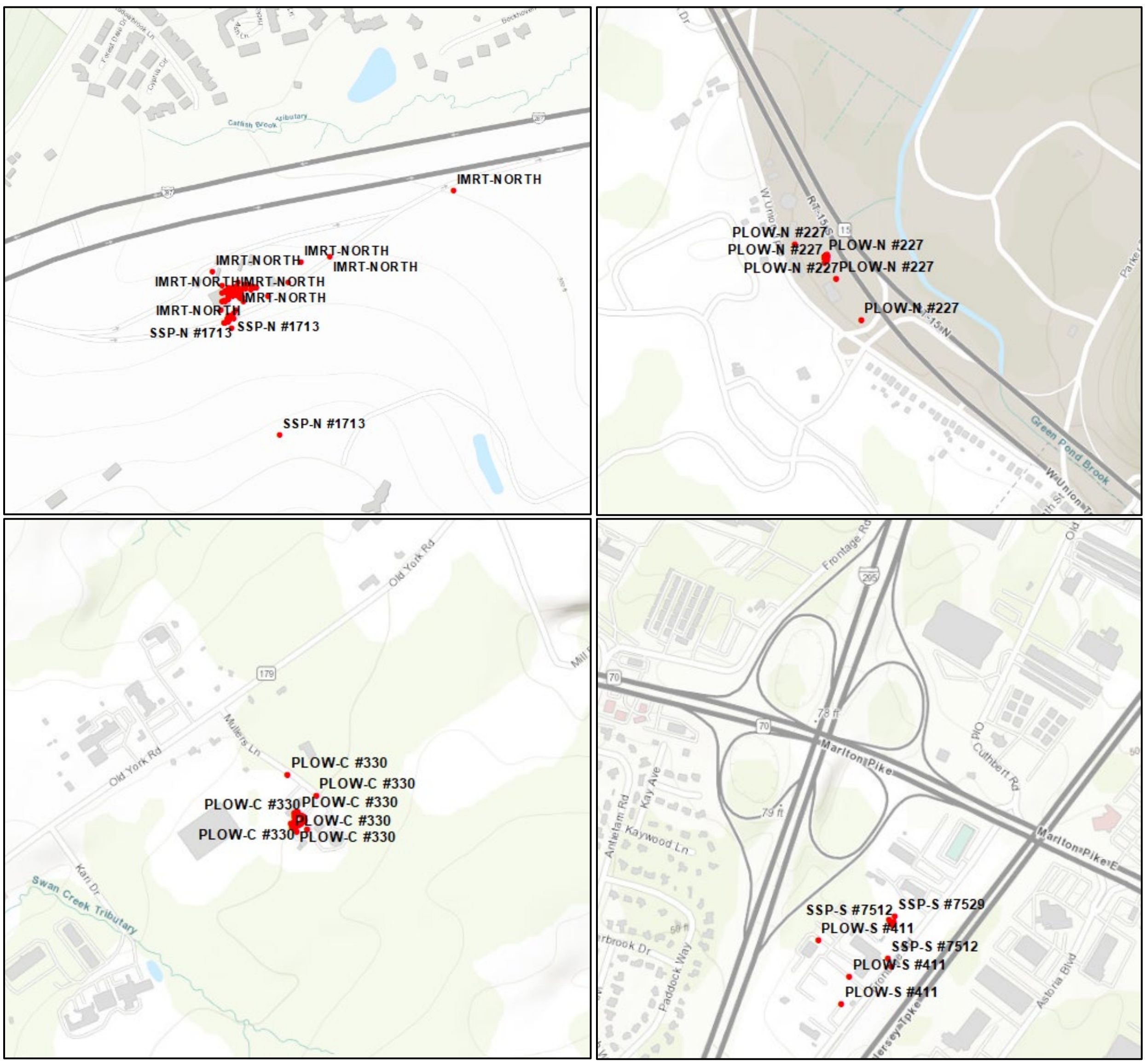


Figure 39. Top 6 clusters with POOR signals (Source: NJIT)

10.2 Analysis of the Network Type and Network Operator Performance

The status reports also included the detected network type and the network operator for each record. Based on the cellular service plan that was used for the IMO vehicle systems, the network operator should be FirstNet, and the network type should be LTE (or more advanced LTE-ADVANCED-PRO). However, in a small number of records the network type is found to be UMTS or "Undefined"[5] – see Table 6. As can be observed in the table, attention should be given to the service area of vehicle system SSP-N #1716, which has the highest number of records transmitted through UMTS network, and PLOW-C #331, which has the highest ratio of records with "Undefined" network type.

Table 6. Number of records with different network service type (Source: NJIT)

System	LTE	LTE-ADVANCED-PRO	UMTS	Undefined	Total
SSP-N #1713	3,556	2,163	116	32	5,867
OPS-S #414	562	4,074	33	1	4,670
OPS-N #216	787	5,246	29		6,062
IMRT-SOUTH	278	4,615	22	1	4,916
OPS-N #220	1,930	4,571	21	20	6,542
SSP-S #7512	4,890	3,572	17	83	8,562
OPS-N #026	946	6,555	15		7,516
IMRT-NORTH	5,102	1,386	11	24	6,523
OPS-N #215	388	4,061	8		4,457
PLOW-C #330	2,598	1,319	7	17	3,941
SSP-N #1716	218	3,820	6		4,044
OPS-S #045	2,468	1,589	2	9	4,068
SSP-N #1711	729	6,806	2		7,537
PLOW-C #331	1,518	308		135	1,961
PLOW-S #411	2,148	643		79	2,870
PLOW-N #227	792	1,220		15	2,027
OPS-C #335	219	2,041			2,260
OPS-C #336	341	1,194			1,535
OPS-SAM	42	127			169
PLOW-N #216	382	2,422			2,804
PLOW-N #231	1,173	2,827			4,000
PLOW-S #456	1,341	2,954			4,295
SSP-S #7513	279	6,079			6,358
SSP-S #7529	416	7,488			7,904

Similarly, in terms of network operator, in about 0.6% of records the network operator was "Undefined"[6] as opposed to FirstNet (Table 7). Among them, PLOW-N #231 and PLOW-S #456 had the highest number of records with "Undefined" operator type.

The locations of the status reports with recorded UMTS or "Undefined" network type are shown on the map in Figure 40. The locations of the status reports with "Undefined" network operator

[5] "Undefined" network type = no indication of the network type in the router status report.
[6] "Undefined" network operator = o indication of the network operator is the router status report.

are shown on the map in Figure 41. It can be observed that these locations (in both figures) generally match the locations with FAIR or POOR values of RSSI.

The network type and operator used by the IMO vehicle systems should be further monitored and discussed with the cellular service provider to determine if and how this affects the reliability and quality of the data communication. It should also be investigated whether any loss of signal is experienced at the locations with FAIR or POOR RSSI, which can only be captured by recording the signal quality on the routers during the vehicle system operation. The possible causes of the occurrence of POOR, FAIR or lost signal should be discussed with the service provider, as well as any corrective action as applicable.

Table 7. Number of records with different network operators (Source: NJIT)

System	FIRSTNET	Undefined	Total
PLOW-N #231	3,880	120	4,000
PLOW-S #456	4,193	102	4,295
SSP-N #1713	5,781	86	5,867
SSP-S #7512	8,513	49	8,562
OPS-S #045	4,021	47	4,068
PLOW-N #227	1,986	41	2,027
PLOW-S #411	2,834	36	2,870
PLOW-C #331	1,927	34	1,961
IMRT-NORTH	6,502	21	6,523
OPS-N #220	6,525	17	6,542
OPS-N #026	7,502	14	7,516
PLOW-N #216	2,798	6	2,804
SSP-N #1711	7,531	6	7,537
OPS-C #335	2,255	5	2,260
OPS-N #215	4,452	5	4,457
OPS-N #216	6,057	5	6,062
PLOW-C #330	3,936	5	3,941
SSP-S #7513	6,353	5	6,358
OPS-S #414	4,666	4	4,670
IMRT-SOUTH	4,913	3	4,916
OPS-C #336	1,533	2	1,535
SSP-S #7529	7,902	2	7,904
SSP-N #1716	4,043	1	4,044
OPS-SAM	169		169

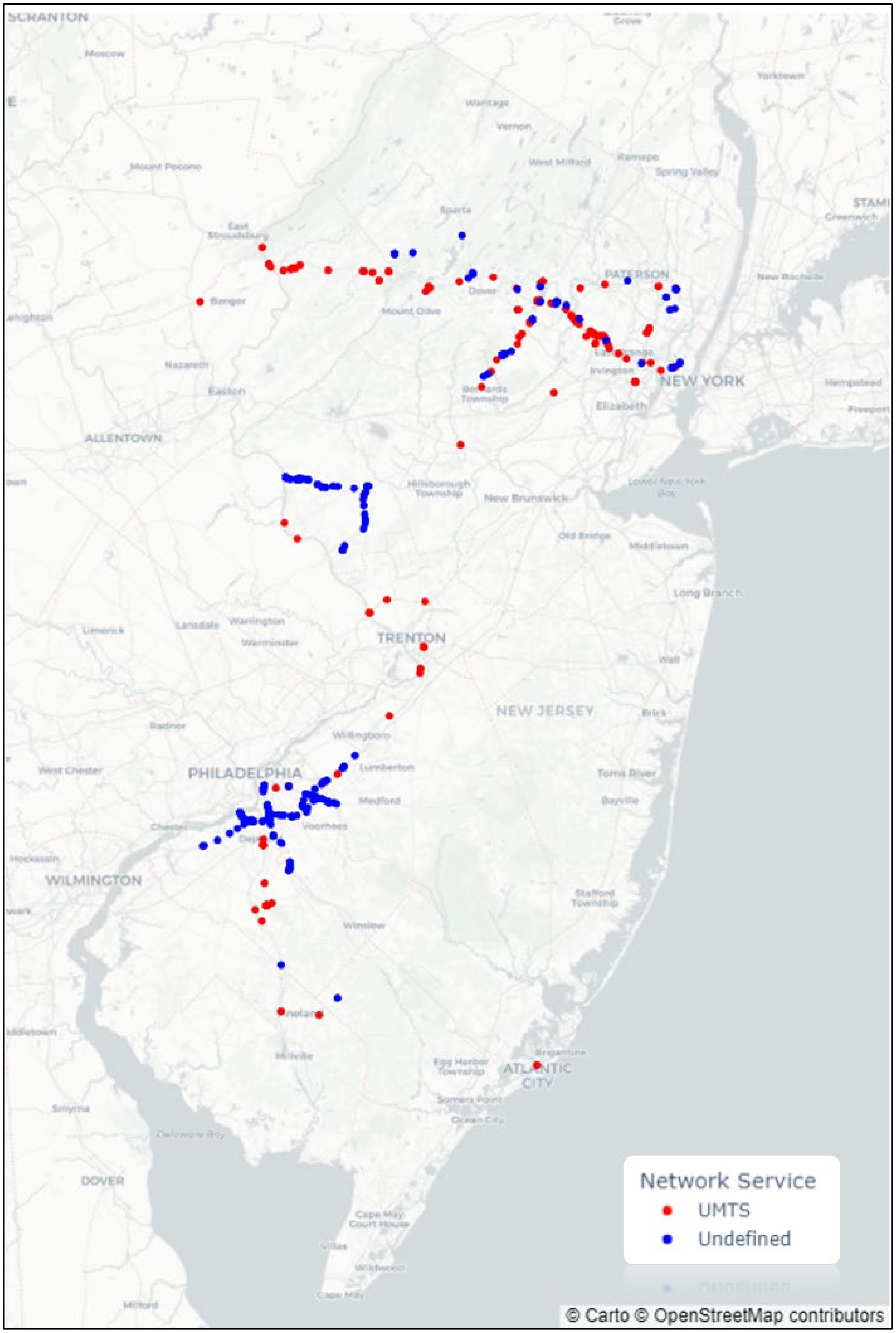


Figure 40. Locations of status reports with UMTS or undefined network service (Source: NJIT)

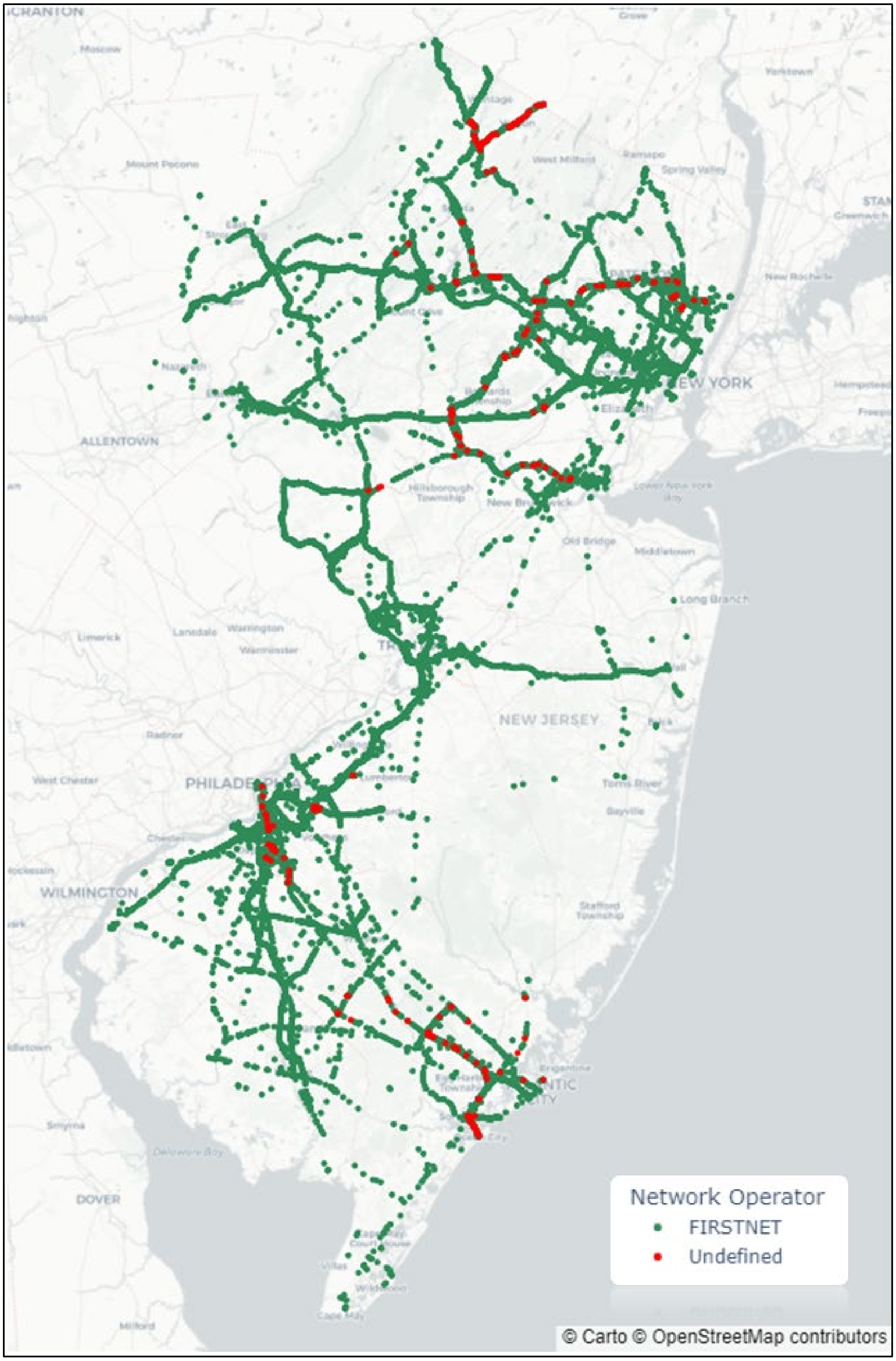


Figure 41. Locations of status reports with undefined network operator (Source: NJIT)

11 COMPARISON BETWEEN RWIS AND MRWIS

11.1 Background and Description of the Comparison Method

One of the intended benefits of the MRWIS is to augment, and in the future possibly replace the stationary RWIS units installed on the roadside. To assist in assessing the feasibility and applicability of such strategic decisions, the road weather data collected during the analysis period (from September 25, 2021 to April 25, 2022) was compared to the data collected by the stationary RWIS units. The resolution of MRWIS recordings is one record every 5 seconds (frequency of 12 per minute), while the temporal resolution of RWIS recordings is one every five minutes (frequency of 0.2 per minute). To make proper comparison between the two datasets, the records from two different sources had to be matched both in spatial and temporal scale.

In total, 16 million MRWIS records were produced by the 24 Weather-Savvy vehicle systems that were operational during the analysis period. Out of this number, about 10 million records were validated to contain complete and correct road weather information (i.e., the records with incomplete road weather data, data warning or data error flags, were excluded). The data sample used in the analysis is illustrated in Figure 42. The map on the left side shows the trajectories of the vehicle systems that provided road weather data, where each color represents a trajectory of a specific vehicle system. It can be observed that the trajectories covered most of the major roadways in the State within NJDOT jurisdiction, thus producing valuable information for both real-time road surface condition monitoring and historical data analysis. The map on the right side shows the locations of stationary RWIS that were used in the analysis. The main criterion for consideration of RWIS stations in the analysis was the confidence level of the reported road weather data – only the road surface temperature data that was reported at the 100% confidence level was included in the analysis. A total of 15 RWIS stations, shown in the map, were reporting surface temperature recordings at a 100% confidence level.

The road surface temperature data recorded at the RWIS stations was downloaded from the FHWA Weather Data Environment (WxDE) online portal[7], which hosts real-time and historical RWIS reports across the United States, including in New Jersey. Each RWIS station is displayed on a map within the WxDE website~~, and~~. The data recorded at each RWIS station can be viewed by clicking on the RWIS map icon and accessing the data display window (a sample is shown in Figure 43). As can be seen in the figure, a set of sensors is reporting the values of different parameters at different confidence levels. Since a confidence level less than 100% may indicate sensor failure, it was decided to only use the data reported with 100% confidence, and focus only on the road surface temperature as the most critical piece of information about roadway condition, when it comes to winter road weather management. It should be noted that some stations may have more than one sensor reporting surface status and temperature.

[7] FHWA Weather Data Environment. Available at: https://wxde.fhwa.dot.gov/wdeMap.jsp?org.apache.catalina.filters.CSRF_NONCE=758EE6E5B5DECD1004508FFC64B160E3

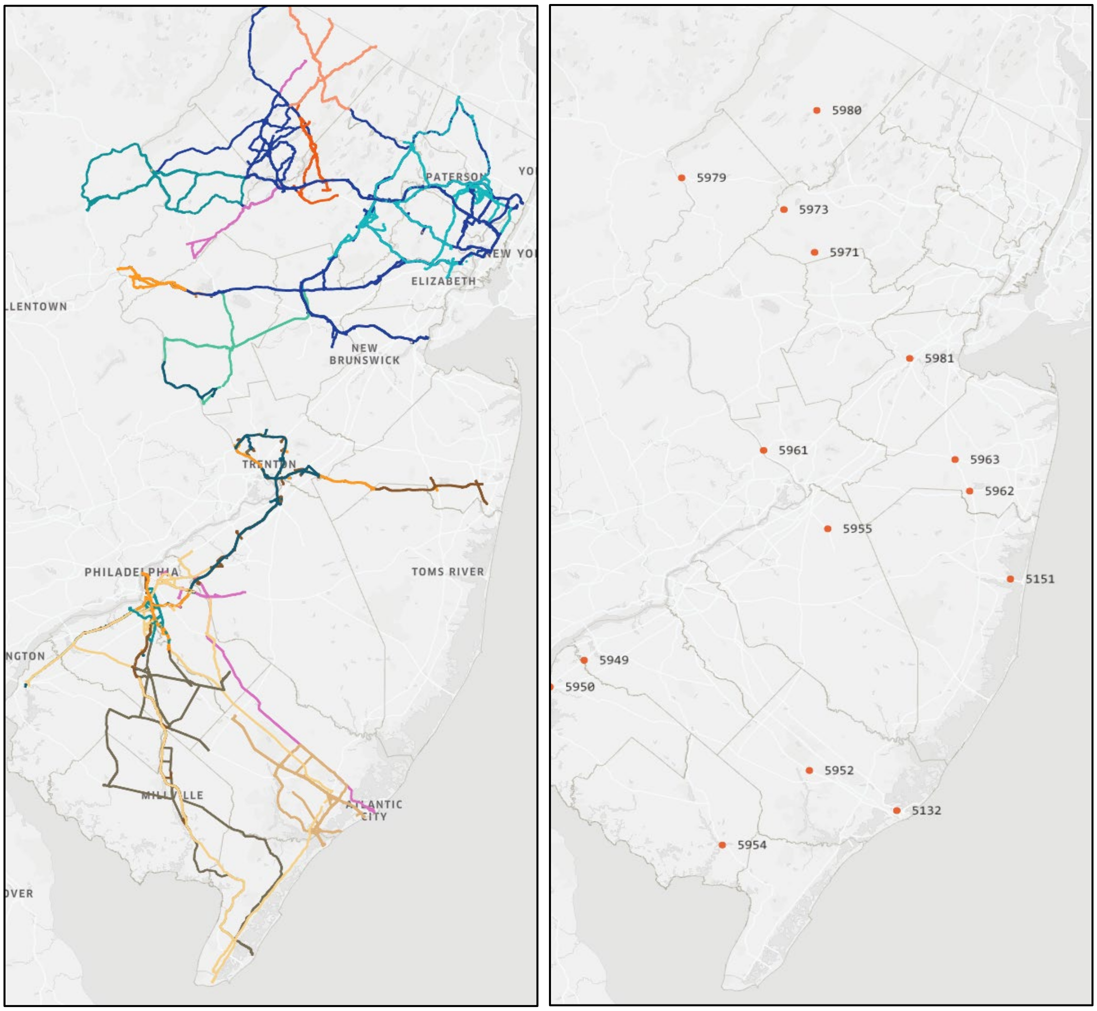


Figure 42. Mobile vehicle recordings in January (left) and RWIS station locations (right) (Source: NJIT)

NJ-010
RT 94 at Paulins Kill River
Lat, Lon: 41.092210, -74.689290
Elevation: 168

Timestamp	Observation Type	Ind	Value	Unit	Conf	Complete	Manual	Sensor Range	Climate Range	Step	Like Instrument	Persistence	IQR Spatial	Barnes Spatial	Dew Point	Sea Level Pressure	Precip Accum	Model Analysis	Neighboring Vehicle	Vehicle Standard Dev
01-05 20:40	essPrecipRate	0	0	in/h	100%	●	–	●		●			●	–						
01-05 20:40	essRelativeHumidity	0	5	%	0%	●	–	⊗	–	–		–	–	–	–				–	–
01-05 20:40	essSurfaceStatus	2	4		100%	●	–	●												
01-05 20:40	essSurfaceTemperature	2	79.34	F	89%	●	–	●	●	●	–	●	⊗	–					–	–
01-05 20:40	essVisibility	0	6561.68	ft	100%	●	–	●		●			●	–						
01-05 20:40	windSensorAvgDirection	0	145	deg	100%	●	–	●		●		●								
01-05 20:40	windSensorAvgSpeed	0	0.62	mph	100%	●	–	●	●	●		●	●	–						
01-05 20:40	windSensorGustSpeed	0	0.62	mph	100%	●	–	●		●		●	●	–						

Figure 43. Pop-up window for RWIS reporting (Source: FHWA WxDE**)**

To compare the road surface temperature data between MRWIS and RWIS records, the data had to be matched spatially and temporally. This matching was done as part of data preprocessing, and included the following three steps:

1. Create a set of buffers around each RWIS station, with 100 ft, 500 ft, 1,000 ft, 1500 ft, and 3000 ft radius, respectively.

2. Select MRWIS records generated at roadway locations within each buffer, while removing any vehicle records that were recorded off the roadway.

3. Among the MRWIS records selected in Step 2, keep only the record(s) that were recorded within 2.5 minutes (before or after) the recording at the adjacent stationary RWIS. If multiple MRWIS records matched one RWIS record within the defined spatial and temporal buffer, the record with the least absolute temperature difference is selected for comparison (taking into account local variation).

Figure 44 shows a sample of MRWIS records that are matched to an RWIS station using a 100 ft buffer and 5-minute interval (within 2.5 minutes before or after the data recording at the stationary RWIS). The red dot represents the RWIS station, with the station ID label. The blue dots represent MRWIS records, with the numbers inside the dots representing the difference in measured road surface temperature from the adjacent stationary RWIS.

Figure 44. An example of matched MRWIS and RWIS records using a 100 ft buffer and 5-minute data record interval (Source: NJIT)

11.2 Comparative Analysis of Road Surface Temperature Measurements

After the preprocessing, the road surface temperature (RST) measurements from matched MRWIS and RWIS sensors were compared. The initial analysis of the dataset is based on the 100 ft spatial buffer, but all five predefined buffer sizes were evaluated as part of the sensitivity analysis, in order to ascertain the potential impact of the distance between MRWIS and RWIS station on the RST measurement deviation. It should be noted that the analysis does not distinguish RWIS stations (or their locations), since the focus of the analysis is the difference between the RST measurements using MRWIS and the adjacent RWIS stations. It is understood that the RWIS location may contribute to the difference between these two data sources, as micro-level RST may vary according to local land use, traffic volume, and pavement characteristics. Nevertheless, the scope of this analysis was limited to quantifying the difference between the two datasets, rather than trying to identify possible reasons or factors contributing to the difference, if any.

When applying the 100-ft buffer, a total of 94 unique matching MRWIS and RWIS records were identified. The corresponding RST measurements for the matched MRWIS and RWIS records and the date/time of the recorded data are shown in Figure 45. It can be observed that most of the MRWIS RST measurements deviate slightly from the corresponding (matched) RWIS RST measurements, although for some timepoints large discrepancies were identified, as high as 19 degrees Fahrenheit.

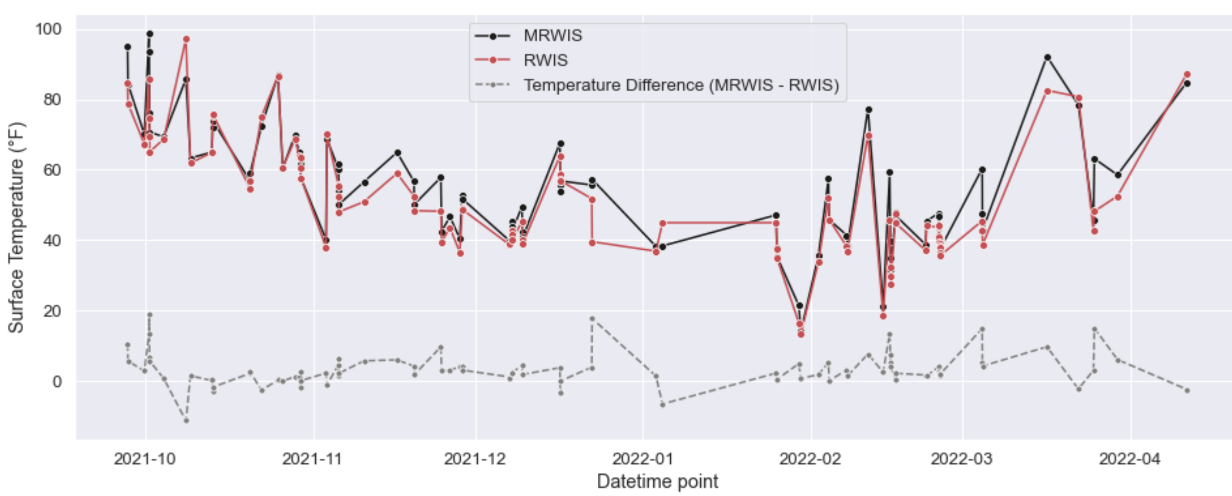


Figure 45. Graphed comparison between the matched MRWIS and RWIS RST measurements (Source: NJIT)

A statistical analysis was conducted to check whether there was a systematic bias in the RST measurements between the two datasets. For this purpose, the Spearman correlation in the data is examined, which evaluates the monotonic relationship between each pair of variables. The analysis revealed a strong positive monotonic relationship between the RST measurements made by MRWIS and RWIS, as illustrated by the coefficients of correlation shown in Table 8. This result is reasonable and desirable. On the other hand, virtually no correlation was found between the RST difference and the RWIS RST measurement, or between the RST difference MRWIS RST measurement. This means that the difference in RST measurements between RWIS and MRWIS is irrelevant to the actual RST value.

Table 8. Spearman Correlation Analysis Results Summary

Correlation	RWIS Temperature	MRWIS Temperature	RST Difference
RWIS Temperature	1.00	0.97	-0.10
MRWIS Temperature	0.97	1.00	0.09
RST Difference	-0.10	0.09	1.00

According to the descriptive statistics, the average difference between the corresponding RST measurements of the MRWIS and RWIS is 3.10 degrees, and the median difference is 2.20 degrees. This means that the MRWIS RST measurements tend to be higher than the corresponding RWIS measurements. Most of the differences are within 5 degrees, but large differences were observed as well, the largest being 19 degrees. As a result, the standard deviation of the difference between the MRWIS and RWIS RST measurements is 4.51 degrees.

Since the average RST difference between the MRWIS and RWIS measurements is calculated from a relatively small sample obtained over the 7-month analysis period, one can ask how representative the calculated statistics are, considering the general trend of the differences between the MRWIS and RWIS measurements. Therefore, it is necessary to determine the confidence interval of the mean and standard deviation calculated from the available data points. In this analysis we calculated 95% confidence intervals for the basic descriptive statistics (mean, median, and standard deviation) using the bootstrap method. The results are shown in Table 9. The mean value of the RST difference obtained from the sample data is 3.10 degrees, with 95% confidence interval between 2.25 and 4.07 degrees. In other words, we can be 95% confident that the true average difference of RST measurements between MRWIS and the corresponding RWIS within 100 ft is between 2.25 degree and 4.07 degrees (or approximately 3.10 ± 0.95 degrees).

Table 9. Confidence Intervals of the Basic Statistics of RST Difference

		95% Confidence Interval	
Statistics	Value	Low	High
Mean	3.10	2.25	4.07
Median	2.20	1.78	2.61
Standard Deviation	4.51	3.57	5.72

11.3 Sensitivity Test Considering Varying Buffer Size

Another item of interest is the potential impact of the buffer sizes around the RWIS on both intra-group variation and inter-group variation of the RST difference. With increased buffer size, there were more matched MRWIS measurements for each RWIS record. The number of matched intervals (i.e., number of matched data points) for each buffer size is shown in Table 10.

Table 10. Number of Matched Records for Different Buffer Sizes

Buffer Size	100 ft	500 ft	1000 ft	1500 ft	3000 ft
Number of Matched Records	94	207	225	324	508

Before getting into the analysis of the impact of buffer size on the difference in RST measurements between the MRWIS and RWIS, it is important to learn how the buffer size affects the within-group variation: (a) whether the average RST measurements from the MRWIS are comparable among the groupings with different buffer sizes, and (b) whether different buffer sizes introduce more variation in the MRWIS RST measurements.

To answer these questions, the average of the MRWIS RST measurements is calculated for all records matched to the corresponding RWIS considering five different buffer sizes. The average RST values are then plotted for each buffer size and date/time of the matching RWIS record, as shown in Figure 46. In general, the average MRWIS measurements are similar among the varying buffer sizes. When compared, the average difference of the RST measurements between different buffer sizes is less than 0.5 degrees, with the maximum difference of 9 degrees found between the average measurements with 100 ft and 1500 ft buffers. In most cases the differences are less than one degree.

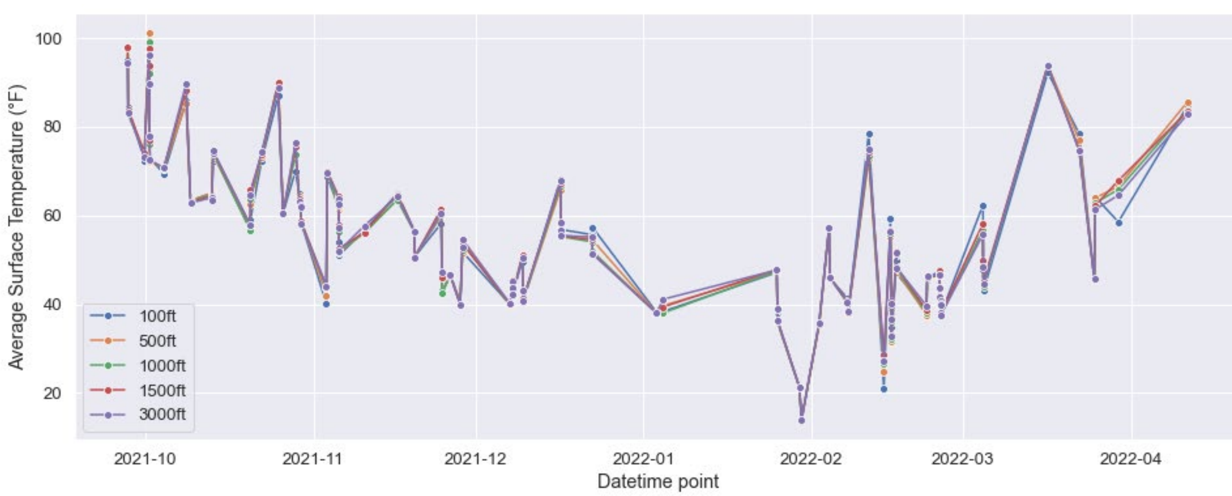


Figure 46. Average MRWIS temperature per time point with different buffer sizes (Source: NJIT)

The ANOVA analysis that was conducted for the average RST measurements also suggested that the mean value of the measured RST is the same across different buffer sizes. Overall, the MRWIS RST measurements are relatively consistent within a reasonable distance from any RWIS station, although with some fluctuations among different buffer sizes.

Next, for each buffer size, the statistics of the RST difference between the corresponding RWIS and MRWIS measurements are plotted in Figure 47. The graph shows a decreasing trend of mean and median values of the RST difference between the MRWIS and RWIS with an increase in buffer size. This finding suggests that a small buffer size may not be ideal considering random variation of RST on local roads when comparing RWIS and MRWIS measurements, while MRWIS and RWIS measurements seem to be comparable within a reasonable distance. The same graph also suggests that a larger buffer size tends to add more variation in the dataset, as demonstrated by the values of standard deviation. This may be due to the inclusion of more distant roadway segments with different characteristics from those represented at the locations of RWIS stations, as the buffer size increases. Shown in Figure 48, MRWIS records within different buffer sizes (marked in different colors) are plotted around the location of the corresponding RWIS station (represented by a light gray dot in the lower right corner of each subplot). It can be observed that with a larger buffer size such as 3000ft, MRWIS from different roadway segments are also included in the analysis. Thus, considering the overall standard deviation and mean value of temperature difference, a buffer size of 500ft or 1000ft around RWIS stations is ideal when matching or joining the MRWIS and RWIS measurements of RST. For those buffer sizes the expected average difference between the MRWIS and RWIS measurements of RST should be in the range of 1.5 degrees Fahrenheit.

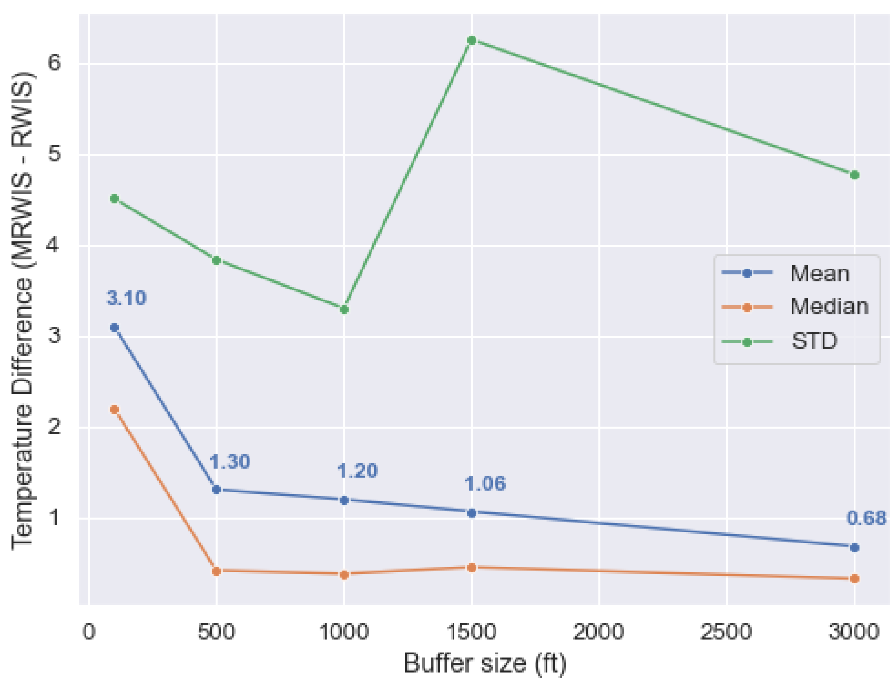


Figure 47. Temperature differences with different buffer size (Source: NJIT)

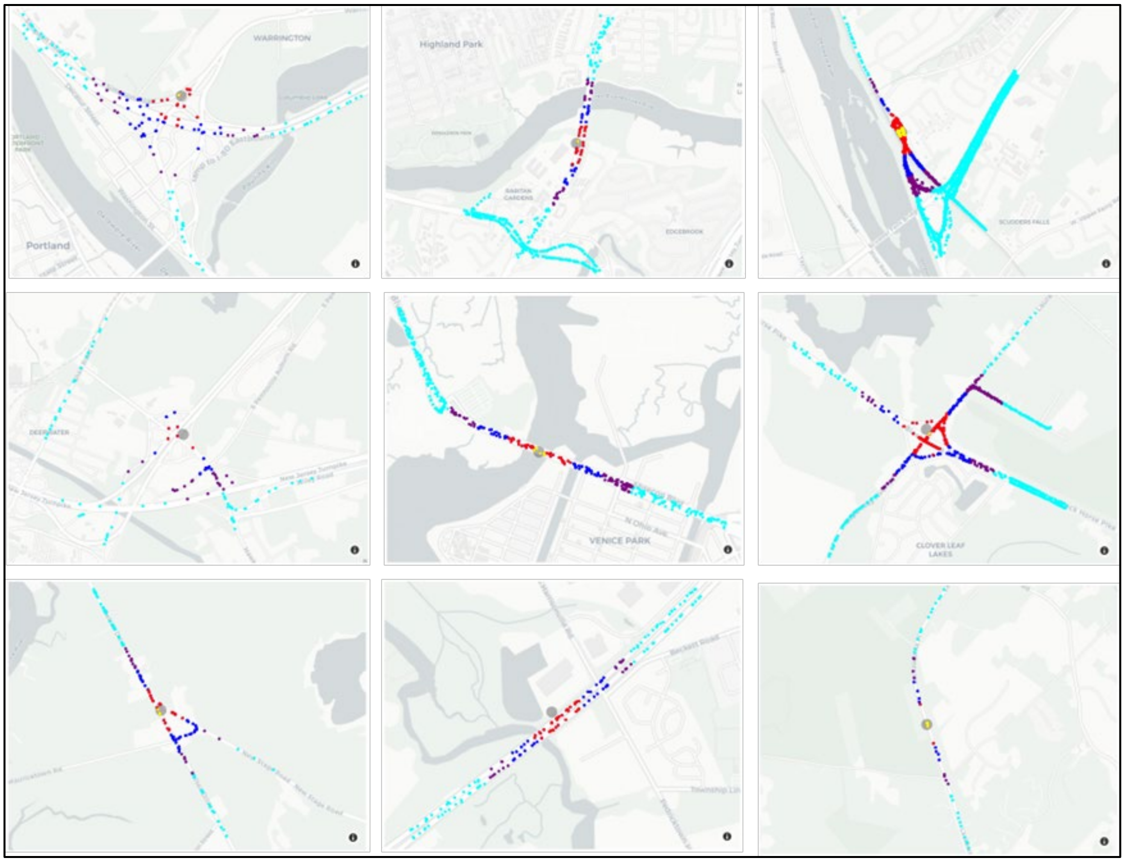


Figure 48. Samples of matched MRWIS records with different buffer sizes (Source: NJIT)

12 PROBLEMS, CHALLENGES, AND LESSONS LEARNED

Since the project inception there have been several issues that required special attention. Some problems, like the impact of the COVID-19 pandemic and procurement-related issues, caused significant delays in the project delivery. Others, such as sensor defects and suspected theft of one of the computers, required additional maintenance or revision of the functional system requirements. Below is a brief summary of the problems encountered, and the lessons learned.

- **Equipment compatibility – video camera system**. During the conceptual design and the system integration planning process it was concluded that the originally proposed dashboard camera system (Mobile-Vision Flashback HD) required hardware and software customization to be fully compatible and functional for the application in this project. In short, the camera system was designed as a stand-alone solution for law-enforcement applications and was not readily customizable for video integration via IP using HTML or RTSP protocols. An alternative solution was researched and determined that IP cameras for vehicle applications met all the requirements and needs of the project. Incidentally, this resulted in cost savings as the AXIS system was less expensive than the one originally budgeted.

- **Equipment compatibility – on-board PC computer**. The selection of the on-board computer was also revised during the procurement phase. After reviewing the PC computer specs provided by the vendor originally included in the project scope, it was concluded that the proposed model had outdated hardware components at a relatively high per-unit cost. The upgrade options for the original configuration were very limited, and not sufficient to match the specs of the more advanced rugged mobile computing devices available on the market at the time in the same price range. Alternative mobile PC computers were researched, and it was concluded that Panasonic Toughpad FZ-G1 or Dell Latitude 7220 would be a good fit for the intended application. Both models are tablet PC computers, installed with detachable physical keyboards, and they met all the requirements and needs of the project with more advanced computing specs and at a slightly lower price. Initially the Dell Latitude 7220 was selected, but it was out of stock for a prolonged period due to COVID-19 pandemic. Thus, it was decided to acquire Panasonic Toughpad FZ-G1 units instead, which had much shorter delivery time. This procurement also resulted in cost savings over the original budget amount for the on-board computers.

- **Project schedule and impact of COVID-19 on project schedule**. The project was authorized by the FHWA in August 2019, and NJIT received the contract in October 2019. The procurement process started immediately following contract execution, but due to the changes in the system design (related to the camera system and on-board computer, as explained in the previous bullets) the orders for the equipment purchases were finalized in late December 2019 and early January 2020. From that point on, the timeline had been severely disrupted by the COVID-19 pandemic. In the first few months of 2020 the main challenge was receiving the ordered equipment and parts. Much of the electronics was manufactured in China, so the lead times kept extending as the production and logistics in China slowed down or halted during the first quarter of 2020. NJIT worked with several suppliers to identify alternatives and available inventory to avoid delays extending into April and May of 2020. In February 2020 it was learned that the Dell Latitude 7220 computers would not be delivered until late April and early May. This was one of the main reasons for canceling the initial order and ordering Panasonic Toughpad FZ-G1 units instead. The Panasonic Touchpads were ordered from two different vendors with slightly different optional components, as priority was given to the units that were in stock and could be shipped within a week or two. Once the equipment was received and first sets were configured and bench-tested at NJIT, the scheduling of installations begun. The installation of all parts except the MD30 sensor was done at the Emergency Accessories and Installation (EAI) in Cherry Hill, NJ, which is on the State contract for the fleet vehicle customization. However, with the COVID-19 lockdown in the State of New Jersey from March through May 2020, the EAI was operating with varying capacity and had to give preference to the emergency vehicles over the vehicles participating in this project. It should be noted that the instrumentation of a single vehicle at EAI took one business day (e.g., a vehicle would be dropped off at the EAI site in the afternoon close to end of business, and it would be ready for pick up with the completed installation by the end of business the next day). Nevertheless, due to limited capacity and personnel availability, the installations extended from March 23 to October 28 for the first 13 vehicles. The installation of the MD30 sensors was done by the Vaisala technician, and the scheduling of those installations was generally more flexible. The MD30 installations were scheduled in most cases within 2-3 weeks from the time of the request, with two sensors installed per day. There is no magic bullet to effectively address this problem as it is mostly dictated by the public health emergency. The best practice, however, would be to build in contingency in the planning early on, with an expectation of additional time for the procurement of equipment and services, and scheduling of the installation.

- **Installations in multiple locations**. As installation of equipment was performed by two separate vendors (Vaisala for installation of the MD30 and EAI for the everything else), it was necessary to coordinate the scheduling of installations between the two. Initially it was planned to set the installation dates at the EAI facility so that the Vaisala technician could install the MD30 sensors right after all the other electronics were installed. However, this proved to be a very difficult task: first, availability of the Vaisala technician and EAI garage did not quite match, and second, it took a full day to EAI to complete the installation on a single vehicle, while the MD30 could be installed in the matter of few hours, allowing the installation of 2-3 units per day. At first it seemed fine to keep the NJDOT vehicles parked for 2-3 days at the EAI facility awaiting the MD30 installation. However, it quickly became clear that some of the vehicles were counted on in daily operations, and the availability of NJDOT personnel to drop off and pick up the vehicles had some limitations, given that some of the vehicle yards were more than 100 miles away from the EAI facility in Cherry Hill. Eventually, it was more efficient to perform MD30 installations independently at NJDOT garages, rather than at the EAI garage. However, it took a lot of coordination ensuring that there was availability of lifts at the garages when the Vaisala technician was available. It was also preferred to install the MD30 sensors after the installation of all the wiring, computing and communication devices at EAI.

- **Installation of the MD30**. Early in the project it was decided to bring the Vaisala technician on board for the installation of the MD30 sensor. This proved to be a good decision, as it became clear during the installations that adjustments were necessary when installing the sensor or the sensor mounting bracket on different makes, models, and even vehicle model and year. This is mainly due to different clearances and availability of adequate mounting surfaces underneath the vehicles. The experience of the Vaisala technician was valuable and ensured all sensors were properly installed and positioned facing the wheel track (as instructed in the sensor installation guide). Another challenge, as noted in section 5.1.1, had to do with the installation of magnetic brackets for the air temperature sensors, which required the vehicle cab or some portion of the cab or the vehicle cap surface to be made of steel. During the installation it became clear that some vehicles, especially newer models included in this project (e.g., Ford F250), had bodies made of non-ferrous metal alloys, so the magnet would not "stick" to them. Instead of using the magnet, it was necessary to bolt the air temperature bracket into the vehicle body for proper exposure of the sensor to airflow, as per the vendor instructions.

- **Calibration of MD30 MRWIS sensors**. Based on the vendor guidelines, the MD30 calibration had to be performed in two steps: calibration using a reference plate, and road adaptation calibration. The first step could be performed at the garage following the MD30 installation. However, the road adaptation required that the vehicle be driven on a dry surface, preferably "old asphalt" in the area of usual vehicle operation. As some of the installations were scheduled weeks in advance, the weather and/or dew could impact the road surface by creating moisture. In such cases, another appointment had to be scheduled for road adaptation. Fortunately, the system was setup in a way that allowed remote access to the onboard computer, so the road adaption could be performed remotely by the NJIT project team.

- **Cleaning of the sensor.** It was found that the sensor cleaning was not easy when installed underneath truck. Since the road surface condition sensor uses optical laser sensing, the laser windows must be clean for accurate detection of moisture on the roadway surface. It was found that many of the sensors would report "window contamination" warning after operation on wet or snowy roadways. This was to be expected, as it was assumed that the sensors would be "back to normal" after regular vehicle cleaning and washing. However, there were instances when a vehicle would be washed after a storm or a period of heavy usage, and the "window contamination" warning would persist. In most cases washing the sensor using a water hose did resolve the problem, but in some cases it was necessary to take off the protective rubber hood from the sensor base and clean the sensor manually. This procedure is not hard to do on the plow trucks, as the sensor is readily accessible. However, reaching the sensor on the pickup trucks required lifting the trucks in a garage as the sensors on those vehicles are installed underneath the vehicle body. This was inconvenient and required additional downtime of the affected vehicle(s) and crew(s).

- **Defects of the Mobile RWIS sensors**: During the equipment monitoring in the 2020/2021 winter season, it was noticed that several MD30 MRWIS units were malfunctioning. The apparent defects seemed unrelated: some units were only reporting road surface temperature and road surface state, while other parameters were reported in error (i.e., as non-numeric values); some stopped reporting surface temperature only, and some stopped reporting only air temperature and humidity, while other parameters were reported accurately; and some sensor units became non-responsive (not able to power up). While all defective units were replaced promptly by the vendor as part of the warranty, the rate of defects seemed high and suggested a systematic failure in design or installation. With the input and detailed diagnostics provided by the NJIT team, and after the examination of defective units, the Vaisala engineering team found a design flaw that was causing the malfunction of the printed circuit board (PCB) inside the sensor housing. Vaisala agreed to replace all MD30 units installed in NJDOT vehicles, including the ones that had not exhibited defects, as a pre-emptive maintenance measure. However, Vaisala needed time to correct the design flaw and fabricate a new series of sensors following a thorough QA/QC protocol. New (replacement) sensors became available in late March 2021, almost at the conclusion of the winter season. Nevertheless, all sensor units were replaced as promised prior to the start of winter season 2021/2022. Unfortunately, in early January 2022, after just a few fairly mild winter storms, the sensor units started malfunctioning again. This time the defects were consistent: all of them exemplified defective surface temperature sensor. During January and February 2022 about 30% of installed sensors became defective. The vendor examined the documentation of defects compiled by the NJDOT and NJIT, as well as several defective units from this project and elsewhere globally, and concluded that this seemed to be a systematic defect. In response, the vendor placed a "quality hold" on the MD30 unit and stopped its fabrication until a thorough engineering study of the defect is conducted and solution found. The vendor estimated that reengineered units may not be available for replacement until August/September 2022. While this experience was somewhat frustrating and had put a significant dent in the project's team ability to conduct robust quantitative studies of the Weather-Savvy IMO system performance, it is understood that MD30 was and still is a new product on the market, and has been put to real-life test in this project. While there are alternative sensors on the market, all of them are much larger and very difficult or impossible to fit safely and efficiently on NJDOT vehicles, given the requirement and practices of the daily operation of those vehicles. Compact design and sophistication of the sensor technology in the MD30 is what led to its selection for this project. Given the reputation of the vendor, and their readiness to honor the warranty and provide replacement services as a courtesy, there is every reason to believe that every effort will be made to correct any design flaws in the product and have the redesigned replacement ready for deployment prior to the winter season 2022/2023.

- **Issues and defects of the computer (PC) stand**. After completing instrumentation on the initial set of vehicles (thirteen in total) it was reported that the PC stand in one of the vehicle types (Volvo plow truck) obstructs the legroom in front of the passenger seat. The reduction of space made the use of this truck by the second crew member quite uncomfortable, especially during longer shifts. This was important because that particular type of truck had the front and a belly blade plows, and can require two people in the cab to operate the plows. Another issue became apparent after the stand in one of the plow trucks broke. This was peculiar as the truck had been one of the most recently instrumented, and had hardly been used or not used heavily. The inspection of the broken part revealed that one of the support brackets appeared not to be installed. After discussion with EAI and their follow-up with the vendor, it became apparent that EAI's vendor had changed the design of the stand just a few months prior to the instrumentation of the last batch of vehicle in this project (total of five). Another defect (fractured support bracket connecting the computer stand column to the dashboard) was discovered in one of those five vehicles after additional inspections were conducted. EAI and their vendor committed to replacing the defective stands free of charge, as well as modifying the stands in the remaining vehicles.

The lesson learned is that a thorough inspection must be conducted when receiving the vehicles from the installation, even when the vendor and installation facilities confirm that all parts have been delivered and installed according to specs.

- **Camera performance**. As noted in section 5.1.2.1, it became clear after just a few weeks of operation that in some of the vehicles the bullet cameras were tilting out of place, many times facing the dashboard instead of windshield. It was reported that this was occurring mainly due to the vehicle vibration. The operators were asked to check and adjust the positioning of the cameras at the start of their shifts, but then the nuts did not stay tight enough to keep the camera fixed and secured on the camera mount, so the camera would come out of the position again. As an alternative, for the second batch of instrumentations it was decided to procure dome cameras, which were affixed to the vehicle headliner and had no moving parts. Generally, dome cameras performed well, and even required a smaller footprint on the electronic board. However, it was necessary to pay attention during the installation to anything on the windshield that would obstruct the view from the camera (such as windshield frit) and adjust the positioning of the camera and/or camera lens accordingly. One advantage of the movable bullet cameras was that it could be directed to different viewing areas outside while the vehicle is stationary, which was useful in traffic incident situations.

- **Web application continuous improvements**. At the onset of the project the web application was envisioned as an auxiliary tool to check and verify the operation of the cameras and sensors in a single portal, as opposed to logging into individual camera and sensor portals. However, soon after the user interface became operational there was a desire to expand its scope and provide more robust toolset and visualization for traffic operations purposes. This was obviously welcomed by the project team, but it came with several challenges that had to be overcome. They included:

    - *System security*. The website for the project was protected by the NJIT firewall, but was not encrypted. In response to the requests by the New Jersey State Office of Information Technology (NJOIT) and Homeland Security Office, SSL was implemented to encrypt the web traffic to/from the website. The web application, data analytics applications, and the database were migrated to dedicated servers and configured with WAF system managed by NJOIT. In addition, security patching was performed on regular bases by NJIT IT Division, which caused intermittent downtime of the web portal, usually on weekend and over a period of several hours.

    - *Large number of users affected application performance*. It was envisioned that the application would only be used by one or two dozen users, not much attention was focused during the development of the application on the server performance, including the processor and memory usage. However, during one of the first winter storms in November 2020 there were more than 50 users monitoring the vehicles, many of them viewing the same camera at the same time. This had caused the application to become slow and for many users unresponsive. A lot of work on the software development side had to be done to make the application run more efficiently, create separate application and proxy service for video streaming, reduce the amount of data being logged in system logs and streamline the queries for dynamic data extraction, etc. At the conclusion of the pilot project there were 138 active users of the application.

- *Video streaming challenges*. Playback of the web application video streams was accomplished in a http video player developed in java, and it is accessed through a proxy server (to avoid each player requesting the feed directly from the camera, which would expose the camera's IP). Modern web browsers limit simultaneous connections to the same IP address to five. It was noticed that internet browsers were not able to close the connections to the video proxy server if the users skip from one vehicle dashboard to the another in short intervals. This, in turn, freezes the webpage and it becomes unresponsive. Addressing this problem required number of patches over time, but in the end the decision had been made to implement video streaming through a professional video server, rather than using code that is not efficient for multicast internet streaming of videos. This solution is not trivial, it requires additional administration and monitoring, and it comes with additional cost for the server and streaming service. However, given the value that dashcam videos bring to this application, the amount of usage it gets during the winter storms, and very positive feedback from the users, the implementation of a video server seems to be the most cost-effective and reliable solution.

- *Developed practice of rebooting servers prior to weekends and storms*. It was noticed that after a period of heavy or prolonged usage, the web application becomes "slower", more sluggish. For this reason, a schedule was established to reboot application servers and flush memory cache, which is like refreshing the application. This practice was first established prior to major storms, to ensure efficient operation during times of anticipated higher user demand. More recently, weekly reboots were instituted to make this process more routine.

- *User experience*. There were several issues that required users to get familiar with the application protocols and not be confused with the application experience. For example, video playback timer runs continuously, while the timer on the dashboard for the data feed is discrete and it shows the time the data was reported by the MRWIS sensor, which is updated roughly every 5 seconds. Thus, the time on the data timer and the video timer are most often different (data timer always lags), which caused confusion with some users. Another issue was the timeout of the login session, which cased users to be automatically logged out after 30 minutes of inactivity. For some of the users, in Microsoft Edge and Google Chrome browsers, this auto-logout would not bring up the log in screen, and they would think they were still logged in. At that time the only way to continue using the application was to log out manually and then log in again. Thus, some time was required for users to get used to the system interface and appearance.

- **In cab GUI application**. The data logging application that was initially developed for this project and installed on in-vehicle PC (tablet) computers, did not have a user interface. Thus, the drivers were not "getting" any data from the sensor, or at least they could not see the data, except through the web-based application. The main reason for not showing any data in the cab was to avoid driver distraction, but also avoid a risk of providing unreliable or inaccurate/imprecise data, given that this is still a pilot project. Nevertheless, some of the drivers have been actively using the in-vehicle PC to conduct work and expressed interest in being able to monitor the data collected by the sensor. With this in mind, a desktop application was developed that replicates to some extent the vehicle dashboard from the web application. The main differences are that the desktop application shows four tiles of road weather data (surface temperature, air temperature, grip, and road surface condition), and that the video player is a separate page (user can toggle between video and data view, but not show them on the same page). The application also allows toggling between the light mode and dark mode, with the dark mode especially convenient for nighttime driving as it causes less glare, making it less distracting to the driver.

13 CONCLUSIONS AND RECOMMENDED NEXT STEPS

13.1 Conclusions

The Weather-Savvy Roads Pilot Deployment Project was initiated with a primary objective of deploying Integrated Mobile Observations (IMO) as a proven, Every Day Counts strategy for more effective and better-informed road weather management practices. As part of the project, 24 NJDOT fleet vehicles have been equipped with windshield cameras, mobile RWIS sensors, portable PC computers, and cellular routers. The equipment in each vehicle was integrated to provide a continuous feed of road weather data and video of the roadway conditions to the remote data center using cellular communication. The data feed from all vehicles was integrated in a unified data management platform, which also provided a web-based graphical user interface for data and video feed visualization. In addition, the web-based data portal also integrated external data sources such as RWIS station data from WxDE, traffic incident data from the NJDOT traffic incident management system T-REX, location of traffic CCTV cameras and video feed, and a static map layer showing of NJDOT snow regions. Over the two winter seasons that the system was deployed, there was a clear benefit to the Operations Management and Mobility Management personnel due to improved situational awareness and the ability to proactively and collaboratively manage traffic during winter weather events.

Similar to other cases of innovative system deployment, this project also faced some challenges, both related to system deployment and operation. Problems in deployment were exacerbated by the onset of the COVID-19 pandemic. Significant delays in production and global supply chain limited the ability to procure, acquire, and deploy the system as initially planned. In terms of operation, there have been problems with the MRWIS sensor, which experienced failures across multiple devices in both winter seasons. Given that these devices are new on the market, it is somewhat understandable that some hardening through operation is needed. It is anticipated that through greater system deployment the experience will grow, and the manufacturer will be able to address all critical design shortcomings. It is, however, unfortunate that data collection was incomplete due to failed sensors. There were also challenges associated with the GUI application, mostly due to wider use of the application, especially the video streaming module. On a positive note, any shortcomings or deficiencies of the web-based data portal application were addressed through continuous improvements and adjustments both in terms of system functionality and efficiency of utilizing computing resources.

13.2 Recommendations

Based on the experience, and the lessons learned from the pilot deployment, there are several directions of improvement that should be pursued as the deployed IMO technology continues to be used as part of NJDOT Weather-Responsive Traffic Management (WRTM) practices.

1. Integrate the Weather-Savvy equipment installed on the fleet vehicles into the regular vehicle maintenance protocols. This will require regular inspection of the equipment operability and working condition of the weather sensor, as well as regular cleaning of the weather sensor.

2. Ensure that essential software on the on-board computer is up to date, including Windows and the client application that collects the data from the sensors and transmits the fused data to the data management center.

3. Deploy the video streaming server as a more robust and reliable solution for multicast video distribution. This approach will also provide flexibility for any future system expansion.

4. Work with the MRWIS vendor to ensure the MRWIS sensors are free of any design defects or errors that may cause erroneous or unreliable measurements.

5. Integrate the IMO road weather data into road maintenance and/or traffic operations management decision support system that can provide even greater efficiency in WRTM practices.

6. Integrate the data collected by the MRWIS with data about the usage of salt and other chemicals used for road treatment. This would be another positive and beneficial outcome of IMO deployment – improving the environmental aspect of winter road maintenance.

7. Integrate the IMO with the on-board spreader control to further improve the ability of dynamically managing resources, thus achieving greater efficiency in winter road maintenance.

8. Investigate the opportunities to expand the system deployment both in terms of scope (or size) and functionality. In terms of scope or size, there is an opportunity to leverage older road temperature sensors that were installed on plow trucks and maintenance supervisor vehicles. These sensors can be integrated in smaller systems with cellular routers and on-board computing units to provide for quick expansion of the IMO-enabled fleet vehicles. The functionality of the vehicle system would be somewhat reduced (i.e., no windshield camera, no data on road surface state or grip), but the road surface temperature and air temperature would be available, which are the most critical data elements when it comes to winter road maintenance. Another possibility is integration of the IMO system into a traffic signal priority connected vehicle application. This application would enable the equipped vehicles to trigger signal priority calls at downstream intersections based on their GPS location and speed. This could be very useful and improve mobility and safety of winter maintenance fleet when it operates in snow plowing and road treatment regimes.

APPENDIX A: DETAILED LISTS OF INSTRUMENTED VEHICLES AND INSTRUMENTATION PARTS

Table A.1 List of Instrumented Vehicles with Location and Crew Number

No.	Vehicle ID	Region	Yard/Location	Crew
1	IMRT-SOUTH	South	Deptford	IMRT South
2	PLOW-N #231	North	Sussex	Crew 231
3	IMRT-NORTH	North	Harding	IMRT North
4	SSP-N #1711	North	Harding	SSP #1711
5	PLOW-S #411	South	Cherry Hill	Crew 411
6	PLOW-N #227	North	Rockaway	Crew 227
7	SSP-S #7529	South	Cherry Hill	SSP #7529
8	PLOW-S #456	South	Mays Landing	Crew 456
9	PLOW-C #331	Central	Flemington	Crew 331
10	PLOW-C #330	Central	West Amwell	Crew 330
11	SSP-S #7513	South	Cherry Hill	SSP #7513
12	SSP-N #1716	North	Harding	SSP #1716
13	OPS-N #026	North	Roxbury	Crew 026
14	OPS-S #414	South	Deptford	Crew 414
15	OPS-S #045	South	Glassboro	Crew 045
16	OPS-SAM	HQ	Ewing HQ	Statewide Manager
17	OPS-C #335	Central	Metuchen	Crew 335
18	OPS-N #225	North	Hanover	Crew 225
19	OPS-N #216	North	Columbia	Crew 216
20	OPS-N #215	North	West Orange	Crew 215
21	SSP-S #7512	South	Cherry Hill	SSP #7512
22	OPS-C #336	Central	Bloomsbury	Crew 336
23	PLOW-N #216	North	Columbia	Crew 216
24	SSP-N #1713	North	Harding	SSP #1713

Table A.2 List of Instrumented Vehicles with Vehicle Year/Make/Model

No.	Vehicle ID	Vehicle Make/Model	Vehicle Year
1	IMRT-SOUTH	Ford F250 Ext. Cab P/U	2017
2	PLOW-N #231	International 7T Dump	2019
3	IMRT-NORTH	Ford F250 Ext. Cab P/U	2017
4	SSP-N #1711	Ford F350	2018
5	PLOW-S #411	International 6T Dump	2018
6	PLOW-N #227	Volvo 10T Tandem	2016
7	SSP-S #7529	Ford F350	2019
8	PLOW-S #456	International 6T Dump	2018
9	PLOW-C #331	Volvo 10T Tandem	2018
10	PLOW-C #330	International 6T Dump	2018
11	SSP-S #7513	Ford F350	2021
12	SSP-N #1716	Ford F350	2017
13	OPS-N #026	Ford F250 Ext. Cab P/U	2018
14	OPS-S #414	Ford F250 P/U	2019
15	OPS-S #045	Ford F250 Ext. Cab P/U	2018
16	OPS-SAM	Dodge Durango	2018
17	OPS-C #335	Ford F250 P/U	2017
18	OPS-N #225	Ford F250 pickup	2020
19	OPS-N #216	Ford F250 pickup	2017
20	OPS-N #215	Ford F250 pickup	2020
21	SSP-S #7512	Ford F350	2019
22	OPS-C #336	Ford F250 pickup	2020
23	PLOW-N #216	International 6T Dump	2018
24	SSP-N #1713	Ford F350	2020

Table A.3 List of Installed MRWIS Sensors by Vehicle ID

No.	Vehicle ID	MRWIS Model
1	IMRT-SOUTH	Vaisala MD30
2	PLOW-N #231	Vaisala MD30
3	IMRT-NORTH	Vaisala MD30
4	SSP-N #1711	Vaisala MD30
5	PLOW-S #411	Vaisala MD30
6	PLOW-N #227	Vaisala MD30
7	SSP-S #7529	Vaisala MD30
8	PLOW-S #456	Vaisala MD30
9	PLOW-C #331	Vaisala MD30
10	PLOW-C #330	Vaisala MD30
11	SSP-S #7513	Vaisala MD30
12	SSP-N #1716	Vaisala MD30
13	OPS-N #026	Vaisala MD30
14	OPS-S #414	Vaisala MD30
15	OPS-S #045	Vaisala MD30
16	OPS-SAM	Vaisala MD30
17	OPS-C #335	Vaisala MD30
18	OPS-N #225	Vaisala MD30
19	OPS-N #216	Vaisala MD30
20	OPS-N #215	Vaisala MD30
21	SSP-S #7512	Vaisala MD30
22	OPS-C #336	Vaisala MD30
23	PLOW-N #216	Vaisala MD30
24	SSP-N #1713	Vaisala MD30

Table A.4 List of Installed Windshield Cameras by Vehicle ID

No.	Vehicle ID	Camera Model	Camera Type
1	IMRT-SOUTH	AXIS F1005E	Bullet
2	PLOW-N #231	AXIS F1005E	Bullet
3	IMRT-NORTH	AXIS F1005E	Bullet
4	SSP-N #1711	AXIS F1005E	Bullet
5	PLOW-S #411	AXIS F1005E	Bullet
6	PLOW-N #227	AXIS F1005E	Bullet
7	SSP-S #7529	AXIS F1005E	Bullet
8	PLOW-S #456	AXIS F1005E	Bullet
9	PLOW-C #331	AXIS F1005E	Bullet
10	PLOW-C #330	AXIS F1005E	Bullet
11	SSP-S #7513	AXIS F1005E	Bullet
12	SSP-N #1716	AXIS F1005E	Bullet
13	OPS-N #026	AXIS F1005E	Bullet
14	OPS-S #414	AXIS P3925-R	Dome
15	OPS-S #045	AXIS F1005E	Bullet
16	OPS-SAM	AXIS F1005E	Bullet
17	OPS-C #335	AXIS F1005E	Bullet
18	OPS-N #225	AXIS P3925-R	Dome
19	OPS-N #216	AXIS F1005E	Bullet
20	OPS-N #215	AXIS F1005E	Bullet
21	SSP-S #7512	AXIS F1005E	Bullet
22	OPS-C #336	AXIS P3935-LR	Dome
23	PLOW-N #216	AXIS P3935-LR	Dome
24	SSP-N #1713	AXIS P3935-LR	Dome

Table A.5 List of Installed Video Processing Units by Vehicle ID

No.	Vehicle ID	Main Unit Model	Main Unit S/N
1	IMRT-SOUTH	AXIS F41	ACCC8EE40A2A
2	PLOW-N #231	AXIS F41	ACCC8EE40C17
3	IMRT-NORTH	AXIS F41	ACCC8EE40167
4	SSP-N #1711	AXIS F41	ACCC8EE40A0A
5	PLOW-S #411	AXIS F41	ACCC8EE4017D
6	PLOW-N #227	AXIS F41	ACCC8EE4006F
7	SSP-S #7529	AXIS F41	ACCC8EE40C0D
8	PLOW-S #456	AXIS F41	ACCC8EE40191
9	PLOW-C #331	AXIS F41	ACCC8EEA3DA6
10	PLOW-C #330	AXIS F41	ACCC8EE41431
11	SSP-S #7513	AXIS F41	ACCC8EE401BF
12	SSP-N #1716	AXIS F41	ACCC8EE411BD
13	OPS-N #026	AXIS F41	ACCC8EF7850B
14	OPS-S #414	Not needed for the camera system	
15	OPS-S #045	AXIS F41	B8A44F063B37
16	OPS-SAM	AXIS F41	B8A44F07AF98
17	OPS-C #335	AXIS F41	B8A44F063ACE
18	OPS-N #225	Not needed for the camera system	
19	OPS-N #216	AXIS F41	B8A44F063AAF
20	OPS-N #215	AXIS F41	B8A44F063B09
21	SSP-S #7512	AXIS F41	B8A44F063B84
22	OPS-C #336	Not needed for the camera system	
23	PLOW-N #216	Not needed for the camera system	
24	SSP-N #1713	Not needed for the camera system	

Table A.6 List of Installed Power-over-Ethernet (PoE) Units by Vehicle ID

No.	Vehicle ID	PoE Model
1	IMRT-SOUTH	AXIS T81B22
2	PLOW-N #231	AXIS T81B23
3	IMRT-NORTH	AXIS T81B24
4	SSP-N #1711	AXIS T81B25
5	PLOW-S #411	AXIS T81B26
6	PLOW-N #227	AXIS T81B27
7	SSP-S #7529	AXIS T81B28
8	PLOW-S #456	AXIS T81B29
9	PLOW-C #331	AXIS T81B30
10	PLOW-C #330	AXIS T81B31
11	SSP-S #7513	AXIS T81B32
12	SSP-N #1716	AXIS T81B33
13	OPS-N #026	Tycon TP-DCDC-1248-M
14	OPS-S #414	Tycon TP-DCDC-1248-M
15	OPS-S #045	Tycon TP-DCDC-1248-M
16	OPS-SAM	Tycon TP-DCDC-1248-M
17	OPS-C #335	Tycon TP-DCDC-1248-M
18	OPS-N #225	Tycon TP-DCDC-1248-M
19	OPS-N #216	Tycon TP-DCDC-1248-M
20	OPS-N #215	Tycon TP-DCDC-1248-M
21	SSP-S #7512	Tycon TP-DCDC-1248-M
22	OPS-C #336	Tycon TP-DCDC-1248GD-M
23	PLOW-N #216	Tycon TP-DCDC-1248GD-M
24	SSP-N #1713	Tycon TP-DCDC-1248GD-M

Table A.7 List of Installed Modem/Router Units by Vehicle ID

No.	Vehicle ID	Modem/Router Model
1	IMRT-SOUTH	Sierra Wireless MP70
2	PLOW-N #231	Sierra Wireless MP70
3	IMRT-NORTH	Sierra Wireless MP70
4	SSP-N #1711	Sierra Wireless MP70
5	PLOW-S #411	Sierra Wireless MP70
6	PLOW-N #227	Sierra Wireless MP70
7	SSP-S #7529	Sierra Wireless MP70
8	PLOW-S #456	Sierra Wireless MP70
9	PLOW-C #331	Sierra Wireless MP70
10	PLOW-C #330	Sierra Wireless MP70
11	SSP-S #7513	Sierra Wireless MP70
12	SSP-N #1716	Sierra Wireless MP70
13	OPS-N #026	Sierra Wireless MP70
14	OPS-S #414	Sierra Wireless MP70
15	OPS-S #045	Sierra Wireless MP70
16	OPS-SAM	Sierra Wireless MP70
17	OPS-C #335	Sierra Wireless MP70
18	OPS-N #225	Sierra Wireless MP70
19	OPS-N #216	Sierra Wireless MP70
20	OPS-N #215	Sierra Wireless MP70
21	SSP-S #7512	Sierra Wireless MP70
22	OPS-C #336	Sierra Wireless MP70
23	PLOW-N #216	Sierra Wireless MP70
24	SSP-N #1713	Sierra Wireless MP70