

Utilization of AVL/GPS Technology: Case Studies

AECOM



research for winter highway maintenance

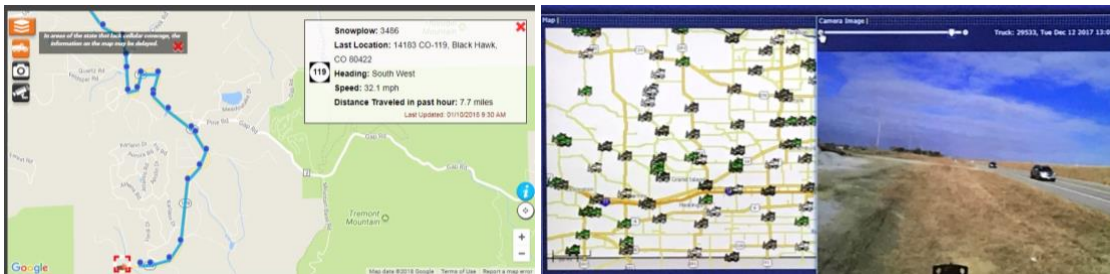
Project 1026092/CR16-01
June 2018

Pooled Fund #TPF-5(218)
www.clearroads.org

This page intentionally left blank

Utilization of AVL/GPS Technology: Case Studies

Final Report



June 2018

Technical Report Documentation Page

1. Report No. CR 16-01	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle Utilization of AVL/GPS Technology: Case Studies		5. Report Date June 2018	
		6. Performing Organization Code	
7. Author(s) Ming-Shiun Lee, Dan Nelson		8. Performing Organization Report No.	
9. Performing Organization Name and Address AECOM 800 LaSalle Avenue, Suite 500 Minneapolis, MN 55402		10. Work Unit No.	
		11. Contract or Grant No. MnDOT Contract No. 1026092	
12. Sponsoring Agency Name and Address Clear Roads Pooled Fund Study Lead State: Minnesota Department of Transportation Research Services Section 395 John Ireland Boulevard, MS 330 St. Paul, MN 55155		13. Type of Report and Period Final Report (February 9, 2017 – September 30, 2018)	
		14. Sponsoring Agency Code	
15. Supplementary Notes Project completed for Clear Roads Pooled Fund program, TPF-5(218). See www.clearroads.org .			
16. Abstract <p>Winter road maintenance accounts for roughly 20 percent of state DOT maintenance budgets. State and local agencies spend over \$2.3 billion on winter operations annually. As such, effective winter maintenance operations incorporating smart uses of methods, techniques, technologies, equipment and materials becomes essential. Among various winter maintenance technologies, automated vehicle location (AVL) and global positioning systems (GPS) have been widely used by transportation agencies to monitor vehicle locations and equipment operational status for winter road maintenance operations.</p> <p>This report summarizes the information gathered during the study conducted for the Clear Roads project entitled <i>Utilization of AVL/GPS Technology: Case Studies</i>. The research team surveyed multiple state DOTs on the current state of AVL/GPS system usage for the purpose of gathering information on the planning, processes, steps, and results observed by agencies with their respective systems. Six state DOTs (Utah, Washington State, Michigan, Wisconsin, Nebraska, and Colorado) were selected to conduct detailed case studies. The case studies were performed through in-person interviews with multiple levels of DOT staff involved in AVL/GPS system planning, procurement, implementation, management and operations. This final report summarizes the key results, findings and lessons learned from the case studies. It also identifies best practices and provides a series of recommendations for winter maintenance agencies to consider in the procurement, deployment and integration of an AVL/GPS system for winter maintenance operations.</p>			
17. Key Words Automated Vehicle Location (AVL), Global Positioning Systems (GPS), Snow Plow, Winter Maintenance, Technology		18. Distribution Statement No restrictions. This document is available to the public through the Clear Roads pooled fund and the Minnesota Department of Transportation.	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 130	22. Price -0-

Acknowledgements

The authors would like to acknowledge the efforts of the Clear Roads Technical Advisory Committee for providing review, input, and comments on all Project Tasks.

The authors would also like to thank Greg Waidley, the project coordinator from CTC & Associates, as well as all the states and agencies for their cooperation and efforts in providing information during our survey.

The authors would like to especially thank each of the six state DOTs that were selected for the case study interviews for their efforts and contributions to the project. Their assistance in scheduling and coordinating interviews, as well as providing valuable input and information, helped to make this a successful project. The authors would especially like to acknowledge the following individuals and their staff:

- Tim Ularich, Utah DOT
- Melissa Longworth, Michigan DOT
- Al Johnson and Mike Adams, Wisconsin DOT
- Mike Mattison, Nebraska DOT
- Joe Schmit and James Morin, Washington State DOT
- Kyle Lester, Colorado DOT

Table of Contents

Executive Summary	1
1. Introduction.....	3
1.1 Background.....	3
1.2 Methodology	3
2. Literature Review.....	5
2.1 Clear Roads Project CR14-01: Synthesis on GPS / AVL Equipment Used for Winter Maintenance	5
2.2 Clear Roads Project CR11-03: Automated Spreading Systems for Winter Maintenance	6
2.3 Roads and Bridges Article on Automated Spreader Technology.....	6
2.4 FHWA Best Practices for Road Weather Management, Version 3.0.....	7
2.5 FHWA Road Weather Management Benefit Cost Analysis Compendium	7
2.6 Other Relevant References	8
2.7 Literature Summary References.....	8
3. Survey Summary	9
3.1 Background Information.....	9
3.2 Summary of Survey Responses	10
3.3 Tiers of AVL/GPS Implementation and Utilization	28
3.4 Tier 1 Agency Analysis.....	30
3.5 Tier 2 Agency Analysis.....	32
3.6 Tier 3 Agency Analysis.....	32
3.7 Recommendations on Case Study Agencies	35
4. Case Study Summary	36
4.1 Introduction	36
4.2 Tier 1 – Utah DOT.....	37
4.3 Tier 2 – Washington State DOT.....	45
4.4 Tier 2 – Michigan DOT	49
4.5 Tier 3 – Wisconsin DOT.....	60
4.6 Tier 3 – Nebraska DOT.....	65
4.7 Colorado DOT.....	70
5. Best Practices and Recommendations	76
5.1 Planning and Decision Making	76
5.2 Procurement	78
5.3 System Implementation	81
5.4 Data Collection and Utilization.....	86
5.5 Operations and Maintenance.....	90

Appendix A – Summary of Survey Responses	A-1
Appendix B – Case Study Interview Summary: Utah DOT	B-1
Appendix C – Case Study Interview Summary: Washington State DOT	C-1
Appendix D – Case Study Interview Summary: Michigan DOT	D-1
Appendix E – Case Study Interview Summary: Wisconsin DOT	E-1
Appendix F – Case Study Interview Summary: Nebraska DOT	F-1
Appendix G – Case Study Interview Summary: Colorado DOT	G-1

List of Figures

Figure 1. Map of Survey Respondents	9
Figure 2. Map of Recommended Agencies for Case Studies.....	35
Figure 3. UDOT Regions	37
Figure 4. Interior Picture of UDOT Snow Plow and Placement of Equipment	38
Figure 5. Location of Verizon NetworkFleet 5500 Model in UDOT Snow Plow.....	38
Figure 6. Screenshot of Verizon NetworkFleet Software Interface for UDOT Vehicle Tracking.....	39
Figure 7. PC-Based Image from UDOT Traffic Information Webpage with Snow Plow Locations	40
Figure 8. Mobile Device Image of UDOT Traffic Information Page with Snow Plow Locations	40
Figure 9. UDOT Snow and Ice Performance Dashboard at RWIS Station	42
Figure 10. UDOT Snow and Ice Performance Dashboard Statewide View	43
Figure 11. UDOT Snow and Ice Performance Dashboard Storm Performance Reports	43
Figure 12. WSDOT Regions	45
Figure 13. WSDOT AVL/GPS System Hardware Units (Un-covered and Covered)	46
Figure 14. WSDOT Snow Plow Equipment and Location of LT6 AVL/GPS System	46
Figure 15. WSDOT In-House Software Interface with AVL Location Data	47
Figure 16. MDOT Regions	50
Figure 17. MDOT and County Partnership	50
Figure 18. MDOT Mobile Data Computer (MDC) and AVL Hardware (above) and Back View of MDC, Antennae and Cable (below)	51
Figure 19. Location of Parsons AVL Hardware in MDOT Snow Plow	52
Figure 20. MDOT AVL/GPS System Interface Graphic from Parsons.....	53
Figure 21. MDOT AVL/GPS Software Interface with Vehicle Camera Image	53
Figure 22. MDOT MDSS Screenshot of Weather Forecast.....	54
Figure 23. MDOT Iteris MDSS Screenshot.....	55
Figure 24. MDOT Salt Efficiency Data Statewide by Region with Direct Forces	56
Figure 25. Grand Region Salt Efficiency Data and Speed Compliance Data	57
Figure 26. MDOT Grand Region County and Garage Material Usage.....	58
Figure 27. MDOT Grand Region Detailed Material Usage Reports for MDOT Counties and Garages	59
Figure 28. WisDOT Regions and Counties.....	61
Figure 29. Location of WisDOT PreCise AVL/GPS Equipment in Sauk County Vehicle	62
Figure 30. NDOT Districts	65

Figure 31. NDOT Snow Plow In-Vehicle Equipment	66
Figure 32. Location of NDOT AVL/GPS System Hardware	66
Figure 33. NDOT AVL/GPS System Software Interface	67
Figure 34. CDOT Regions	71
Figure 35. CDOT Maintenance Sections	71
Figure 36. CDOT Snow Plow and Zonar System Tablet Installation Location / Screen.....	72
Figure 37. CDOT Snow Plow and Example Reporting Puck for Pre-Trip and Post-Trip Reports.....	72

List of Tables

Table 1. Survey Respondents.....	10
Table 2. Tier 1 Agencies.....	28
Table 3. Criteria for Evaluation of Tiers 2 & 3 Agencies in AVL/GPS Implementation.....	29
Table 4. Summary of Tiers 2 & 3 Agencies and Level of Integration with AVL/GPS Systems	29
Table 5. Summary of Agency Candidates for Tier 1 Case Study.....	31
Table 6. Summary of Agency Candidates for Tier 2 Case Studies.....	33
Table 7. Summary of Agency Candidates for Tier 3 Case Studies.....	34
Table 8. Recommended Case Study Agencies	35
Table 9. In-Person Interviews for Case Studies.....	36
Table 10. Levels of Staff Interviewed and Topics of Discussion	36
Table 11. Percent of Vehicle Fleet with AVL/GPS Technology from 2017 Survey.....	77

Executive Summary

The purpose of this research project is to help state departments of transportation (DOTs) make more informed decisions with respect to the implementation of Automated Vehicle Locator (AVL) / Global Positioning Systems (GPS) technology for winter maintenance activities. While it is understood that the technology can assist dispatchers and maintenance supervisors through vehicle tracking and monitoring, AVL/GPS systems can perform many other valuable functions for state DOTs, mainly through integration with existing vehicle components used for snow plow operations.

The research team surveyed multiple state DOTs on the current state of AVL/GPS system usage for the purpose of gathering information on the planning, processes, steps, and results observed by agencies with their respective systems. From these survey responses, the research team selected six state DOTs (Utah, Washington State, Michigan, Wisconsin, Nebraska, and Colorado) to conduct detailed case studies. The case studies were performed through in-person interviews with multiple levels of DOT staff that have been involved in AVL/GPS system planning, procurement, implementation, management and operations.

Six stand-alone case study reports were developed based on the information gathered through interviews, along with additional input from and documentation shared by each interviewed agency. Those case study reports collect and synthesize detailed information on varying levels of AVL/GPS implementation with respect to agencies' decision-making processes, implementation steps, issues and challenges, lessons learned, and costs and benefits. There were varying levels of AVL/GPS implementation from gathering and monitoring basic vehicle locations to a more sophisticated and integrated system. The case study reports summarize specific issues by type that are related to winter maintenance AVL/GPS utilization and can be used as a guidance and template to help state DOTs successfully implement and optimally utilize different levels of AVL/GPS applications based on their unique geographic characteristics, organizational settings, winter maintenance needs, and technical capabilities. The lessons learned and recommendations derived from the case studies provide long-term support to agencies for initiating, ramping up, modifying and upgrading AVL/GPS implementation for winter maintenance operations.

This final report summarized the key results, findings and lessons learned from the case studies. It also identifies best practices and provides a series of recommendations for winter maintenance agencies to consider in the procurement, deployment and integration of an AVL/GPS system for winter maintenance operations. Key recommendations offered from this research include:

- **Planning and Decision Making**
 - Involve agency leadership and management throughout the project
 - Identify agency's needs, goals and objectives for an AVL/GPS system
 - Assess the number of vehicles within the agency fleet that will require AVL/GPS system hardware and integration based on needs and financial flexibility
 - Conduct research and/or pilot projects to gain knowledge as well as identify issues and opportunities prior to full system implementation
 - Consider phased implementation to ease adoption of technology
- **Procurement**
 - Use a Systems Engineering approach in the development of system requirements and specifications.
 - Leverage other agencies' experience in requirements and RFP development
 - Clearly state agency's expectations in the RFP
 - Consider the use of a Request for Information (RFI) process to gather information on the current state of AVL/GPS system technology
 - Use best value procurement for selecting an AVL/GPS vendor

- Consider the use of a turnkey contract for complex implementation
- Leverage existing contracting vehicles for expedited procurement
- **System Implementation**
 - Arrange installation schedule to minimize impacts to winter maintenance operations
 - Install AVL/GPS equipment at protected locations with access for maintenance
 - Involve and train agency mechanics for AVL hardware installation
 - Anticipate issues and challenges associated with integration between other equipment and an AVL/GPS system
 - Communicate with bidders regarding anticipated challenges with system integration during procurement
 - Perform regular outreach to maintenance field operations personnel
 - Communicate and demonstrate the purpose of the system to snow plow operators to alleviate concerns
 - Be prepared for dealing with winter maintenance cultural changes
 - Evaluate cellular providers to maximize coverage and supplement with other communications methods to fill the gaps
 - Provide training to all levels of system users before, during and after system implementation
 - Require AVL vendor to provide initial training to agency winter maintenance staff on system operations and maintenance
 - Communicate the benefits of the AVL/GPS system operations as part of training to establish buy-in with the system among system users
 - Conduct recurring training to winter maintenance agency staff to improve the agency's ability to achieve operational objectives
 - Establish a "train the trainer" program to help retain system knowledge within the agency
- **Data Collection and Utilization**
 - Require AVL vendor to make system data available to the agency
 - Understand the limitations on material usage data accuracy
 - Identify agency staffing and resources needed to support the management of the AVL/GPS System prior to system procurement
 - Use real-time system data to make adjustments to resource allocation and maintenance strategies
 - Integrate other road condition data with mobile observations from AVL/GPS systems
 - Establish a performance management program to document performance and benefits
 - Work with system vendors to develop agency desired data reporting features and performance dashboards
 - Use internal resources to develop agency desired reporting features and performance dashboard
 - Consider sharing vehicle location data with the general public
- **Operations and Maintenance**
 - Obtain support and secure funding to sustain on-going operations and maintenance

1. Introduction

Winter road maintenance accounts for roughly 20 percent of state DOT maintenance budgets. State and local agencies spend over \$2.3 billion on winter operations annually. As such, effective winter maintenance operations incorporating smart uses of methods, techniques, technologies, equipment and materials becomes essential. Among various winter maintenance technologies, automated vehicle location (AVL) and global positioning systems (GPS) have been widely used by transportation agencies to monitor vehicle locations and equipment operational status for winter road maintenance operations.

AVL/GPS systems are generally comprised of hardware installed in the cab of the vehicle, vehicle-based communications equipment that facilitates data exchanges between vehicles and a central software system, and central software that allows for viewing and tracking of vehicle locations throughout a geographic region, among other information. The hardware installed in the vehicle can include a Vehicle Logic Unit (VLU) that contains the firmware that allows a vehicle to identify and report on its location and other information about the vehicle. The VLU can interface with the vehicle's Controller Area Network (CAN) bus to receive information from the vehicle, and it generally includes a GPS receiver embedded in the device for vehicle location reporting, and can also include a cellular modem for communications. There may also be a Mobile Data Computer (MDC) that serves as an interface with the driver of the vehicle, allowing them to enter information about the vehicle, and also see and receive vehicle-related information communicated to them from a dispatch center or a central software system.

1.1 Background

Many agencies involved in winter maintenance operations are interested in procuring, or planning, for future procurement of AVL/GPS systems as new implementation or upgrades to current systems. To help state DOTs and other agencies make more informed decisions to better implement AVL/GPS technologies for winter maintenance operations, the Clear Roads research program initiated this project (Clear Roads Project 16-01: Utilization of AVL/GPS Technology: Case Studies). The goal of this project is to conduct case studies and synthesize agencies' experiences and lessons learned in planning, implementation and utilization of AVL/ GPS technologies for winter maintenance.

While the main function of the system is to provide automated vehicle location tracking for dispatchers and maintenance supervisors, AVL/GPS systems can also provide valuable information on vehicle diagnostics to maintenance supervisors. Furthermore, AVL/GPS systems can be integrated with existing vehicle components used for snow plow operations, such as spreader controllers and plow blades to provide reports to maintenance supervisors on plow usage and material applied by snow plow operators.

The purpose of this report and its companion case study reports are to help other state DOTs make more informed decisions with respect to the implementation of AVL/GPS technology for winter maintenance activities. Those reports are intended to bring to light more nuanced issues related to the use of AVL/GPS technology for winter maintenance. Those reports also highlight the types of issues other state DOTs / agencies should consider prior to system procurement, provides guidance for successful implementation of the technology, and serves as a possible template for agencies to get the best value out of different levels their AVL/GPS applications.

1.2 Methodology

The research team utilized the following methodology to complete the project as described below.

1.2.1 Literature Review

The research team first completed a review of relevant literature and project documents to gain a better understanding of transportation agencies' AVL/GPS implementation and utilization experiences. This

included a prior Clear Roads Project CR14-01 which collected survey information from agencies on their prior use of AVL/GPS systems. The literature review performed by the research team is contained in Section 2 of this report.

1.2.2 Survey

In the spring of 2017, a survey was distributed to multiple state DOTs to gather basic, high-level information regarding each agency's level of AVL/GPS implementation, as well as detailed information on the planning, processes, steps, and results observed by agencies with their respective systems. Based on the survey responses, agencies were categorized into the following three levels of AVL/GPS implementation and utilization:

- **Tier 1:** Basic Location Tracking/Monitoring with or without collection of vehicle diagnostic data
- **Tier 2:** Medium implementation with basic location tracking, with additional data collection, equipment integration, and system reporting features
- **Tier 3:** High implementation with added, more complex data collection, integration, and reporting features

The research team presented the results of the survey summary to the Clear Roads Project Committee and recommended the following agencies for in-person interviews and case studies:

- Tier 1: Utah DOT
- Tier 2: Michigan DOT and Washington State DOT
- Tier 3: Wisconsin DOT, Nebraska DOT, Colorado DOT

A summary of the survey results and the analysis performed by the research team is contained in Section 3 of this report.

1.2.3 Interviews and Case Studies

In-person interviews were conducted with staff from each of the recommended state DOTs to gain a detailed understanding on how their AVL/GPS system was utilized for winter maintenance operations. Interviews were conducted between November 2017 and January 2018 with the six agencies selected through the project survey. Interview summaries for each agency are contained in the Appendices B through G of this report.

With the information gathered from these interviews, the research team developed individual case study reports documenting on how each agency implements and utilizes their AVL/GPS system. A summary of the case studies is contained in Section 4 of this report. Full versions of the case study reports are published separately on the Clear Roads Program website (<http://clearroads.org/>).

1.2.4 Best Practices and Recommendations

After completion of the case study reports, recommendations were developed to summarize the key takeaways from the in-person interviews with each state DOT. In addition, best practices were also identified and highlighted. The recommendations as well as best practices from the case studies are included in Section 5 of this report.

2. Literature Review

This literature summary provides an overview of key literature related to the implementation of AVL/GPS systems for winter maintenance operations. The list of literature reviewed includes documents recommended by the Clear Roads project subcommittee and additional literature identified and reviewed by the research team. The Clear Roads Project CR14-01 completed in 2016 provided the main source of information for this literature review, which described the extent of AVL/GPS utilization for winter maintenance activities. In addition, the research team conducted a literature search and reviewed agency (in particular Federal Highway Administration) publications, conference papers, presentations and proceedings, and professional and trade journals to identify and gain a better understanding of transportation agencies' AVL/GPS implementation experience. To build upon and supplement the literature that has already been reviewed in Project CR14-01, literature search for this current effort focuses on recent literature that is published within the past five years. A summary of the literature search is presented in the following paragraphs.

2.1 Clear Roads Project CR14-01: Synthesis on GPS / AVL Equipment Used for Winter Maintenance

The main document reviewed for this literature summary was recently completed in July 2016 and is titled "Synthesis on Global Positioning Systems / Automatic Vehicle Location Equipment Used for Winter Maintenance". The document features an extensive summary of available GPS/AVL systems for state DOT agencies that are considering the use of those types of systems for winter maintenance.

Researchers surveyed several state and local agencies to collect information about available GPS/AVL equipment and how it is currently being used. Based on the information collected, a GPS/AVL system guide was developed to describe the capabilities of currently available systems, including positive and negative experiences with these systems.

Survey responses were gathered from twenty-six state DOTs, four city agencies, one county agency, and one manufacturer. A summary of key responses is provided below:

1. Agency respondents reported using GPS/AVL hardware from nine different GPS/AVL equipment manufacturers
2. Cellular networks are commonly used to communicate data between vehicles and central servers, though a few agencies reported the use of Wi-Fi and data radio systems. Verizon's network received positive reports from all survey respondents as well.
3. Most agencies have equipped only part of their fleet with GPS/AVL equipment, likely due to the cost and maturity of the technology. States reported having equipped an average of 35 percent of their vehicles with an AVL system.
4. The most frequently reported uses for GPS/AVL system data included making plowing and material application decisions, tracking data to create shift reports for managers, sharing information with other agencies and the public, and assigning staff during winter events.
5. The most common types of information that were collected from vehicles were plow position, pavement temperatures, and air temperatures. Some agencies also collect dashcam images or video or data input through a user interface in the vehicle cab.
6. Adequate communications network coverage was one of the most significant concerns identified by survey respondents, given some minor gaps in cellular network coverage in winter maintenance areas.

The equipment guide developed for the report relied primarily on the survey responses, and focused on what agencies reported as having in common with their equipment. The two main issues reported in the survey were: 1) Vehicle sensors reporting inaccurate or inconsistent data, and 2) The amount of time and effort required by agencies to maintain the GPS/AVL systems.

Finally, researchers found no publicly available state or local policies related to how GPS/AVL system data is accessed or stored, likely due to the recent widespread use of these systems for winter maintenance. Instead, researchers identified topics that agencies may wish to consider in policies, such as who is allowed to access data, how long data will be stored, whether data can be used in litigation and whether GPS tracking can be used for employee discipline.

2.2 Clear Roads Project CR11-03: Automated Spreading Systems for Winter Maintenance

The Clear Roads subcommittee recommended the research team to review project 11-03 titled “Automated Spreading Systems for Winter Maintenance” dated February 2014. Similar to the GPS/AVL research conducted in project 14-01, surveys were distributed to multiple state DOTs to identify and evaluate currently available automated salt spreaders. The surveys indicated that spreader automation was likely to increase in coming years despite some skepticism about the automation process. Given the survey results, researchers developed multiple educational guides, including an overview of available systems comparing the features of different products.

Researchers also described four levels of automation in salt spreading that were available. In some cases, automated spreading is driven by travel speeds or pavement temperatures detected by vehicle sensors. In other cases, spreading is automated based on the vehicle’s location determined by GPS systems in relation to bridge decks, hills, or intersections. Remote automation from central offices was identified as one type of automation that was currently under research and testing at the time. Upon further research by the research team, no agencies were identified that were currently using that type of salt spreader automation.

One of the most significant gaps identified in that study was field testing of the accuracy of automated spreading technology. Researchers found only two quantitative studies, both from Europe conducted in 2010. Current accuracy testing in the United States was not available then, and could not be found in 2017 either.

2.3 Roads and Bridges Article on Automated Spreader Technology

Despite the relative lack of accuracy testing of automated spreading technology as noted in the CR11-03 project, multiple state DOTs have reported positive experiences through the use of automated salt spreader equipment. This has been described in an August 2016 Roads and Bridges article that can be accessed at the following link: <https://www.roadsbridges.com/controlling-spread>.

The state DOTs interviewed in the article included the Massachusetts DOT, the Maine DOT, and the Idaho Transportation Department (ITD). Specifically, the article described a recent system implemented by the ITD known as the Winter Automated Reporting System (WARS). This system converts GPS-coordinate data from the vehicle spreader control system to a linear-referencing system, which is based on vehicle routes and mileposts. From the converted data, the WARS can identify the specific spreading activities of a truck and generate an automated work order.

The ITD estimated that the department would save approximately 750 man-hours per year with the reduced time for manually inputting the operator work order data. Other benefits include reduced material use. The ITD estimated the payback period for the system would be around four years for a 12-year life of the spreader controller.

2.4 FHWA Best Practices for Road Weather Management, Version 3.0

The Federal Highway Administration (FHWA) conducted multiple case studies in 2012 with state DOTs throughout the U.S. on how they respond to inclement weather conditions with different technology applications. The report contains 27 case studies from municipal and state transportation agencies. Each case study has six sections including a general description of the system, system components, operational procedures, resulting transportation outcomes, implementation issues, as well as contact information and references. With regards to winter maintenance, the South Dakota DOT Maintenance Decision Support System (MDSS) was featured in a case study that briefly described the benefits of the research conducted in the MDSS Pooled Fund Study. Implementation issues listed included the adoption of new communications technologies in the vehicles and the overall user acceptance of the technology and its level of accuracy.

In addition, several case studies contain information on the use of AVL/GPS technology as well as its integration with road surface and air temperature sensors as data sources for road weather information systems. Systems included in those case studies are: Idaho's Winter Maintenance Performance System, Iowa's WeatherView Road Weather Travel Information System, and Utah's Traveler Information Weather Program.

2.5 FHWA Road Weather Management Benefit Cost Analysis Compendium

The Road Weather Management Benefit Cost Analysis Compendium (RWM Compendium) is a companion to the broader Transportation Systems Management and Operations Benefit Cost Analysis Compendium (TSMO Compendium). Both documents are additions to the series of reference documents and tools developed by the FHWA Office of Operations to assist planners and operations professionals in evaluating the benefits and costs of TSMO strategies and technologies. The RWM Compendium expands the road weather management technologies and strategies covered in the TSMO Compendium to provide a more thorough and complete coverage of benefit cost analyses (BCAs) of road weather management projects.

The RWM Compendium is a collection of cases from across the country where benefit cost analyses have been applied to specific RWM technologies or operational strategies. Two of the case studies in the document are relevant to the use of AVL/GPS for winter maintenance activities.

The first relevant case study was the use of AVL for highway maintenance activities, especially snow removal, by the Kansas DOT. As part of the process, the study included a BCA associated with implementing AVL in their maintenance and operations. The BCA took into account costs for implementation (which included costs of communications, in-vehicle unit, and road and air temperature sensors), operations and maintenance. The assessment indicated that the application of AVL in highway maintenance has a benefit-to-cost ratio ranging from 2.6:1 using conservative assumptions, to 24:1 (or higher) using moderate assumptions. The study showed that the potential for AVL to improve the efficiency and effectiveness of highway maintenance operations appears to be significant. The study concluded that because the technology is well established and there is some precedent among transportation agencies from which to learn, AVL implementation can be cost-effectively accomplished with a high level of confidence that the system will prove beneficial.

The second relevant case study was a hypothetical study on the use of AVL for winter maintenance. The case study assumes a hypothetical Midwestern traffic management agency is conducting a study on the use of AVL for highway maintenance activities, especially snow removal. The overall goal of the system is to facilitate: (1) continuous location of snowplow fleet operations, (2) ability to identify vehicles with abnormal behavior, (3) increase safety for the vehicle operator, (4) ability to detect and minimize waste and fraud, (5) ability to capture statistical data, and (6) improved communications efficiency. Cost data,

and qualitative and perceived benefits data were collected from State and local transportation agencies in the United States and Canada. The study concluded that the two primary benefits of AVL deployments are improvements in operating efficiency of the fleet and a reduction in expected crashes. The case study also demonstrated that with AVL there was better allocation of maintenance resources, resulting in less energy use.

2.6 Other Relevant References

Additional literature relevant to the current project includes a current summary of the AVL/GPS/MDSS implementation by the Michigan DOT (MDOT). The presentation provided an overview the process followed by MDOT in selecting an AVL/GPS vendor, along with a definition of the vendor and MDOT roles and responsibilities in MDSS operations. The system allowed for quantitative analyses of their operational efficiencies and post incident reviews. Lessons learned in their deployment were summarized, along with advice to other agencies considering a similar type of MDSS deployment through the use of AVL and GPS technologies.

The Iowa DOT also recently presented on the successes of their AVL/GPS system installed in 2013. Similar to MDOT, the AVL/GPS system allows the Iowa DOT to analyze winter maintenance expenditures in terms of materials, equipment and labor. Additional information is also provided on dashcam images taken from iPhones inside the vehicles. Images from each vehicle are linked to that vehicle's location for the general public to see road conditions in real-time as the snow plow is in operation, which has received a lot of positive feedback from the general public. Lessons learned in their deployment included noting that collecting data from vehicles is much easier than providing good information to the general public.

2.7 Literature Summary References

1. Synthesis on Global Positioning Systems/Automatic Vehicle Location Equipment Used for Winter Maintenance. Clear Roads Project 14-01. July 2016. Available at: <http://clearroads.org/project/synthesis-on-gpsavl-equipment-used-for-winter-maintenance/>
2. Automated Spreading Systems for Winter Maintenance. Clear Roads Project 11-03. February 2014. Available at: <http://clearroads.org/project/development-of-a-totally-automated-spreading-system/>
3. Controlling the Spread. Roads and Bridges. August 29, 2016. By Paul Mortell. Available at <https://www.roadsbridges.com/controlling-spread>
4. Best Practices for Road Weather Management, Version 3.0. FHWA-HOP-12-046. June 1012. Available at: <https://ops.fhwa.dot.gov/publications/fhwahop12046/>
5. Road Weather Management Benefit Cost Analysis Compendium. FHWA-HOP-14-033. August 2014. Available at: <https://ops.fhwa.dot.gov/publications/fhwahop14033/>
6. AVL/GPS/MDSS Use for Winter Maintenance. PPT Presentation at 2015 AASHTO SCOM Meeting. Presented by Tim Croze, P.E., Michigan Department of Transportation. Available at: http://maintenance.transportation.org/Documents/2015%20Meeting%20Presentations/AVL-GPS-MDSS%20Use%20for%20Winter%20Maintenance_MDOT.pdf
7. Iowa DOTs Mobile Truck Cameras and GPS Experience. PPT Presentation at Peoria APWA Meeting. Presented by Tina Greenfield, Iowa Department of Transportation. Available at: http://pavementvideo.s3.amazonaws.com/2016_EMTSP_National/PDF/16_Iowa%20DOTs%20Mobile%20Truck%20Cameras%20and%20GPS%20Experience_May.pdf

Table 1. Survey Respondents

Name	Agency	Name	Agency
Frank Sharpe	Illinois DOT	Joe Thompson	New York State DOT
Charlie Chiasson	SNC Lavalin	Tony McClellan	Indiana DOT
Phillip Anderle	WVB East End Partners	Brandon Klenk	Utah DOT
Jon Henderson	City of Bozeman	Darien Manley	Maryland DOT - SHA
Elizabeth Held	Mpls. Public Works Fleet Services	Todd Law	Vermont Agency of Transportation
Craig Bargfrede	Iowa DOT	Clay Adams	Kansas DOT
Michael Williams	Kentucky Transportation Cabinet	Torgeir Vaa	Norwegian Public Roads Admin
Jon Fleming	Pennsylvania DOT	Kyle Lester	Colorado DOT
Mike Sproul	Wisconsin DOT	Sam Salfity	Massachusetts DOT
Mike Mattison	Nebraska DOT	Steve Spoor	Idaho Transportation Department
Alastair Probert	Delaware DOT	Joe Schmit	Washington State DOT
Gregory Perry	Michigan DOT	R. Todd Miller	Missouri DOT
Brandon Beise	North Dakota DOT	Scott Lucas	Ohio DOT
David Gray	New Hampshire DOT	Allen Williams	Virginia DOT
Mark Trennepohl	Arizona DOT	Patti Caswell	Oregon DOT
Mindy Heinkel	Minnesota DOT	Russell Modrell	Caltrans
Mike Miller	Montana DOT	John DeCastro	Connecticut DOT
Jeff Gleason	Montana DOT	Tom Renninger	Alaska DOT & PF
Brian Burne	Maine DOT	Dan Varilek	South Dakota DOT
Clifford Spoonemore	Wyoming DOT	Joseph A Bucci	Rhode Island DOT

3.2 Summary of Survey Responses

The survey consisted of 32 questions organized into the following 7 parts:

- Part 1 – General questions on the extent of AVL/GPS implementation by agencies.
- Part 2 – Questions on the level of integration between the AVL/GPS system and other winter maintenance vehicle equipment.
- Part 3 – Questions on how AVL/GPS system data is captured from vehicle equipment and how that data is utilized and shared by agencies in performing winter maintenance activities.
- Part 4 – Questions on how the AVL/GPS System communicates with the central offices and other winter maintenance vehicle equipment.
- Part 5 – Questions on the operational and procurement aspects of the AVL/GPS system installed by various agencies.
- Part 6 – Questions on any available cost and benefit information on the AVL/GPS system.
- Part 7 – Questions on lessons learned that the agencies would like to share and whether follow-up questions on the AVL/GPS system could be requested.

Only one survey respondent indicated their agency had not installed AVL/GPS system and had no plans for any future installations (WVB East End Partners). Also, only one agency provided two separate responses to the survey (Montana DOT). Therefore, a total of 38 winter maintenance agencies are included within the results below. It should be noted that one of these agencies currently does not have AVL/GPS equipment, but does have plans to deploy this equipment.

3.2.1 Part 1: Questions 1-9: AVL/GPS System Deployment

The first part of the survey contained nine questions to help understand the extent of the AVL/GPS implementation by various agencies. While there was a total of 40 responses, two responses were from

one agency (Montana DOT), and another agency (WVB East End Partners) indicated they had no AVL/GPS system installed currently, and had no plans to implement the technology in the near future. Therefore, a total of 38 winter maintenance agencies responded positively that they had implemented AVL/GPS systems and / or had plans to implement or expand the technology in future years.

Question 1. Are you currently using an AVL/GPS system to automatically collect data for your winter maintenance operations?

Yes	No
27	11

Question 2. Does your agency have plans to implement or expand AVL/GPS technologies on your winter maintenance vehicles in future years?

Yes	No
36	2

If yes, please describe the anticipated implementation or expansion:

Agency	Anticipated Implementation / Expansion Plans
Illinois DOT	Within 6 months we will be going live on 200 plow trucks as a pilot run for our GPS/AVL implementation.
SNC Lavalin	Possible spread on/pause function for salt application.
City of Bozeman	Water/Sewer & Parks Fleet.
Minneapolis Public Works Fleet Services	We are still in the early roll out phase and are working through some interface issues before expansion.
Iowa DOT	We have currently outfitted 100% of our snowplow trucks. Our future expansion would be focused more on the data. What analysis and tools can we develop for the field staff using the data gathered by the GPS/AVL system.
Kentucky Transportation Cabinet	Plan to expand truck coverage.
Vermont Agency of Transportation	We would like to have our AVL data housed and used with our RWIS data.
Wisconsin DOT	The Goal is to have 100% of the county trucks who work on the state system equipped with the technology.
Nebraska DOT	One third (225) of our plow truck fleet were equipped with AVL/GPS in the last 8 months. We intend to install AVL/GPS in all remaining plow trucks by before the next winter season.
Delaware DOT	This year approximately 1/3 of fleet will be implemented.
Michigan DOT	Expand as we update our fleet.
North Dakota DOT	Currently NDDOT only has 35 snow plows equipped with AVL. NDDOT wants to expand the use of AVL in the plow fleet but right now there are no definite plans to do so.
New Hampshire DOT	Plan to roll out trucks

Agency	Anticipated Implementation / Expansion Plans
Arizona DOT	Currently 75% of our plow truck fleet is AVL equipped. Will continue to up fit new plow trucks with AVL and should have 100% of our plow fleet AVL equipped by 2019.
Minnesota DOT	57 trucks per year.
Maine DOT	We have been updating our spreader controllers as we have replaced trucks. We are a little over halfway there.
New York State DOT	EAMP/MMS w/ Agile Assets presently has this in their scope of work and is under contract w/ New York State DOT.
Indiana DOT	We will collect spreader and plow information.
Utah DOT	We will be expanding into plow up/down sensors and hopefully amount of material applied.
Maryland DOT-SHA	Presently we have AVL units on all SHA winter maintenance vehicles and 1,000 contract winter maintenance vehicles. We would like to expand the use of AVLs to an additional 1,000 contract winter maintenance vehicles.
Pennsylvania DOT	Continued roll out over 9 years.
Norwegian Public Roads Administration	Winter maintenance in Norway has been outsourced since 2003. AVL/GPS will be required in all 103 contract areas when they are renewed.
Montana DOT	We currently have trucks capable of gathering the information we would use, at this time we are working on putting in place a new Maintenance Management system. Once that system is up and working we will look at how to incorporate the vehicle information into the system to aid in winter maintenance activities.
Colorado DOT	100% deployed. We will continue to improve the reliability of the data in Fleet operations, Highway operations, and our winter operations. Focused mostly on integrating data sets into all of our operating systems and processes. In addition we are looking at improve technology and added additional sensors.
Massachusetts DOT	We are looking into collecting data of all our materials and location of all equipment.
Rhode Island DOT	We are expanding our winter fleet and all new vehicles will have AVL/GPS technologies on them. RIDOT is also currently looking into installing AVL/GPS on all light fleet vehicles.
Washington State DOT	100% fleet implementation goal, with about 80% complete to date. Enhanced roadway surface condition sensors as well.
Missouri DOT	We have just kicked off a Maintenance Management System Development Project and the first deliverable is deploying an AVL system statewide and this should occur in the next year and a half.
Ohio DOT	We are reviewing bids currently for our project.
Virginia DOT	All VDOT vehicles outfitted by 6/30/17 and all contractor vehicles by 6/30/19.
Oregon DOT	Considering full telematics in vehicles that are 2009 and newer to collect application material and rate by truck ID and location, plus plow position. In older trucks (that don't have electronic hydraulic systems) we may put in basic GPS or go with a system that would allow the collection of plow position and spreader on/off. This plan would take roughly 13-16 years before all winter 10-yard trucks had the system.
Alaska DOT&PF	Anticipated expansion in Fall 2017.

Agency	Anticipated Implementation / Expansion Plans
Idaho Transportation Department	We are fully implemented with AVL/GPS on all 409 snowplow trucks.
South Dakota DOT	Currently undergoing an Operations study to see how much to expand.

Question 3. Approximately how many vehicles are in your winter maintenance fleet?

Vehicle Fleet Size	Less than 100	101 to 300	301 to 700	More than 700
Number of Agencies	2	6	13	17

Question 4. How many of your winter maintenance vehicles are equipped with AVL/GPS technology?

Vehicle Fleet Size with AVL/GPS	Less than 100	101 to 300	301 to 700	More than 700
Number of Agencies	10	10	10	8

Question 5. Who is your contracted AVL/GPS vendor?

AVL/GPS System Vendor	Total Agencies
Motorola and CompassCom	1
CD Ware	1
CompassCom	2
Verizon Networkfleet	5
Skyhawk Telematics/US Cellular	1
Webtech Wireless	4
Force/PreCise	1
Parsons	3
Location Technologies Inc.	3
SkyHawk Telematics	1
PreCise	1
Ameritrak Fleet Solutions	1
Certified Cirrus Control Systems	2
Gauge Telematics	1
AT&T	2
Zeekit, Mowic, Trimble	1
Zonar and Network Fleet	1
Technologys	1
Just GPS Verizon	1
Network Fleet, GPS Insight, CAT Visionlink	1
N/A	3

Question 6. What modem / GPS brand(s) does your agency utilize?

Modem / GPS Brand	Total Agencies
Airlink Sierra Wireless RV50/Garmin	1

Modem / GPS Brand	Total Agencies
AmeriTrak AT-500	1
AT&T	3
CarAmp	1
Cypress	2
Location Technologies	4
Motorola	1
Parsons	2
Quatech	1
Verizon	7
Webtech Wireless	3
Wi-Fi	1
Zonar	1
Unknown / Unsure	10

Question 7. Who performed the installation of your AVL/GPS system? Was it the system vendor or DOT agency staff?

System Vendor	DOT Agency Staff	Both
18	16	3

Question 8. Who is maintaining the AVL/GPS system after installation? Is there a maintenance contract with the system vendor, or is it maintained in house by DOT agency staff?

System Vendor	DOT Agency Staff
8	29

Question 9. Were there any issues with the installation of your AVL/GPS system?

Yes	No
18	19

If yes, please describe.

Agency	Installation Issues
Iowa DOT	Minor issues by garage staff. All very easy fixes once they were identified.
Kentucky Transportation Cabinet	Compatibility issues with controllers, difficulty with hardware and some units not working once installed.
Vermont Agency of Transportation	We have had some issues with calibration and spread controllers.
Wisconsin DOT	If we have issues within the warranty period we send it back to the vendor. The equipment is maintained by county highway staff.
Nebraska DOT	Connection to spreader controller required additional hardware from controller manufacturers. Low-band two-way radio transmit caused AVL/GPS to reboot/temporarily quit working. These problems are being addressed by the vendor.

Agency	Installation Issues
North Dakota DOT	Learning curve. Many iterations of proper placement, sensor connections, and communications.
New Hampshire DOT	Plow Sensors are not giving us the data we need. Problems with Salt numbers.
Minnesota DOT	Logistics mainly but not any real issues.
Wyoming DOT	Vendor placed the units in the easiest location they could. They were not consistent in their installation. This has caused Wyoming DOT issues with maintenance of the equipment.
Indiana DOT	Caused some CANBus and Instrumentation issues - bad installations in some cases.
Maryland DOT-SHA	Driver acceptance and device tampering. Compatibility with multiple spreader controllers and having to maintain multiple firmware versions for the various controllers. Operator errors including using pause, using manual mode, and running spreader when empty. Quality of initial installation and not standardized across the state as planned. Manufacturer/provider changing AVL devices midway through deployment affecting parts, firmware, cabling, settings, and compatibility with spreader devices.
Pennsylvania DOT	Compatibility with the new spreader controls which is being worked out at the manufacturer level.
Norwegian Public Roads Administration	The systems have been unstable, but I believe there has been made some improvements.
Colorado DOT	Minor issues due to Regional preferences.
Massachusetts DOT	Could not get material data from certified power unit.
Oregon DOT	Trouble in getting accurate communication between Parker IQAN controller and modem. Needed different programming than what we were using when the modem was hooked up.
Caltrans	Several, too many to describe.
Alaska DOT&PF	Some issues with install and proper reporting based on key on/off & master switch on/off, currently still working this out for accurate idle and usage reporting.

3.2.2 Part 2: Questions 10-12: Integration

The second part of the survey contained three questions to help understand the level of integration between the AVL/GPS System and other winter maintenance vehicle equipment.

Question 10. What auxiliary equipment and sensors are installed on the vehicles and integrated with your AVL system?

Auxiliary Equipment and Sensors Integrated with AVL	Count of Agencies Reporting
Spreader controller	28
Plow controller	12
Plow position sensor	20
Mobile data terminal/computer	10
Pavement temperature sensor	23
Air temperature sensor	21

Humidity Sensor	1
Dashcam	10
Other, please describe:	8
Other Items (by Agency):	
Wisconsin DOT	Wing plow sensors, gate sensors
Nebraska DOT	OBDII port (engine diagnostics) from truck is connected to the AVL/GPS.
Arizona DOT	Two cameras installed for operator to see directly behind the plow truck, and to see a RH mid mount wing if installed.
New York State DOT	On Board Engine Computer OBDC.
Pennsylvania DOT	Brine pump.
Colorado DOT	Dash camera is coming. We had cameras with our previous system but when we changed vendors we had to work through a new solution.
Rhode Island DOT	RIDOT's system is expandable to include other sensors if desired.
Missouri DOT	With painting operations, sprayer on/off
Alaska DOT&PF	Currently have light bar on/off reporting through telematics for State Trooper vehicles.

Question 11. Have you experienced difficulty integrating above equipment or sensors into your AVL/GPS system? If so, please describe.

Yes	No
18	19

Agency	Integration Issues
Illinois DOT	Sensors to detect plow position have been a concern given the vibrations and tough environment; I believe we settled on a mercury switch rather than a contact plate.
SNC Lavalin	Communications error with newer vehicle models when connecting to ECU.
Iowa DOT	We are having problems with the Plow Up/Down sensors. Still troubleshooting/testing different solutions.
Kentucky Transportation Cabinet	Yes. RoadWatch temp sensors not working well, some cabling issues between components, units not lasting very long in trucks.
Nebraska DOT	Spreader/Plow controller required additional hardware from controller manufacturer. Monroe MC840 controllers will not connect and are no longer supported.
North Dakota DOT	Sending and receiving spreader controller proprietary data through the AVL computer. Proper type of plow position sensors. Collecting and sending all data to MDSS provider.
NHDOT	Plow sensor is giving us false data when our plows are off.
Minnesota DOT	Mainly software compatibility.
Wyoming DOT	Different controlling group that has a different mission.

Agency	Integration Issues
New York State DOT	The Verizon 5500 doesn't have an API (Application Process Interface) to our materials spreaders (DICKY-john).
Pennsylvania DOT	Yes, difficulty with the new Certified Cirrus controllers to work with the system.
Maryland DOT - SHA	Driver acceptance and device tampering. Compatibility with multiple spreader controllers and having to maintain multiple firmware versions for the various controllers. Operator errors including using pause, using manual mode, and running spreader when empty. Quality of initial installation and not standardized across the state as planned. Manufacturer/provider changing AVL devices midway through deployment affecting parts, firmware, cabling, settings, and compatibility with spreader devices.
Colorado DOT	Yes, cameras have been an issue due to data charges. Integrating sensors due to licensing agreements between vendors.
Washington State DOT	Vendor's specifications do not always do what they state they do. It takes time to validate specs prior to implementing.
Oregon DOT	Temperature sensor (RoadWatch) seems to give erroneous readings-- need to run down potential communication error; had trouble (as noted in previous question) getting the Parker IQAN controller to communicate correctly with the LT6 modem-- the controller needed to be programmed differently to improve communication and data collection.
Alaska DOT&PF	Initially tried plow position sensors and had problems w/ accurate reporting

Question 12. What brand(s) of spreader controller does your agency use?

Spreader Controller	Total Agencies*
Force America	15
Cirrus Spread Smart Controller	11
Dickey Johns	8
Certified Power	6
Monroe	4
RexRoth	4
Muncie	4
Raven	3
Parker	2
Schmidt	1
Henderson	1
Pengwen	1

*Note: Many agencies use multiple types of spreader controllers.

3.2.3 Part 3: Questions 13-19: Data Management

The third part of the survey contained seven questions to help understand how the AVL/GPS System data is captured from vehicle equipment and how that data is utilized and shared by the agencies in performing winter maintenance activities.

Question 13. What types of data other than vehicle location are being captured with your AVL system? What is the data capture frequency?

Data Captured	Capture Frequency				
	≤1 min.	≤5 min.	≤10 min.	≤15 min.	Not Captured
Plow position	11	7	1	1	17
Material application rate	18	9	0	0	10
Type of material applied	15	8	0	1	13
Mobile data terminal messages	4	4	0	0	29
Pavement temperature	15	8	0	0	14
Air temperature	13	7	0	0	17
Humidity	0	1	1	0	35
Surface friction	0	1	1	0	35
Dashcam	4	5	2	2	24
Engine diagnostics	2	9	2	0	24
Other, please describe below:	1	1	1	2	32
Minneapolis Public Works Fleet Services	Mileage.				
Arizona DOT	We collect pre-wet data and direct liquid data where applicable.				
Missouri DOT	Paint sprayer for striping operations.				
Oregon DOT	System should also capture state changes that occur outside the set timeframe; this hasn't been confirmed.				

Question 14. Where does the AVL system data reside after it is transmitted from the vehicles?

	Vendor-Hosted / Cloud-Based	Internal Agency Servers	Both	N/A
Number of Agencies	22	6	6	3

Question 15. Do you use the AVL system data to perform any of the following items?

Additional System Functions	Count of Agencies Reporting
Vehicle location tracking / fleet monitoring	31
Route/operational planning and optimization	14
Material usage tracking and analysis	23
Treatment recommendations	11
Providing data to a maintenance decision support system (MDSS)	8
Operational analysis, evaluation and performance reporting	19
Collection of vehicle diagnostic data	12
Sharing of vehicle location through agency traveler information webpage	11
Road weather condition reporting	6
Staffing analysis and management	10
Other, please describe (below by Agency):	5
Oregon DOT	Tort claims; otherwise hasn't been used much by the field; too much difficulty getting it to function correctly.

Additional System Functions		Count of Agencies Reporting
Nebraska DOT	OBDDII port (engine diagnostics) from truck is connected to the AVL/GPS.	
North Dakota DOT	Live internet connection to view weather, timesheets, or other webpages.	
Alaska DOT&PF	Lightbar use for State Trooper vehicles.	
Wyoming DOT	Complaint management.	

Question 16. Does your agency share data collected through the AVL system *internally* with other divisions or offices within the department?

Yes	No
23	14

If yes, what do those divisions/offices use the data for (e.g., operational analysis, planning, performance reporting, budgeting, etc.)?

Agency	Data Shared Internally within Agency
Minneapolis Public Works Fleet Services	Adjusting routes, vehicle tracking/monitoring, analysis and management.
Kentucky Transportation Cabinet	Operational analysis and performance reporting.
Vermont Agency of Transportation	Locations for customer service.
Iowa DOT	1. Populate a public facing page that shows snowplow trucks locations and photos from our Plow Cam; 2. Data populates a Winter Cost Calculator; 3. Claims Management uses this data to verify claims against the department involving our snowplow trucks; and 4. Bridge is considering using this data to track chloride applications on various bridge decks. This information will potentially help them forecast bridge maintenance activities.
Nebraska DOT	Only observation at this time.
Delaware DOT	Public relations.
Michigan DOT	ITS department.
New Hampshire DOT	Vehicle location.
Arizona DOT	Risk mgmt., performance monitoring/measurements, event reconstruction, operational analysis, seasonal material totals.
Minnesota DOT	Operational analysis, reporting, planning, etc.
Maine DOT	Legal - Complaint/Claim Research.
New York State DOT	Situational awareness.
Indiana DOT	Operational analysis.
Utah DOT	Traffic for the public info page.
Maryland DOT - SHA	Human resource matters.
Pennsylvania DOT	All aspects of winter maintenance from County to District to Central Office.

Agency	Data Shared Internally within Agency
Colorado DOT	Public Relations for location information.
Massachusetts DOT	Planning, reporting.
Missouri DOT	Mostly situational awareness.
Idaho Transportation Department	Process improvement.
South Dakota DOT	Planning, budgeting and performance measures.

Question 17. Does your agency share AVL system data *externally* with other public agencies?

Yes	No
6	31

If yes, please describe what data is being shared with these other agencies.

Agency	Data Shared Externally with Public Agencies
SNC Lavalin	Our client.
Iowa DOT	Iowa State - INTRANS uses our data for various projects that we are collaborating on: Crash analysis, traffic speed data, and we are planning to explore a route optimization project.
Vermont Agency of Transportation	On public facing website.
North Dakota DOT	Sometimes highway patrol will ask if an AVL dashcam was in area. We will manually check the data, but it is not automatically shared with HP.
Minnesota DOT	NCAR / WEDE.
New York State DOT	Speed / location.
Virginia DOT	Vehicle location, but no crumb trail.

Question 18. Does your agency share AVL system data *externally* with any private agencies, such as private weather service providers?

Yes	No
10	27

If yes, please describe what data is being shared with these other agencies.

Agency	Data Shared Externally with Private Agencies
Kentucky Transportation Cabinet	Only the road and air temps.
Wisconsin DOT	Iteris provides the MDSS data.
Michigan DOT	Location, material usage, photos.
North Dakota DOT	Iteris (MDSS provider).
Arizona DOT	Location, speed, plow position, spreader status, spreader setting, pre-wet status, pre-wet setting, material type, distance spread, road temp.
Maine DOT	We would like to share with NWS at some point and have discussed it with them.

Agency	Data Shared Externally with Private Agencies
Indiana DOT	Spreader plow and location information.
Colorado DOT	Iteris for MDSD and PikAlert.
Washington State DOT	Location, surface and air temp.

Question 19. Does your agency share AVL system data with the general public?

Yes	No
10	27

If yes, please describe what AVL system data is being shared with the general public.

Agency	Data Shared with General Public
Illinois DOT	Plow truck locations is the only publicly released data.
Iowa DOT	Snowplow truck locations are posted to a public facing map during the winter season along with photos from our PlowCam's.
Kentucky Transportation Cabinet	Only the road and air temps.
Vermont Agency of Transportation	Via public facing vehicle location pm the agency website.
Delaware DOT	location of trucks with a delay built in.
Michigan DOT	Location and photos.
Minnesota DOT	Plow cam images.
Utah DOT	We show the public a bread crumb trail of where our plows have been for the past 30 min.
Pennsylvania DOT	511 location only.
Colorado DOT	Location information is posted on our public facing website.

3.2.4 Part 4: Questions 20-21: Communications

The fourth part of the survey contained the following two questions to help understand how the AVL/GPS system communicates with the central offices and other winter maintenance vehicle equipment.

Question 20. What type of communications does your AVL/GPS system use to transfer data? Please check all that apply:

Communications Methods Reported	Count of Agencies Reporting
Cellular network	32
Satellite	3
Data radio system	3
Wi-Fi	8
Other	2

Question 21. How would you rate the coverage of your communications system?

Coverage of Communications System	Count of Agencies Reporting
Covers all of maintenance areas	8
Covers most of maintenance areas with acceptable gaps	21
Covers most of maintenance areas with unacceptable gaps	4
Substantial gaps in coverage	4

3.2.5 Part 5: Questions 22-27: Operational and Procurement Aspects

The fifth part of the survey contained the following six questions to help understand the operational and procurement aspects of the AVL/GPS System installed by various agencies.

Question 22. Do you have a distributed approach to tracking vehicle locations (i.e. by district or geographic boundaries)? Or is there a centralized method of tracking all vehicles within the agency boundaries? Or do you use a mix of both approaches?

Vehicle Location Tracking Approach	Count of Agencies Reporting
Distributed approach	13
Centralized approach	7
Both	17

Question 23. Is your agency's AVL system equipment provided by a single vendor or multiple vendors?

AVL System	Count of Agencies Reporting
Single vendor	30
Multiple vendors	7

Question 24. Does your agency utilize a web-based interface accessible over the internet to access operational information?

Yes	No
30	7

If yes, how is the data that can be extracted from the interface utilized to improve upon winter maintenance operations?

Agency	Data Used to Improve Winter Maintenance Operations
Iowa DOT	We have multiple reports that can be produced that provide us with information down to the individual truck. We can use these reports to identify problem areas, coach/mentor new operators, validate spreader calibration, etc.
Kentucky Transportation Cabinet	Truck location, route coverage and material rates.

Agency	Data Used to Improve Winter Maintenance Operations
Vermont Agency of Transportation	Plans to utilize AVL with RWIS to track the success of winter operations.
Wisconsin DOT	It's used for treatment recommendations.
Nebraska DOT	Vehicle location, material application rate, and camera images are used to evaluate maintenance practices and results relative to weather and road conditions.
Michigan DOT	Monitors material usage and labor.
North Dakota DOT	There are only a select few with access to the vendor's website. Iteris pulls data from the server for the MDSS integration. Data through MDSS can be viewed by any plow operator or maintenance staff. Basic MDSS data includes treatment recommendations, weather info, and truck info (bread crumb, speed, materials, locations, and summary reports).
New Hampshire DOT	Still beginning stages of use so we haven't used any of the data yet.
Arizona DOT	We have developed a number of web based tools that utilize AVL raw data. The web based tools that are primarily for use by maintenance superintendents, supervisors, and crews to manage pre storm, during storm, and post storm operations. There is a group of management tools for cost analysis and performance measurement.
Minnesota DOT	Analyzed for performance and reporting purposes.
Maine DOT	Review time of response and applications.
Indiana DOT	Excel spreadsheets.
Utah DOT	We are working on that. It isn't used for much of anything other than tracking right now.
Maryland DOT - SHA	Resources can be deployed in a more efficient manner based on location. During and post-storm reporting data can be utilized to evaluate driver performance which can help identify driver training needs.
Pennsylvania DOT	Efficiencies in knowing exactly what operators are doing at any one time.
Colorado DOT	Location data, material data, road condition reporting.
Rhode Island DOT	Application rates are monitored; vehicles speeds tracked to ensure efficiencies and safe operations are being followed.
Washington State DOT	Web mapping and SQL reports, Excel.
Missouri DOT	It has been used mostly for situational awareness so far but we have had limited engagement with this.
Virginia DOT	Monitor vehicle location and track, vehicle idle time, vehicle non-use time.
Oregon DOT	So far it has only been viewed but not used to evaluate or improve performance.
Idaho Transportation Dept.	We monitor material application rates, frequency, lap times, etc. for process improvement and efficiency improvements.
South Dakota DOT	The web-based program is only used by DOT inter agency for performance measurements, budgeting and manning.

Question 25. Does your agency extract data from the AVL/GPS system and / or web-based interface for separate analyses to improve upon winter maintenance operations after winter weather events?

Yes	No
20	17

If yes, please describe how the data is utilized by your agency.

Agency	Data Extracted for Separate Analyses
City of Bozeman	Analyzed by GIS Department for performance metrics.
Iowa DOT	Various projects with Iowa State University.
Vermont Agency of Transportation	Not currently.
Wisconsin DOT	We use it in the summer too for other maintenance functions.
Nebraska DOT	Vehicle location, material application rate, and camera images are used to evaluate maintenance practices and results relative to weather and road conditions.
Michigan DOT	Only if there was a severe crash, or involving several vehicles.
Arizona DOT	We have developed a number of web based tools that utilize AVL raw data. The web based tools that are primarily for use by maintenance superintendents, supervisors, and crews to manage pre-storm, during storm, and post storm operations. There is a group of management tools for cost analysis and performance measurement.
Minnesota DOT	Budget / reporting / performance / application.
Maine DOT	Review application rates and salt usage.
New York State DOT	Managers use AVL data to monitor truck speeds in addition to well-timed response. Engine idling data is used to check conformance to Policy.
Indiana DOT	Better application rates.
Maryland DOT - SHA	Resources can be deployed in a more efficient manner based on location. During and post-storm reporting data can be utilized to evaluate driver performance which can help identify driver training needs.
Pennsylvania DOT	Ability to show managers differences in operators on the same route.
Colorado DOT	Road condition reporting for performance on a storm by storm basis.
Massachusetts DOT	Early call out and material handling.
Rhode Island DOT	Not specific to individual events necessarily.
Washington State DOT	Monitoring application rates and aligning treatment goals.
Ohio Department of Transportation	We plan to in the future.
Idaho Transportation Department	Our objective is to use post storm analysis to develop opportunities for improvement.
South Dakota DOT	We compare the AVL reports to our in-house Winter Performance System to see how the AVL providers' recommendations compare to the non-AVL trucks.

Question 26. What was the procurement process used for your AVL/GPS system (i.e. Request for Proposals (RFP), Invitation for Bids (IFB))?

Procurement Process		
Request for Proposals	Invitation for Bids	Other
19	3	15

Was a demonstration of the system included as part of the evaluation of respondents?

Yes	No
20	15

Question 27. Does your agency move your AVL/GPS vehicle units to different trucks or equipment for use during summer maintenance operations?

Yes	No
3	34

3.2.6 Part 6: Questions 28-30: Costs and Benefits

The sixth part of the survey contained the following three questions to help understand what cost and benefit information on the AVL/GPS system could be shared by the responding agency that might be useful in a potential case study that will be performed at a later stage in the project.

Question 28. Do you have cost information associated with your AVL system?

Yes	Not Sure	No
25	5	7

Question 29. What cost information would you be able to provide?

Cost Information for Review	Count of Agencies Reporting
AVL equipment costs	28
Installation & integration costs	17
Costs associated with on-going operations (staffing, communications, software licensing, etc.)	17
Maintenance costs	10

Question 30. Has there been any formal or informal benefits assessment or benefit-cost analysis performed on your AVL system and/or other technology for winter maintenance operations?

Yes	Not Sure	No
11	9	17

3.2.7 Part 7: Questions 31-32: Deployment Experience

The final part of the survey contained the following two questions to gather lessons learned that the agencies would like to share in the survey and determine whether or not follow-up questions on the AVL/GPS system could be requested.

Question 31. Please share any general lessons learned in the deployment of AVL/GPS technologies below that would assist agencies considering a future deployment of these technologies.

Agency	General Lessons Learned
Illinois DOT	Resistance from plow drivers and managers to having reporting capabilities via in-truck tablet has been a challenge that IDOT is currently facing.
SNC Lavalin	Make sure service offered is really what you need. Many cheap systems out there, but you pay what you get!
City of Bozeman	Analysis for performance measures is critical.
Minneapolis Public Works Fleet Services	Interfaces may not work as expected and need modification.
Iowa DOT	<ol style="list-style-type: none"> 1. To be successful, you must have field involvement from the very beginning of this project. They must feel that they are a part of the decision process. 2. Standardize equipment, i.e. use one spreader controller rather than multiple types. 3. This program must be centrally managed to be successful.
Kentucky Transportation Cabinet	Need a good solid strategy for long term implementation. Best to have IT and operational folks on lead team.
Vermont Agency of Transportation	Ensure you get all of the data/ information you want, not just GPS location.
Wisconsin DOT	We should have waited until the AVL patent issues were resolved before jumping into the pond. Not being able to feed information back to the vehicles has really stymied our use of the technology.
Nebraska DOT	It is important to know how you intend to use the technology and what your needs are before writing specifications. Operators and managers should be informed well in advance and throughout the project what the expectations are. Problems should be addressed as quickly as possible. If possible, do a pilot project in advance to identify issues and opportunities. Be open to possibilities for additional use of the technology. Look for all of the value that you can get. Learn from the experience of your peers in other organizations.
Delaware DOT	Need to ensure equipment can handle multiple nonproprietary sensor inputs.
Michigan DOT	Had issues with the non-user friendly vendor website and hydraulic sensors.
North Dakota DOT	I think most will recognize the benefits of an AVL system in the winter maintenance fleet. The big concern NDDOT has is proving to Legislature the tangible benefits and how the benefits relate to the bottom line costs. There are many benefits to having a fully equipped AVL fleet (CV, engine data, travel info, MDSS, data driven operations, etc.) and having the proper systems in place to analyze the data is key. Having the right people to implement changes based on data is also very important. I hope this Clear Roads project summarizes all the value added to an agency that an AVL system can bring. Combining efforts with other pooled fund studies might be a great resource to further this research project.
New Hampshire DOT	The spreaders we have are having issues with calibration which is causing the AVL to not be accurate.
Arizona DOT	Implementation/employee buy in is the key to a successful AVL program. There is always the perception that "big brother" is watching and that people will lose their jobs. We've Been using AVL since 2007, and no one has ever lost a job or been reprimanded. It all depends on how you sell it to the folks in the field.

Agency	General Lessons Learned
Minnesota DOT	1) Making sure you have enough staffing to support, train and implement. 2) Make sure you have buy in from management. 3) Sustainable funding for the future - all in approach. 4) Buy in and working with field staff to utilize and understand the business benefit and not just a big brother.
Maine DOT	Don't underestimate the maintenance involved to keep it all working correctly.
Wyoming DOT	Know that the intent of the AVL/GPS is needed for. In our case the controlling group has a different mission than that of the maintenance group that could also use the AVL/GPS system.
New York State DOT	Map your Agencies data inputs including component or system limitations and their stream to and from other systems. When selecting a provider, insist on a Service Level Agreement that includes penalties for failure to deliver those critical data streams required for processing system outputs.
Indiana DOT	Need qualified installers, better demonstrations, and better contract language for life of the units.
Utah DOT	The diagnostic function has saved our technicians a lot of time since they don't have to make 2 trips to fix a problem. We also used the info from storms in our plow route optimization.
Maryland DOT-SHA	Driver acceptance and device tampering. Compatibility with multiple spreader controllers and having to maintain multiple firmware versions for the various controllers. Operator errors including using pause, using manual mode, and running spreader when empty. Quality of initial installation and not standardized across the state as planned. Manufacturer/provider changing AVL devices midway through deployment affecting parts, firmware, cabling, settings, and compatibility with spreader devices.
Pennsylvania DOT	Know what you want the system to deliver before designing a system.
Norwegian Public Roads Administration	We have no specifications for the AVL/GPS technologies here in Norway, and I think this is the most important lesson learned. The market (contractor and system provider) should relate to clear requirements defined by the road owner.
Montana DOT-SHA	Look at what other states have done.
Colorado DOT	Be prepared that technology is dated. With the lead time to deploy and the time it takes to be accepted by the employees, by the time the system is fully operational there will be a new and improved system out on the market.
Massachusetts DOT	Could not find one company that could intergrade one unit to report from all spreaders units.
Rhode Island DOT	We have noticed cost savings from tracking and monitoring our material spreading. We have also improved our plow route efficiency by using these technologies
Washington State DOT	DOT's need to implement a sound training and support structure for AVL. Without an internal support network -- the program will have little traction and likely will not progress in a positive way.
Missouri DOT	Our monthly costs are \$18 per month per unit.
Ohio DOT	Nothing yet.
Virginia DOT	Monitoring of data requires dedicated personnel with a sound technology background. The data from the system is more beneficial to the agency if the upfront time is put into developing the system boundaries and mapping.
Oregon DOT	Within the agency there are many differences of opinion about what people want to know or what info people want to be able to access regarding winter maintenance. Folks get the tort claim issue, and they readily admit hard copy logs.

Agency	General Lessons Learned
Caltrans	Hope to have AVL system in place by Jan. 2018
CONNECTICUT DOT	Currently have not deployed system statewide. Was able to pilot 16 trucks late on winter season 2016-2017.
Alaska DOT&PF	Greatest value comes from evaluating data to drive decisions on how to optimize equipment. This requires a commitment to data analysis and accurate reporting to managers.
Idaho Transportation Department	Commonality of components is critical for consistent data on a statewide basis.
South Dakota DOT	Great communication among inner agencies when planning routes. Decide whether you want to utilize the AVL system for more than winter usage. Verify that AVL system will work for your needs and expectations. Make it as easy for the drivers to use.

Question 32. May we contact you with follow-up questions about your system(s)?

Yes	No
34	3

3.3 Tiers of AVL/GPS Implementation and Utilization

Upon collecting and summarizing the survey responses, agencies were categorized into three tiers based on the level of AVL/GPS implementation and utilization. The three tiers are defined below:

- Tier 1: Basic Location Tracking/Monitoring with or without collection of vehicle diagnostic data
- Tier 2: Medium implementation with basic location tracking, with additional data collection, equipment integration, and system reporting features
- Tier 3: High implementation with added, more complex data collection, integration, and reporting features

9 out of the 37 agencies responding to the survey fall into Tier 1, as listed in Table 2. These agencies are further described and analyzed in Section 4.

Table 2. Tier 1 Agencies

Location Tracking without Vehicle Diagnostic Data	Location Tracking with Vehicle Diagnostic Data
New York State DOT Virginia DOT Wyoming DOT Connecticut DOT	Utah DOT Delaware DOT Minneapolis Public Works Fleet Services Alaska DOT & PF Caltrans

The remaining 28 agencies were considered as either Tier 2 or Tier 3 agencies. Further analysis was performed to categorize those agencies into two tiers based on their levels of implementation, integration, and data collection and utilization. The analysis primarily used the information gathered from survey questions 10, 13, and 15 as shown in Table 3.

Table 3. Criteria for Evaluation of Tiers 2 & 3 Agencies in AVL/GPS Implementation

Evaluation Criteria	Survey Questions
Number and type of equipment / sensors integrated	10
Number and type of data elements captured	13
Number and type of tasks performed with AVL/GPS data	15

The research team utilized a simplified scoring method to assess and rank each agency’s level of implementation and integration. Three different scoring systems were utilized:

1. A total sum of (1) the number of equipment / sensors integrated, (2) the number of data elements captured, and (3) the number of winter maintenance tasks performed with the AVL/GPS data.
2. A weighted sum of the above three factors with 3/3/4 distribution:

$$\text{Weighted Sum\#1} = (\text{No. of Integrated Equipment}) \times 3 + (\text{No. of Captured Data Elements}) \times 3 + (\text{No. of Tasks Performed}) \times 4$$
3. A weighted sum of the above three factors with 4/2/4 distribution:

$$\text{Weighted Sum\#2} = (\text{No. of Integrated Equipment}) \times 4 + (\text{No. of Captured Data Elements}) \times 2 + (\text{No. of Tasks Performed}) \times 4$$

Based on the score distribution, agencies were categorized into Tiers 2 and 3 in Table 4.

Table 4. Summary of Tiers 2 & 3 Agencies and Level of Integration with AVL/GPS Systems

Agencies		Responses to Survey Questions			Scores		
		#10	#13	#15	Total Sum	Weighted Sum #1	Weighted Sum #2
Tier 2	Maryland DOT - SHA	2	3	2	7	23	22
	Massachusetts DOT	1	2	5	8	29	28
	New Hampshire DOT	2	3	4	9	31	30
	Montana DOT	4	6	0	10	30	28
	Missouri DOT	5	3	3	11	36	38
	Maine DOT	3	4	4	11	37	36
	City of Bozeman	3	2	6	11	39	40
	Norwegian Public Roads Admin.	5	5	2	12	38	38
	Washington State DOT	4	5	3	12	39	38
	Pennsylvania DOT	4	4	4	12	40	40
	Oregon DOT	4	6	3	13	42	40
	Kentucky Transportation Cabinet	4	5	4	13	43	42
	Illinois DOT	3	4	6	13	45	44
	Vermont Agency of Transportation	5	5	4	14	46	46
Michigan DOT	3	7	5	15	50	46	
Tier 3	North Dakota DOT	6	7	4	17	55	54
	Arizona DOT	6	6	5	17	56	56
	Idaho Trans. Dept.	7	5	5	17	56	58
	Indiana DOT	5	5	7	17	58	58
	Rhode Island DOT	4	6	7	17	58	56

Agencies	Responses to Survey Questions			Scores		
	#10	#13	#15	Total Sum	Weighted Sum #1	Weighted Sum #2
Iowa DOT	6	7	5	18	59	58
South Dakota DOT	6	6	7	19	64	64
SNC Lavalin	4	11	5	20	65	58
Minnesota DOT	6	7	7	20	67	66
Nebraska DOT	7	7	7	21	70	70
Wisconsin DOT	7	6	8	21	71	72
Colorado DOT	8	10	10	28	94	92

3.4 Tier 1 Agency Analysis

As noted previously, nine winter maintenance agencies were assigned within Tier 1. A further review of the survey responses allowed for narrowing down the list of candidates for consideration in the selection of case study agencies. For example, Connecticut DOT piloted the AVL/GPS on 16 trucks in the last winter season and has not expanded the deployment. Caltrans is moving forward with a new system that will likely be in place by January 2018. Five agencies were identified as potential candidates for conducting case studies. They were further evaluated with respect to the following factors:

- Fleet size and percent of fleet with AVL
- Number and type of equipment/sensors integrated with the AVL/GPS system
- Number and brand of spreader controllers installed
- Number of type of data collected
- Number of tasks performed using the AVL data
- AVL data sharing policy and practice
- Availability of cost and benefit data

Table 5 on the next page lists and compares the five potential candidates with the above factors along with other information.

The **Utah DOT** was recommended as a case study Interview agency for Tier 1, given its current use of the system for vehicle location tracking and collection of vehicle diagnostic data, as well as for the amount of internal and external data sharing reported and the ability to provide documented benefits of AVL/GPS system implementation.

The **New York State DOT** was also recommended as a candidate for a Tier 1 case study due to its utilization of AVL data for various planning and operational analysis tasks as well as the ability to provide documented costs and benefits of system implementation.

Given the similarities of the AVL/GPS systems, and in the responses presented in Table 5, the research team recommended that one case study agency was selected from the group of Tier 1 agencies. The research team recommends the **Utah DOT** as a case study interview agency for the group of Tiers 1. The New York State DOT was recommended as a backup candidate in an event if interviews with the Utah DOT could not be arranged.

Table 5. Summary of Agency Candidates for Tier 1 Case Study

Agency	New York	Virginia	Utah*	Alaska	City of Minneapolis
Fleet Size (% with AVL) (Q3-4)	1600 (100%)	11000 (68%)	505 (100%)	1000 (32%)	200 (13%)
AVL/GPS Vendor (Q5)	Verizon NetworkFleet	Verizon NetworkFleet	Verizon NetworkFleet	Verizon NetworkFleet, GPS Insight, CAT Visionlink	Verizon NetworkFleet
Communications (Q20)	Cellular	Cellular	Cellular	Cellular / Satellite	Cellular
Data Server (Q14)	Vendor hosted	Vendor hosted	Vendor hosted	Vendor hosted	Vendor hosted
Types of spreader controller (Q12)	1 (DICKEY-John: Control Point Control System & Flex4)	1 (Certified Power Component Technologies Storm Guard)	1 (FORCE America)	2 (FORCE America, Certified Cirus)	N/A
Number & types of equipment & sensors integrated with AVL (Q10)	1 (On Board Engine Computer OBDc)	0 (None)	1 (Plow position sensor)	1 (Light bar)	0 (None)
Number & types of data elements captured (Q13)	0 (None)	0 (None)	1 (Engine diagnostics)	2 (Engine diagnostics, Light bar for State Trooper vehicles)	2 (Engine diagnostics, Vehicle mileage)
Number & types of tasks performed with AVL (Q15)	5 (Vehicle location, Operational analysis, Vehicle diagnostics, Info sharing, Staffing)	3 (Vehicle location, Info sharing, Staffing)	4 (Vehicle location, Route planning, Vehicle diagnostics, Info sharing)	4 (Vehicle location, Route planning, Operational analysis, Vehicle diagnostics)	4 (Vehicle location, Route planning, Vehicle diagnostics, Staffing)
Agency policy for AVL/GPS data sharing (Q16-19)	Internal and external (Data shared with ITS dept., Speed and location of vehicles)	Internal and external (Vehicle location but no crumb trail)	Internal only (Truck locations on public website)	Internal only (Data shared with fleet, highway maintenance and operations)	Internal only (route planning, vehicle location and operational analysis)
Location Shared with Public (Q19)	No	No	Yes	No	No
Documented costs and benefits of implementation (Q28-30)	<u>Costs:</u> AVL equipment, and maintenance costs <u>Benefits:</u> Yes	<u>Costs:</u> AVL equipment, and operations costs <u>Benefits:</u> Not sure	<u>Costs:</u> AVL equipment, integration, and operations costs <u>Benefits:</u> Yes	<u>Costs:</u> AVL equipment and integration costs <u>Benefits:</u> Not sure	<u>Costs:</u> AVL equipment and operations costs <u>Benefits:</u> No

Notes: * Recommended Case Study Agency

3.5 Tier 2 Agency Analysis

Fifteen winter maintenance agencies were assigned within Tier 2 based on the level of AVL/GPS system integration as presented in Table 4 previously. Factors for evaluating and selecting recommended agencies for case studies include:

- Fleet size and percent of fleet with AVL
- Number and type of equipment/sensors integrated with the AVL/GPS system
- Number and brand of spreader controllers installed
- Number of type of data collected
- Number of tasks performed using the AVL data
- AVL data sharing policy and practice
- Availability of cost and benefit data

Upon review of the survey responses from the fifteen agencies, five of these Tier 2 agencies were selected for further review and comparison to determine which agencies had different types of AVL/GPS integration, as well as different characteristics in how their AVL/GPS systems were implemented and utilized. Table 6 on the following page presents the characteristics of these five candidate case study agencies.

In reviewing the responses, it was recommended that two of these agencies – the **Michigan DOT** and the **Washington State DOT** – be selected as Tier 2 case study agencies given their current use of the system for vehicle location tracking and collection of vehicle diagnostic data, and for the additional data collection, integration, and reporting features noted in their survey responses. The Vermont Agency of Transportation and the Pennsylvania DOT, respectively, are recommended as primary and secondary backup candidates in an event if interviews with the Michigan DOT and Washington State DOT cannot be arranged.

3.6 Tier 3 Agency Analysis

Twelve winter maintenance agencies were assigned within Tier 3 based on the level of AVL/GPS system integration as presented in Table 4 previously. Upon review of the survey responses from the twelve agencies, five of these Tier 3 agencies were selected for further review and comparison to determine which agencies had different types of AVL/GPS integration, as well as different characteristics in how their AVL/GPS systems were implemented and utilized. Table 7 presents the characteristics of these five candidate case study agencies.

Tier 3 represents agencies that have more sophisticated AVL/GPS system implementation, integration and data utilization. As such, the research team recommended selecting three agencies in Tier 3 for case studies. In reviewing the five responses, it was recommended that three of these agencies – the **Colorado DOT**, the **Wisconsin DOT** and the **Nebraska DOT** – be selected as Tier 3 case study agencies given their current use of the system for vehicle location tracking and collection of vehicle diagnostic data, as well as for the additional data collection, integration, and reporting features. The Minnesota DOT and the Iowa DOT, respectively, are recommended as primary and secondary backup candidates in the event that interviews with either of the recommended DOTs cannot be arranged.

Table 6. Summary of Agency Candidates for Tier 2 Case Studies

Agency	Michigan*	Washington*	Vermont**	Pennsylvania**	Kentucky
Fleet Size (% with AVL) (Q3-4)	340 (94%)	500 (80%)	250 (100%)	2250 (100%)	1430 (17%)
AVL/GPS Vendor (Q5)	Parsons	Location Technologies	Webtech Wireless	AT&T	Webtech
Communications (Q20)	Cellular	Cellular / Data Radio System	Cellular	Cellular	Cellular / Satellite
Data Server (Q14)	Vendor hosted	Vendor hosted and internal	Vendor hosted	Vendor hosted and internal	Vendor hosted and internal
Types of spreader controller (Q12)	1 (DICKY-John)	5 (DICKY-John, Force America, Parker, Raven, Schmidt)	2 (Cirrus Controls, Certified Power)	2 (Cirrus Controls, Certified Power)	3 (DICKY-John (state veh.), FORCE America (contract veh.), Muncie Power Products)
Number & types of equipment & sensors integrated with AVL (Q10)	3 (Spreader controller, Plow position sensor, Dashcam)	4 (Spreader controller, Plow position sensor, Pavement temperature sensor, Air temperature sensor)	5 (Spreader controller, Plow controller, Plow position sensor, Pavement temperature sensor, Air temperature sensor)	4 (Spreader controller, Pavement temperature sensor, Air temperature sensor, Brine pump)	4 (Spreader controller, Plow position sensor, Pavement temperature sensor, Air temperature sensor)
Number & types of data elements captured (Q13)	7 (Plow position, Material application rate, Type of material, Pavement temperature, Air temperature, Dashcam, Engine diagnostics)	5 (Plow position, Material application rate, Type of material, Pavement temperature, Air temperature)	5 (Plow position, Material application rate, Type of material, Pavement temperature, Air temperature)	4 (Material application rate, Type of material, Pavement temperature, Air temperature)	5 (Plow position, Material application rate, Type of material, Pavement temperature, Air temperature)
Number & types of tasks performed with AVL (Q15)	5 (Vehicle location, Material usage, Operational analysis, Vehicle diagnostics, Info sharing)	3 (Material usage, Operational analysis, Road weather)	4 (Vehicle location, Material usage, Info sharing, Staffing)	4 (Vehicle location, Route planning, Material usage, Operational analysis)	4 (Vehicle location, Route planning, Material usage, Operational analysis)
Agency policy for AVL/GPS data sharing (Q16-19)	Internal and external (Data shared with ITS dept., material usage and photos of vehicle operations)	No Sharing	Internal and external (Truck locations for customer service and on public website)	Internal only (Data shared with County, District & Central offices)	Internal and external (Operational analysis and performance reporting, road and air temperature with private agencies)
Location Shared with Public (Q19)	Yes	No	Yes	Yes	Yes
Documented costs and benefits of implementation (Q28-30)	<u>Costs</u> : Yes / Types to be determined <u>Benefits</u> : No	<u>Costs</u> : AVL equipment, integration, and maintenance costs <u>Benefits</u> : No	<u>Costs</u> : AVL equipment, integration, operations and maintenance costs <u>Benefits</u> : Not sure	<u>Costs</u> : AVL equipment, integration, and operations costs <u>Benefits</u> : Yes	<u>Costs</u> : AVL equipment <u>Benefits</u> : No

Notes: * Recommended Case Study Agency
 ** Recommended Backup Case Study Agency

Table 7. Summary of Agency Candidates for Tier 3 Case Studies

Agency	Colorado*	Wisconsin*	Nebraska*	Minnesota**	Iowa**
Fleet Size (% with AVL) (Q3-4)	1200 (100%)	754 (53%)	675 (33%)	850 (76%)	902 (100%)
AVL/GPS Vendor (Q5)	Zonar and Networkfleet	Force/PreCise	Parsons	Ameritrak Fleet Solutions	SkyHawk Telematics
Communications (Q20)	Cellular / WiFi	Cellular / WiFi	Cellular	Cellular / DSRC	Cellular / WiFi
Data Server (Q14)	Vendor hosted	Vendor hosted and internal	3 rd party server	Local server	Vendor hosted with local backup
Types of spreader controller (Q12)	1 (Cirus Controls)	2 (FORCE America 5100 and 6100)	5 (FORCE America, Certified Power, Cirus Controls, Raven, Monroe)	2 (DICKEY-John, FORCE America 6100)	1 (Cirus Controls)
Number & types of equipment & sensors integrated with AVL (Q10)	8 (Spreader controller, Plow controller, Plow position sensor, MDC, Pavement temperature sensor, Air temperature sensor, Humidity sensor, Dashcam (future))	7 (Spreader controller, Plow controller, Plow position sensor, MDC, Pavement temperature sensor, Air temperature sensor, Wing plow sensor, Gate sensor)	7 (Spreader controller, Plow controller, MDC, Pavement temperature sensor, Air temperature sensor, Dashcam, OBDII)	6 (Spreader controller, Plow position sensor, MDC, Pavement temperature sensor, Air temperature sensor, Dashcam)	6 (Spreader controller, Plow controller, Plow position sensor, Pavement temperature sensor, Air temperature sensor, Dashcam)
Number & types of data elements captured (Q13)	10 (Plow position, Material application rate and type, Mobile data messages, Pavement temperature, Air temperature, Humidity, Surface friction, Dashcam, Engine diagnostics)	6 (Plow position, Material application rate and type, Pavement temperature, Air temperature, Engine diagnostics)	7 (Material application rate and type, Mobile data messages, Pavement temperature, Air temperature, Dashcam, Engine diagnostics)	7 (Plow position, Material application rate and type, Pavement temperature, Air temperature, Dashcam, Engine diagnostics)	7 (Plow position, Material application rate and type, Pavement temperature, Air temperature, Dashcam, Engine diagnostics)
Number & types of tasks performed with AVL (Q15)	10 (Vehicle location, Route planning, Material usage, Treatment recommendations, MDSS, Operational analysis, Vehicle diagnostics, Info sharing, Road weather, Staffing)	8 (Vehicle location, Route planning, Material usage, Treatment recommendations, MDSS, Operational analysis, Vehicle diagnostics, Staffing)	7 (Vehicle location, Material usage, Treatment recommendations, MDSS, Operational analysis, Vehicle diagnostics, Road weather)	7 (Vehicle location, Material usage, Treatment recommendations, MDSS, Operational analysis, Vehicle diagnostics, Info sharing)	6 (Vehicle location, Material usage, Operational analysis, Vehicle diagnostics, Info sharing)
Agency policy for AVL/GPS data sharing (Q16-19)	Internal and external (data shared with MDSS provider)	External only (shared with MDSS provider)	Internal only (observation and analysis only at this time)	Internal and external (operational analysis use; plow cam images on public website)	Internal and external (bridge office considering use of data for forecast of bridge maintenance)
Location Shared with Public (Q19)	Yes	No	No	Yes	Yes
Documented costs and benefits of implementation (Q28-30)	<u>Costs:</u> AVL equipment, integration, operations, and maintenance costs <u>Benefits:</u> Yes	<u>Costs:</u> AVL equipment, integration, operations, and maintenance costs <u>Benefits:</u> Yes	<u>Costs:</u> AVL equipment, integration, operations, and maintenance costs <u>Benefits:</u> Yes	<u>Costs:</u> Integration costs <u>Benefits:</u> Yes	<u>Costs:</u> AVL equipment, integration, operations, and maintenance costs <u>Benefits:</u> Yes

Notes: * Recommended Case Study Agency

** Recommended Backup Case Study Agency

3.7 Recommendations on Case Study Agencies

In summary, the research team offered the following recommendations for the selection of case study agencies:

- The primary difference among Tier 1 agencies is the collection of vehicle diagnostic data. Given the similarities of the AVL/GPS implementation and utilization, the research team recommended selecting one agency from Tier 1 for a case study.
- Tier 3 represents agencies that have more sophisticated AVL/GPS system implementation, integration and data utilization. This group of agencies offers a greater opportunity to show subtle differences in system implementation, integration and utilization. As such, the research team recommended selecting three agencies from Tier 3 for case studies.

Agencies recommended and ultimately selected for case studies are listed in Table 8.

Table 8. Recommended Case Study Agencies

Tiers	Primary Agencies	Backup Agencies
Tiers 1 and 2	Utah DOT	New York State DOT
Tier 3A	Michigan DOT Washington State DOT	Vermont Agency of Transportation Pennsylvania DOT
Tier 3B	Colorado DOT Wisconsin DOT Nebraska DOT	Minnesota DOT Iowa DOT

Figure 2 depicts the locations of the agencies recommended for Tiers 1, 2, and 3 case study interviews along with backup agencies.

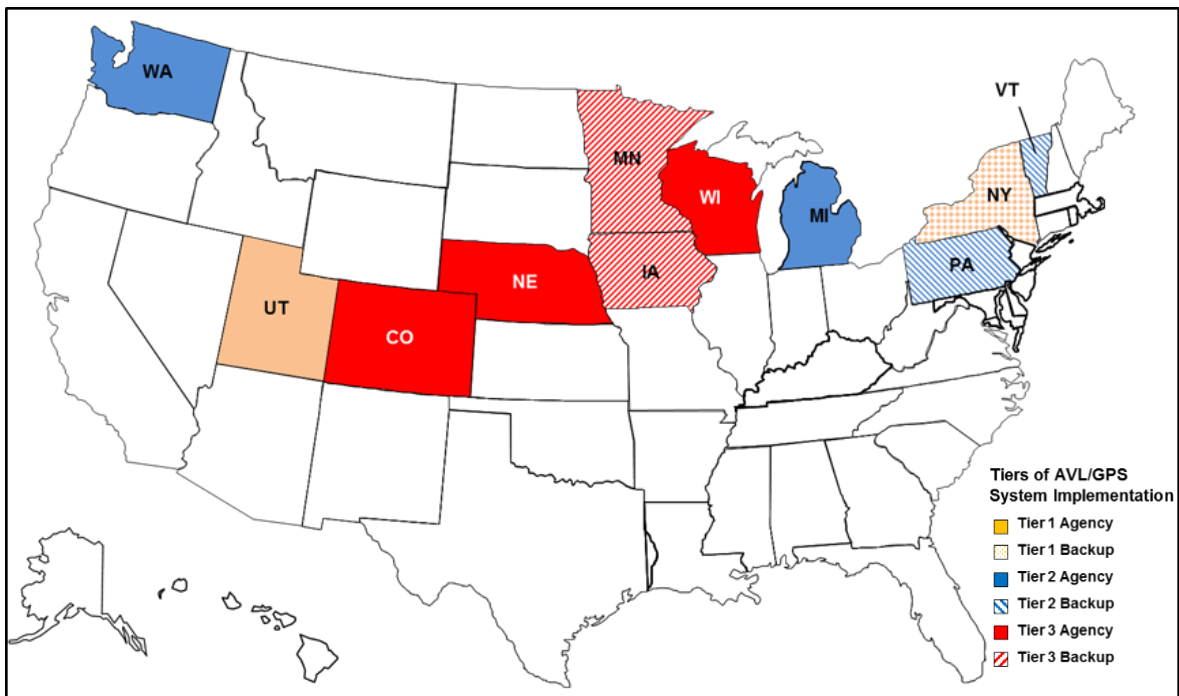


Figure 2. Map of Recommended Agencies for Case Studies

4. Case Study Summary

Upon selection of the agencies for detailed case studies, the research team contacted key representatives from each agency to schedule in-person interviews and provide an overview of the subjects which would be discussed with each agency.

4.1 Introduction

To obtain the information needed for developing case study reports, in-person interviews were conducted over a period of one or two days with multiple levels of agency staff. Table 9 presents the interview dates with each state DOT and the Clear Roads representatives who assisted with coordinating the scheduling of the interviews and attendance of other key staff at the meeting.

Table 9. In-Person Interviews for Case Studies

Tiers	Agencies	Interview Dates	Clear Roads Representatives
Tier 1	Utah DOT	Nov. 27 th / Nov. 28 th	Tim Ularich
Tier 2	Michigan DOT	Nov. 30 th	Melissa Longworth
Tier 2	Washington State DOT	Dec. 18 th / Dec. 19 th	James Morin
Tier 3	Wisconsin DOT	Dec. 11 th / 12 th	Al Johnson
Tier 3	Nebraska DOT	Dec. 13 th / Dec. 14 th	Mike Mattison
Tier 3	Colorado DOT	Jan. 9 th / Jan. 10 th	Kyle Lester

A set of interview questions were drafted for multiple levels of agency staff involved in the deployment and operation of the AVL/GPS systems. The levels of staff and topics of questions covered in the interviews are presented in Table 9. The focus of the interviews was designed to gather sufficient information for the case study reports. A summary of the information gathered from each of the in-person interviews is contained in the Appendices B through G of this report.

Table 10. Levels of Staff Interviewed and Topics of Discussion

Staff Level	Topics/Areas of Discussion
Executives/Directors	<ul style="list-style-type: none"> • Decision-making process • Procurement process • Data collection policy • Data sharing policy • Overall experience
Winter Maintenance Managers and Supervisors	<ul style="list-style-type: none"> • Implementation and integration decisions • Hardware and software selection • Data collection, utilization and management • Communications • Implementation issues • Operations issues • Procurement • Costs and benefits • Recommendations and lessons learned
Technicians and Snow Plow Operators	<ul style="list-style-type: none"> • Hardware Installation • Technology issues and testing • Operations • Maintenance
IT / GIS / Data Server Management Staff	<ul style="list-style-type: none"> • Communications • Software and interfaces • Data storage and management

A total of six case study reports were developed. They are available on the Clear Roads website (<http://clearroads.org/>). A high-level summary of the case study results and findings are presented on the following pages.

4.2 Tier 1 – Utah DOT

4.2.1 Agency Overview

The Utah DOT (UDOT) is divided into four regional offices. Personnel in each region oversee administration, construction, and maintenance of all state roads, highways and freeways within their areas. A map of the four regions is presented in Figure 3.

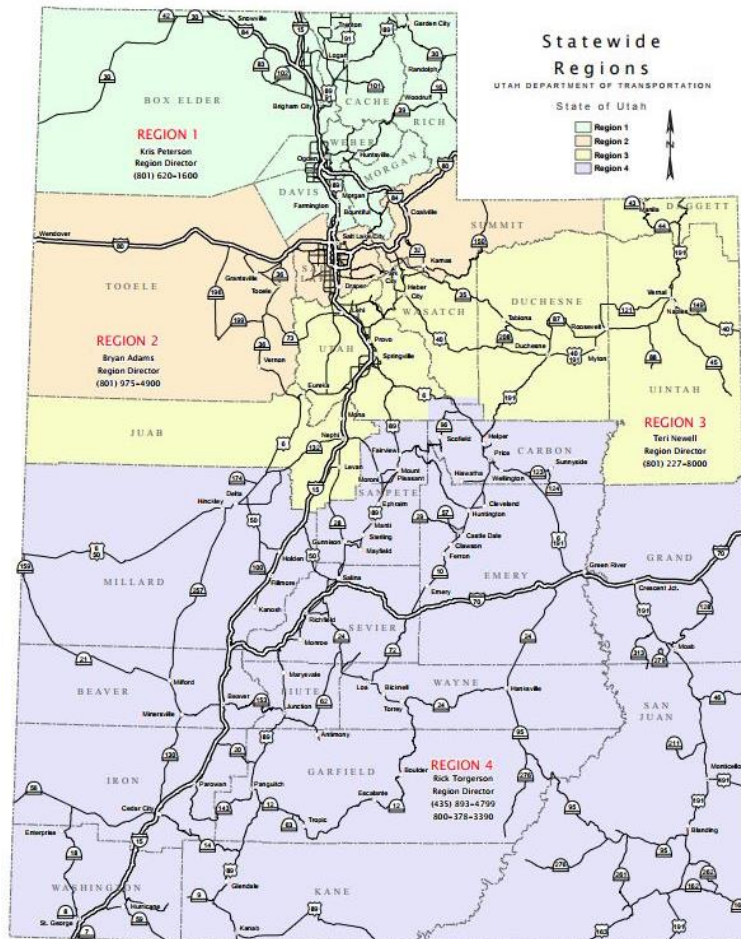


Figure 3. UDOT Regions¹

On average, Utah experiences more than 25 winter storms annually, and UDOT crews in different areas of the state see different conditions. For example, the snow plow crews at Logan Summit in Region 1 clear snow nearly 40 percent of the year, while the St. George crew in Region 4 clears snow only a few times a year.²

¹ Source: <https://www.udot.utah.gov/main/f?p=100:pg:0:::1:T,V:38>,

² Source: <https://www.udot.utah.gov/main/f?p=100:pg:0:::1:T,V:2,70433>

4.2.2 AVL/GPS System Hardware

UDOT has installed a Verizon AVL/GPS system on their entire fleet of winter maintenance vehicles as shown in Figure 4. The hardware is approximately 5 inches long, by 3 inches wide by one inch tall, and weighs about 5 ounces. The small size and weight allow for the hardware unit to be installed in a location behind the vehicle's dashboard where it can be safely mounted as shown in Figure 5.

UDOT has procured and installed AVL/GPS equipment on all 508 Class 8 winter maintenance vehicles throughout the state. In addition to snowplows, UDOT has also implemented the AVL/GPS on its Incident Maintenance Trucks (IMTs) that assist motorists involved in incidents along UDOT roads and highways.

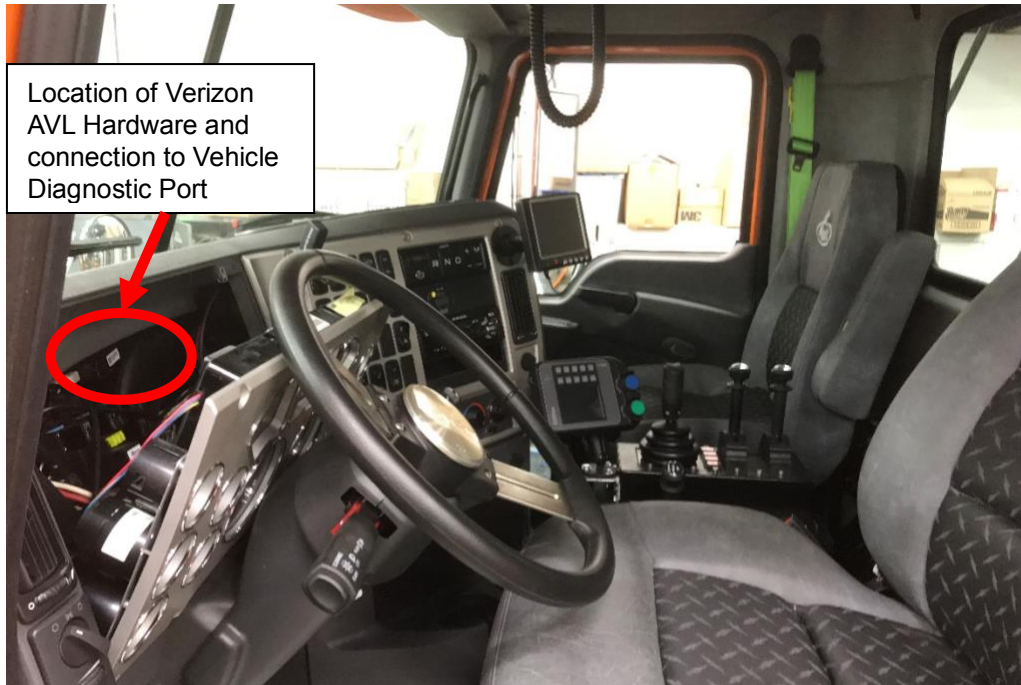


Figure 4. Interior Picture of UDOT Snow Plow and Placement of Equipment



Figure 5. Location of Verizon NetworkFleet 5500 Model in UDOT Snow Plow

4.2.3 AVL/GPS System Software

UDOT utilizes the Verizon NetworkFleet software interface to manage their vehicle fleet equipped with the Verizon AVL system as shown in Figure 6. One of the primary features of the software is the ability to generate automated alerts as desired by UDOT maintenance staff for items of interest. These alerts can be configured to be sent via email to the appropriate maintenance staff. UDOT Maintenance Supervisors can also use the NetworkFleet software package to have automated reports generated for specific system users on items of concern, namely vehicle idling for extended periods of time or high speeds of travel in excess of pre-defined speed values on specific routes. These reports can be presented by supervisors to specific drivers as informational reports, which have had an observed positive impact on driver behavior. The information can also be used for training, retraining and coaching of new or targeted drivers.

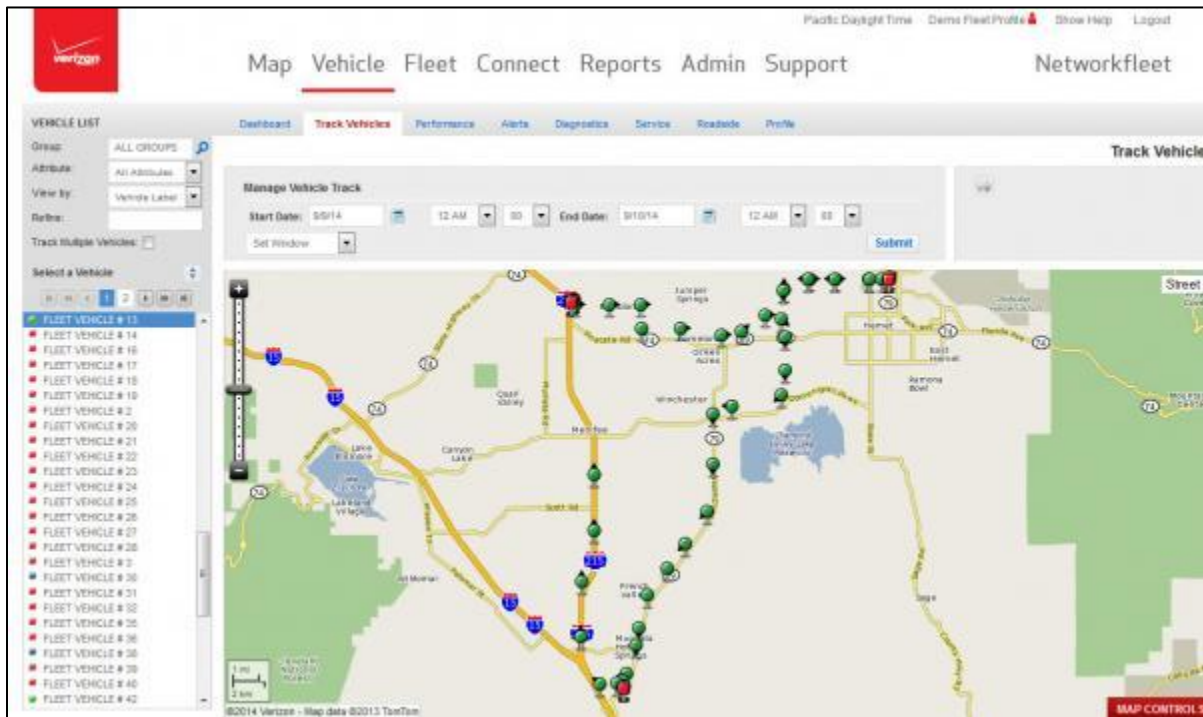


Figure 6. Screenshot of Verizon NetworkFleet Software Interface for UDOT Vehicle Tracking

UDOT utilized an Application Programming Interface (API) to download select portions of raw vehicle data and store the data on a UDOT GIS database. This allows UDOT staff to display the vehicle location on the UDOT traffic information webpage and mobile application, as shown in Figure 7 and Figure 8, respectively.

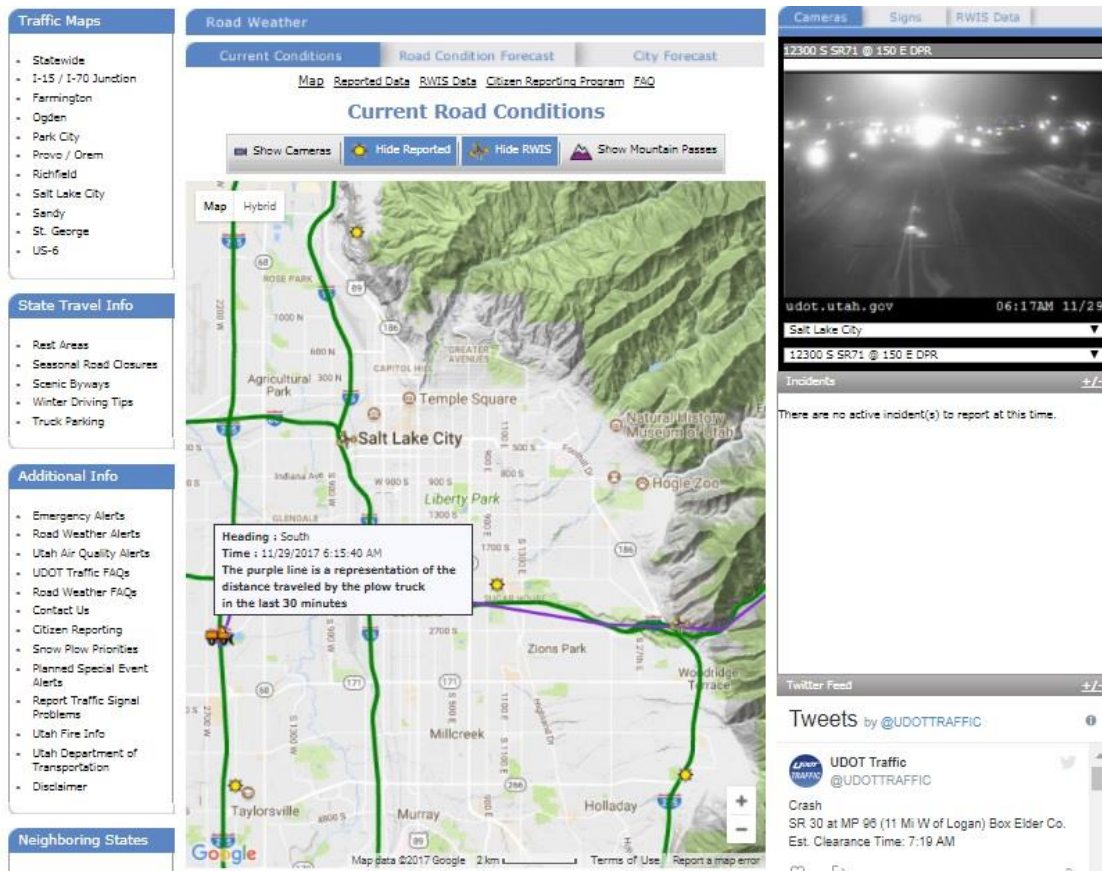


Figure 7. PC-Based Image from UDOT Traffic Information Webpage with Snow Plow Locations

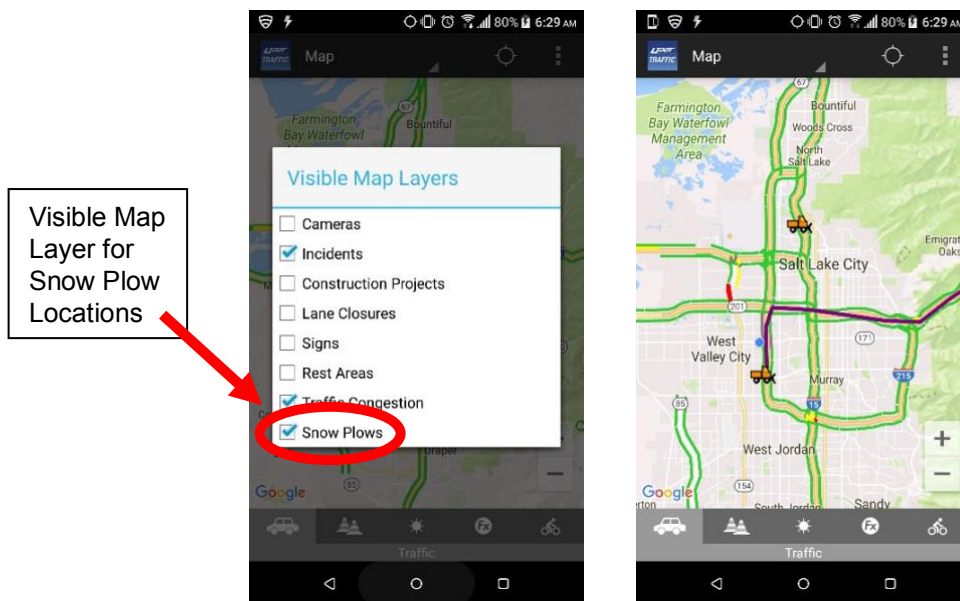


Figure 8. Mobile Device Image of UDOT Traffic Information Page with Snow Plow Locations

4.2.4 Decision Making Process

UDOT determined in 2014 to install AVL/GPS technology in winter maintenance vehicles in an effort to increase the public transparency of their operations by providing snow plow locations to the general public via a public UDOT traffic information page and mobile application.

UDOT chose to install a Verizon AVL/GPS system through a pre-negotiated contract with a larger group of states under the National Association of State Procurement Officials (NASPO). With this contract, UDOT could implement their entire fleet of winter maintenance vehicles with the Verizon AVL system and still accomplish the objective of public transparency while staying within the available project budget.

UDOT requested a demonstration of the overall system in 2015, which was monitored through the AVL software package (NetworkFleet) by UDOT staff and features of the software were observed to confirm that the system was functioning properly. Upon successful completion of the demonstration, UDOT then began to implement the entire fleet of snow plow vehicles, as well as Incident Management (Safety Service Patrol) vehicles.

4.2.5 UDOT Data Collection and Utilization

Cellular communications over the Verizon wireless network is the center-to-vehicle communications method for transmission of vehicle data to a central server. In the event of loss in cellular coverage, vehicle hardware stores data that cannot be communicated until it returns to cell coverage to forward that information to the Verizon servers.

All data from UDOT vehicles is initially stored on Verizon servers communicated from UDOT winter maintenance vehicles. Through the use of the API provided by Verizon, UDOT then downloads select portions of the raw data from the Verizon server to a UDOT server and stores the data in its GIS database. Verizon stores UDOT AVL data on its server for one year.

The following types of data are collected by UDOT at 30 second intervals for storage and review on their database:

- Vehicle Identification Number (VIN)
- Fleet Identification Number
- Message Timestamp
- Vehicle Latitude and Longitude
- Vehicle Ignition Status
- Vehicle Speed (MPH)
- Vehicle Odometer

UDOT utilizes vehicle location for sharing UDOT snow plow locations through the UDOT traveler information webpage and UDOT Traffic mobile app.

UDOT Maintenance staff utilize the NetworkFleet software primarily for monitoring vehicle locations, operational analysis, and for post-storm analysis purposes. District Engineers and Area Supervisors use the software package on a more frequent basis than Station Supervisors, who also are active in plowing snow during winter weather events. Area Supervisors noted the ability to monitor vehicle locations to enable sharing and relocating resources was extremely useful. In addition to monitoring vehicle locations, Area Supervisors felt the system was very useful for:

- Verifying snow maintenance activities
- Coupled with UDOT cameras, verifying and confirming pavement conditions

UDOT has developed a Snow and Ice Performance Dashboard that has real-time statistics. UDOT maintenance crews utilize the real-time statistics to determine how effective they were at maintaining

good road conditions during a storm. Several metrics go into creating the performance measure, including the intensity of the storm, length of time the storm is ongoing, resources allocated to the maintenance station covering the geographic area, field instrumentation on the RWIS units, and AVL data. The resulting information is utilized to measure storm performance, identify best practices and possibly re-allocate resources to better cover areas in need.

Figure 9 shows the dashboard when snow plows pass an RWIS station installed along US 6 at Soldier Summit. Figure 10 presents a statewide view of winter storm statistics and overall performance. Figure 11 presents a display of storm performance reports that can be filtered by UDOT Region and along specific UDOT routes.

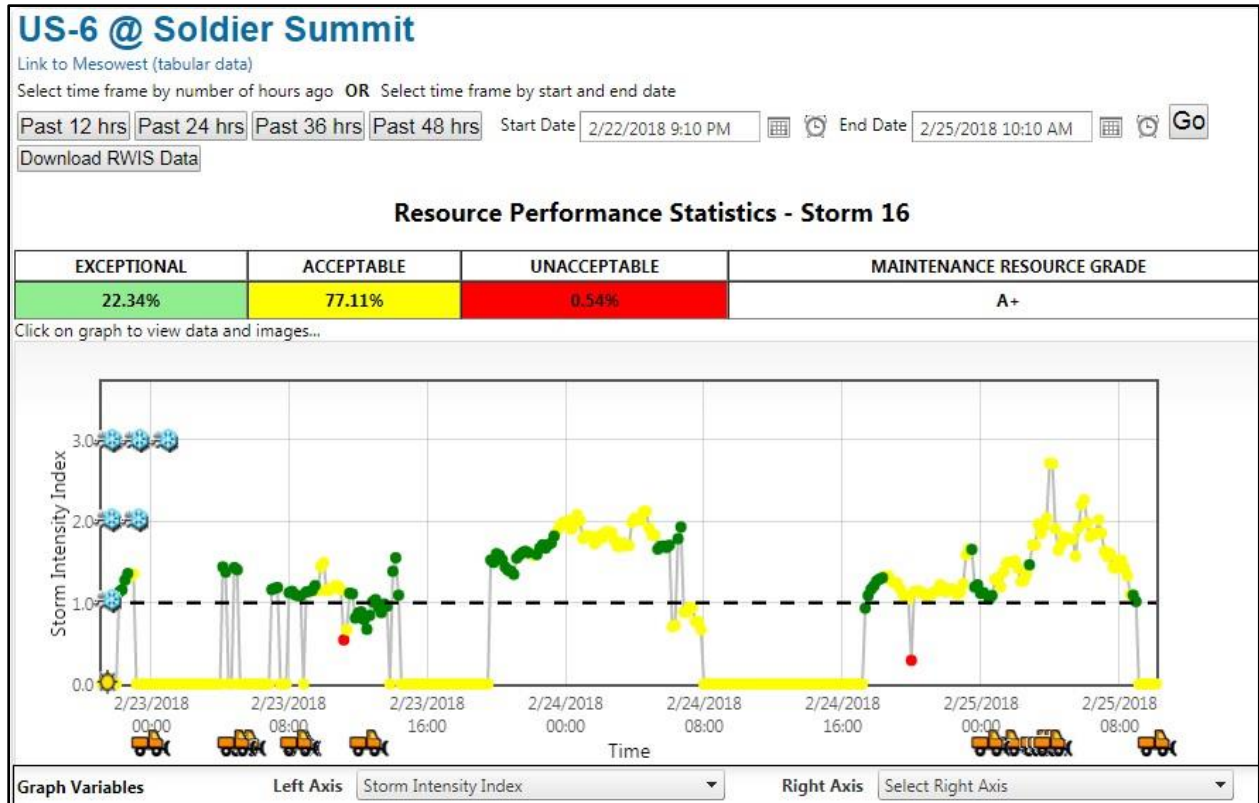


Figure 9. UDOT Snow and Ice Performance Dashboard at RWIS Station

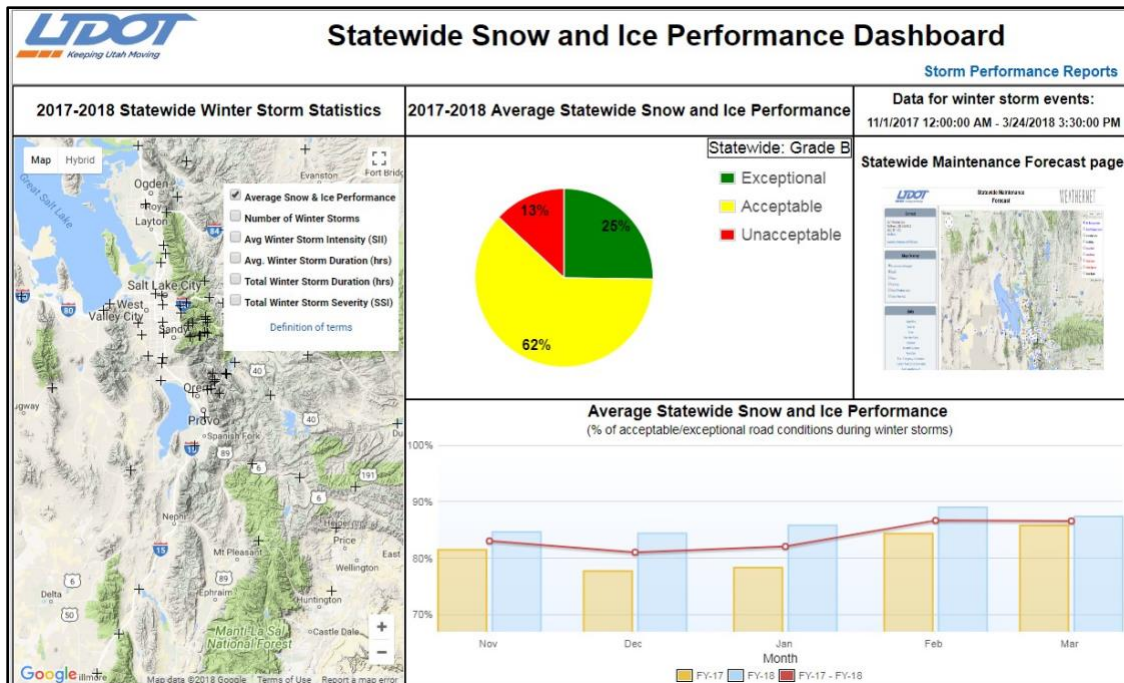


Figure 10. UDOT Snow and Ice Performance Dashboard Statewide View

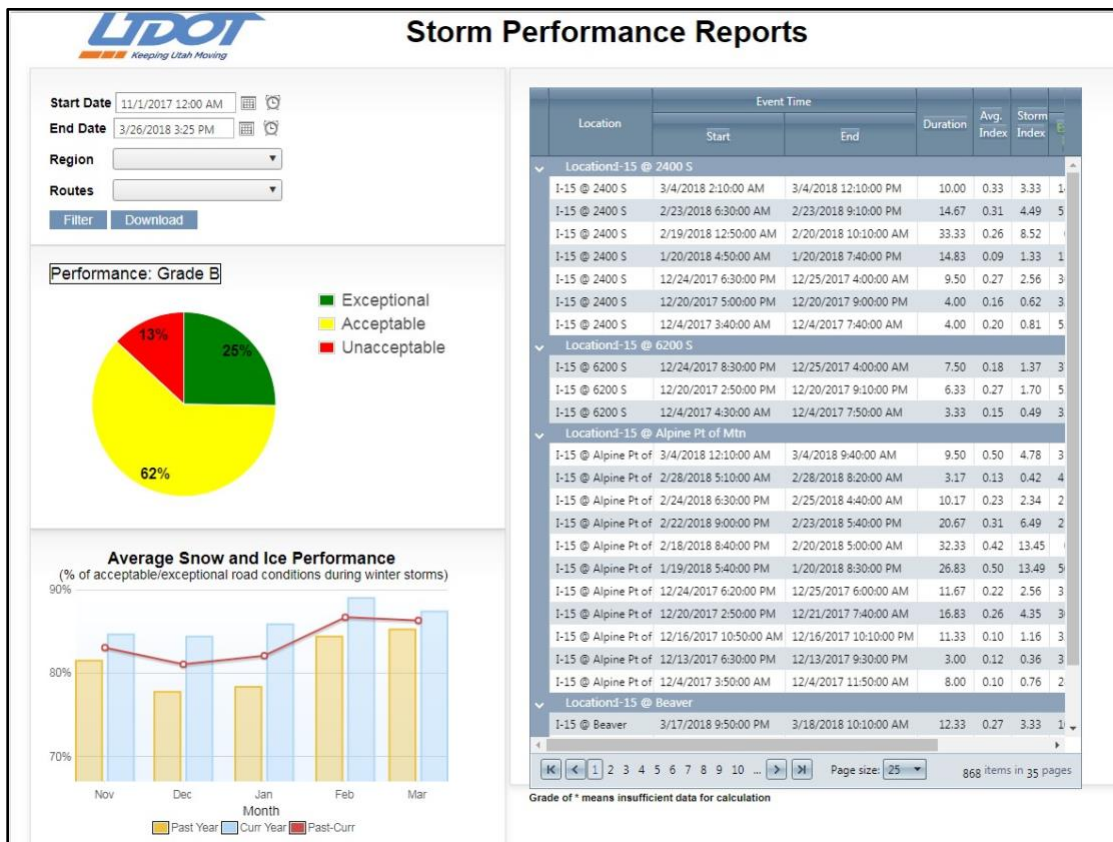


Figure 11. UDOT Snow and Ice Performance Dashboard Storm Performance Reports

4.2.6 UDOT Training and Outreach

UDOT staff noted that “Big Brother” types of concerns over the use of an AVL/GPS system by supervisors for disciplinary reasons have lessened over time as drivers have realized that the system is not used in this manner. Drivers have found that the AVL/GPS system has actually been able to exonerate them from public complaints about potential damage they may have caused through the use of the “bread crumb” trail reporting feature that supervisors can use to confirm where UDOT snow plows were in relation to the public complaint. Although it was noted by UDOT staff that there are still “Big Brother” concerns from drivers, it is anticipated these concerns will continue to lessen over time.

In addition to providing continued training to gain buy-in to the system in each region, UDOT holds monthly meetings with District Engineers to identify and discuss innovations, best practices, etc.

4.2.7 UDOT AVL/GPS Lessons Learned

The following lessons learned are offered based on the UDOT case study.

- The ability to monitor winter maintenance vehicle locations enables improved resource sharing and allocation as well as cross-regional coordination.
- AVL data supports winter maintenance performance monitoring and management. Integrating AVL data with RWIS data and other real-time road conditions information helps better situational awareness and facilitates improved winter maintenance practices. Coupled with UDOT cameras, real-time road conditions information help verify and confirm pavement conditions.
- Involvement from leadership at District and Region levels is key to buy-in and implementation success. In addition to providing continued training to gain buy-in to the system in each region, UDOT holds monthly meetings with District Engineers to identify and discuss innovations, best practices, etc.
- Making vehicle location data and associated performance measures available to the public promotes public trust.
- Showing the vehicle locations on the public webpage doesn't create issues or damages to drivers, which helps alleviate drivers' “Big Brother” concern.
- Delaying vehicle location reporting on the public webpage by 2-3 minutes alleviates driver concerns that real-time vehicle location could be used by individuals to plan specific attacks on the snow plow vehicles.

UDOT noted their future plan related to expanding the system capabilities to winter operations. The future plan includes:

- Integrating AVL system with spreader controllers to gather material usage data.
- Further development and enhancement of performance measures and management program.
- Investigating and implementing connect vehicle technologies.
- Equipping DSRC to snow plows to help with signal priority and I2V communications.

4.2.8 UDOT AVL/GPS System Benefits

Key benefits identified by UDOT include the following:

- Ability to provide records of plow locations and activities, which help achieve public transparency.
- AVL data helps address liability issues and resolve tort claims.
- AVL data provides assistance in route planning and prevents gaps in plowing routes.
- AVL data with RWIS data provides real-time road conditions information which is integrated in UDOT's Snow and Ice Performance Dashboard.
- The system facilitates better resource sharing and cross-regional coordination.

- AVL data supports performance management. AVL data enables UDOT to make performance measures available to the public, which in turn promotes public trust.
- Truck diagnostics have helped UDOT mechanics optimize their time by allowing for truck error code access to perform a preliminary diagnostic on mechanical issues.

4.3 Tier 2 – Washington State DOT

4.3.1 Agency Overview

The Washington State DOT (WSDOT) is divided into six different regions as illustrated in Figure 12. These are the Olympic, Southwest, Northwest, North Central, South Central, and Eastern regions. Maintenance Superintendents and Supervisors maintain communication with each other utilizing vehicle radio equipment. Snow plow operators within an Area of a Region may be called upon to divert from their planned route to assist with snow clearance along other roads as needed.



Figure 12. WSDOT Regions³

4.3.2 WSDOT AVL/GPS System Hardware

WSDOT has procured and installed AVL/GPS equipment on approximately 400 of its 500 snow plow vehicles throughout the state. The AVL equipment was procured from Location Technologies in 2015 and was installed by WSDOT vehicle technicians. The Location Technologies LT6 AVL/GPS system hardware is pictured in Figure 13 in an un-covered and covered configuration for reference. Additional images of the AVL/GPS system as well as its typical installation are provided in Figure 14.

³ Source: <http://www.michigan.gov/WSDOT/0,4616,7-151-9623-36042--,00.html>



Figure 13. WSDOT AVL/GPS System Hardware Units (Un-covered and Covered)



Figure 14. WSDOT Snow Plow Equipment and Location of LT6 AVL/GPS System

WSDOT has integrated the vehicle’s spreader controllers and air/pavement temperature sensors with the LT6 AVL hardware unit. WSDOT’s winter maintenance vehicles have a variety of spreader controllers from Force America, DICKEY-john, Parker, Raven and Schmidt.

Plow position sensors were also integrated with the AVL system to detect plow up/down and track usage. Plow position sensors were only installed to track front plows. Some WSDOT winter maintenance trucks were also equipped with wing plows or belly plows, however they were not tracked.

In addition to plow position sensors, WSDOT winter maintenance trucks also equipped with hydraulic sensors for front plows. The hydraulic sensors were used to indicate the plow position of the vehicle to the spreader controller.

4.3.3 WSDOT AVL/GPS System Software

Location Technologies provided WSDOT two views of the AVL data: a web map view and a reporting engine that includes user tools. Through the LT6 software interface, WSDOT staff can generate pre-defined reports that provide information on vehicle operations and material amounts utilized per vehicle within an Area. Currently, WSDOT only utilizes a “General Activity” and “Material Summary” report from the software.

WSDOT noted that LT6 made its API available for the purposes of getting key AVL system attributes, such as GPS coordinates, vehicle ID numbers, and material names, to enable WSDOT to download and report the data such as the vehicle location and other attribute on a GIS software interface developed in-house

by WSDOT (Figure 15). Active vehicles in Figure 15 show the location of plows that have their plow down or up, as well as those vehicles applying liquids and material by types.

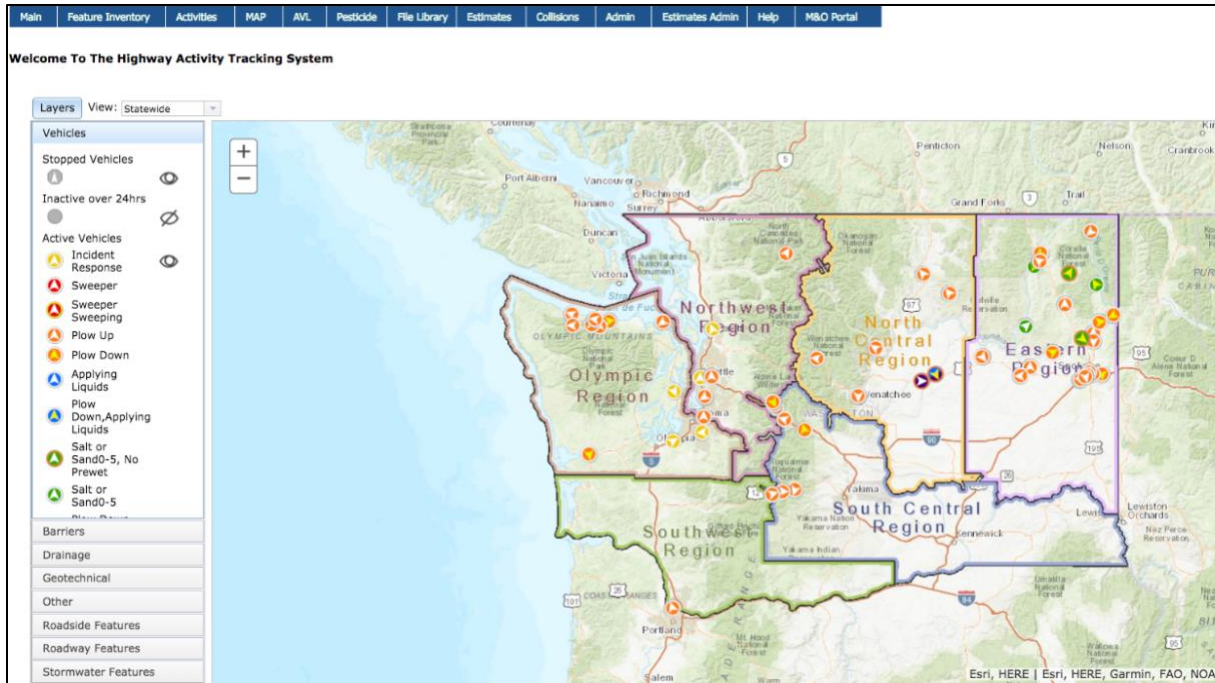


Figure 15. WSDOT In-House Software Interface with AVL Location Data

4.3.4 Decision Making Process

Location Technologies was selected by WSDOT through a formal solicitation process in 2015, and the requested quantities of AVL hardware for all WSDOT snow plow vehicles were then installed by agency staff. The procurement also expanded the AVL installation to sweepers and emergency response vehicles. WSDOT relied on its prior experience with AVL system pilot projects, as well as peer exchange to gain knowledge on the system qualifications from other states experience.

The level of management involved from WSDOT in the decision making included the technology resource group as part of the WSDOT Maintenance Division and other WSDOT staff in the Snow and Ice Program.

The impetuses for WSDOT's AVL system implementation are:

- Real-time tracking of vehicle locations and material usage to support and improve operational efficiency
- Supporting and minimizing tort liability
- As an advisory tool for improving resource planning and route adjustments as well as reducing repeating work on same routes

4.3.5 WSDOT Data Collection and Utilization

WSDOT noted that in addition to vehicle location data, the LT6 AVL system collects the following data:

- Material type
- Pre-wetting or not

- Material application rate
- Pavement surface and air temperatures
- Plow position (up/down) – front plow only

WSDOT polls the data from the Location Technologies server once every minute to get this information. Data is stored on a high availability WSDOT server and would be saved for at least seven years for future use by WSDOT.

As noted previously, the most desired feature of the system is material usage reporting. WSDOT felt the estimated material usage from the system would provide a reasonable baseline; however, WSDOT was not satisfied with the accuracy of the estimates. In addition to the use of material reports, AVL system data is also used primarily by WSDOT Maintenance Supervisors and Superintendents for vehicle location monitoring and situational awareness during winter storms. Maintenance Supervisors and Superintendents used the real-time data to monitor winter maintenance activities and make adjustments to resource allocation and route assignments.

The stored data is also used for material usage reporting and occasionally for post-event review/analysis as well as for review in the event of a tort claim of WSDOT liability in a traffic accident.

4.3.6 WSDOT Training and Outreach

WSDOT noted that a high staff turnover rate in some WSDOT Regions and Areas is a significant issue and is one of the reasons for keeping the operation of the AVL/GPS system as simple as possible. Training becomes very important to address the high rate of staff turnover. The main responsibility for WSDOT snow plow operators with respect to AVL operations is to monitor the power indicators on the AVL hardware within the vehicle before they begin their snow plow route, and to report on faulty hardware when detected. This reduces the amount of work to be performed by snow plow operators related to AVL operations and simplifies the overall operator training procedures.

Gathering buy-in from snow plow operators on the value of the AVL/GPS system was still an issue for WSDOT, as there were some reported instances of operators pulling the fuse to disable the system or causing some damage to the system. Another concern was that the operators union wanted to limit WSDOT's ability to look into how operators performed their work. WSDOT focused on communicating positives of the system as a strategy to alleviate operators' concern. Key messages to facilitate operators buy-in included:

- The system is for tracking material usage not for tracking operators.
- The system data helps protect operators from tort claims.

WSDOT staff noted that operator concerns have lessened over time, yet opposition still exists.

4.3.7 WSDOT AVL/GPS Lessons Learned

The following lessons learned are offered based on the WSDOT case study.

- Agencies can benefit from pilot testing prior to full system deployment. Pilot testing helps agencies understand the technology and its limitations. It helps agencies gain knowledge on the system and identify potential issues they may encounter during installation, integration, operations and maintenance. Experience and lessons learned from pilots also help develop a better project scope and specifications/requirements.
- Similarly, research on AVL systems and equipment desired to be integrated is extremely valuable. This includes obtaining experience from other agencies. Research helps agencies gain a better understanding on AVL systems and other equipment and how they could be integrated. Confirming research findings with vendors and manufacturers is also important.

- On-going training for both operations and maintenance is crucial to the success of an AVL program. Training should reach to the ground level staff involved in operations (operators) and maintenance (mechanics/technicians).
- A “train the trainer” program can ensure system knowledge resides within the agency. The train the trainer program also helps build a network to share knowledge and best practice as well as support on-going operations and maintenance of the system.
- Agency-owned radio communications systems can be a viable option to fill gaps in cellular communications.
- Buy-in and engagement from agency leadership is critical. It helps in establishing and procuring an AVL program. It also supports timely installation and maintenance as well as and encourages property use of the system.
- Positives of the system relevant to snow plow operators should be the focus when communicating with operators to promote buy-in.
- The AVL system can result in significant financial benefits to agencies as related to tort liability. This benefit can be translated as one of positive impacts to snow plow operators to promote their buy-in.

4.3.8 WSDOT AVL/GPS System Benefits

One of the primary benefits that WSDOT has observed with the AVL/GPS system is the overall savings to WSDOT in terms of tort liability in the event of claims of damage by WSDOT snow plow vehicles. With the AVL software’s ability to provide detailed bread crumb trails on where WSDOT snow plows have traveled and when, this has significantly reduced the annual average of payments made by WSDOT resulting from tort claims from an average of \$2 million per year down to an average \$500,000 per year.

One of the other main benefits that WSDOT has observed with the AVL/GPS system is the improved operational awareness of maintenance superintendents as they respond to winter storms. This has been noted by Maintenance Superintendents and Region Maintenance Engineers that have used either the LT6 software interface and / or the in-house developed WSDOT interface for viewing vehicle locations and making operational adjustments based on situations.

4.4 Tier 2 – Michigan DOT

4.4.1 Agency Overview

The Michigan DOT (MDOT) is divided into seven different regions as shown in Figure 16. MDOT uses both MDOT Direct Forces and contract county agencies to perform winter maintenance activities on Interstates and State routes. MDOT winter maintenance personnel operate out of the Region and Transportation Service Center (TSC) offices and perform snow plowing on Interstates and State routes within each region. MDOT contracts individually with many counties in the state as well to perform winter maintenance. In general, MDOT Direct Forces perform snow plow operations on about 30% of the Interstates and State routes within the state, while Counties maintain the other 70%, as shown in Figure 17.

On average, MDOT spends roughly \$100 million on winter maintenance each season, which represents approximately forty percent of its total maintenance budget.⁴

⁴ Source: https://ops.fhwa.dot.gov/weather/best_practices/casestudies/015.pdf

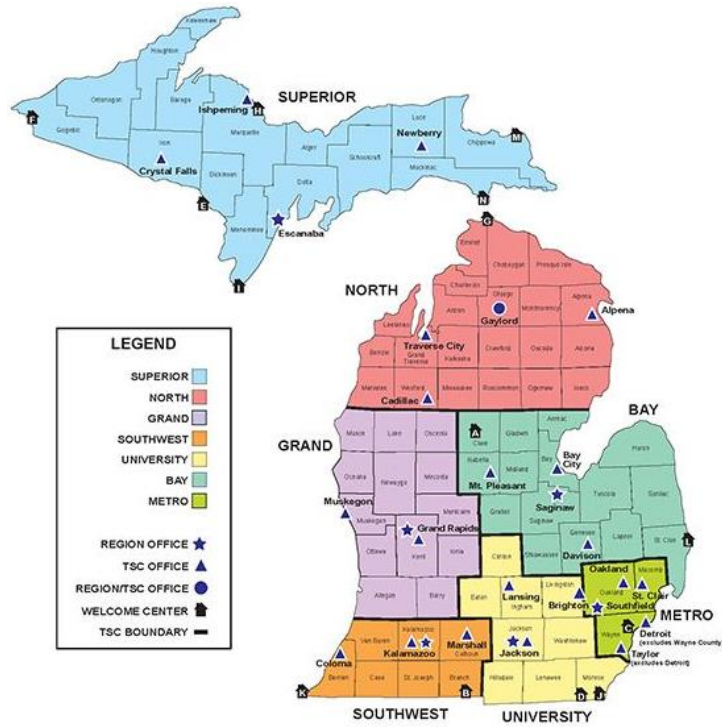


Figure 16. MDOT Regions⁵

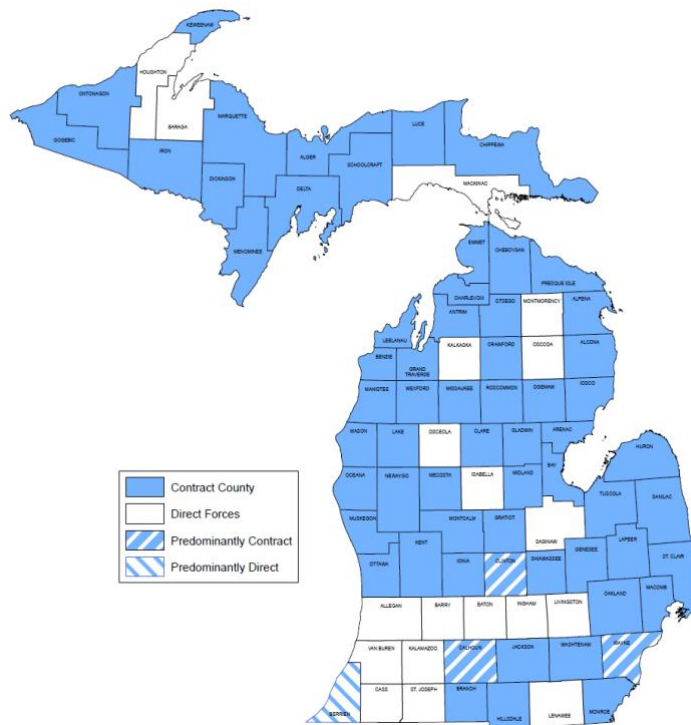


Figure 17. MDOT and County Partnership

⁵ Source: <http://www.michigan.gov/mdot/0,4616,7-151-9623-36042--,00.html>

4.4.2 MDOT AVL/GPS System Hardware

MDOT released an RFP in the spring of 2013 and requested a single point of contact from a Contractor that would be responsible for managing both an AVL system and a Maintenance Decision Support Systems (MDSS), as a means of ensuring accountability in the integration of the two systems by the selected Contractor. Through frequent meetings and communication with the Contractor and its project team, MDOT achieved the desired outcome of implementing the system prior to the 2013-2014 winter season. Figure 18 and Figure 19 display the AVL hardware installed in MDOT snow plow vehicles.

MDOT has integrated the AVL hardware with the following equipment for data reporting:

- DICKEY-john ControlPoint spreader controllers
- RoadWatch pavement temperature sensors
- Wing plow position sensors
- Tow plow position sensors,
- Gate sensors,
- Hydraulic meter sensors,
- OBD-II port, and
- Front-facing Logitech vehicle dash-cams.

MDOT staff noted that the integration of the AVL functionality within the MDSS software package provides MDOT maintenance supervisors and operations staff with the most effective tool for responding to winter weather events. Melissa Longworth noted that only a handful of states have performed the integration given the integration effort involved, but that it has proven to be effective for winter maintenance operations.



Figure 18. MDOT Mobile Data Computer (MDC) and AVL Hardware (above) and Back View of MDC, Antennae and Cable (below)

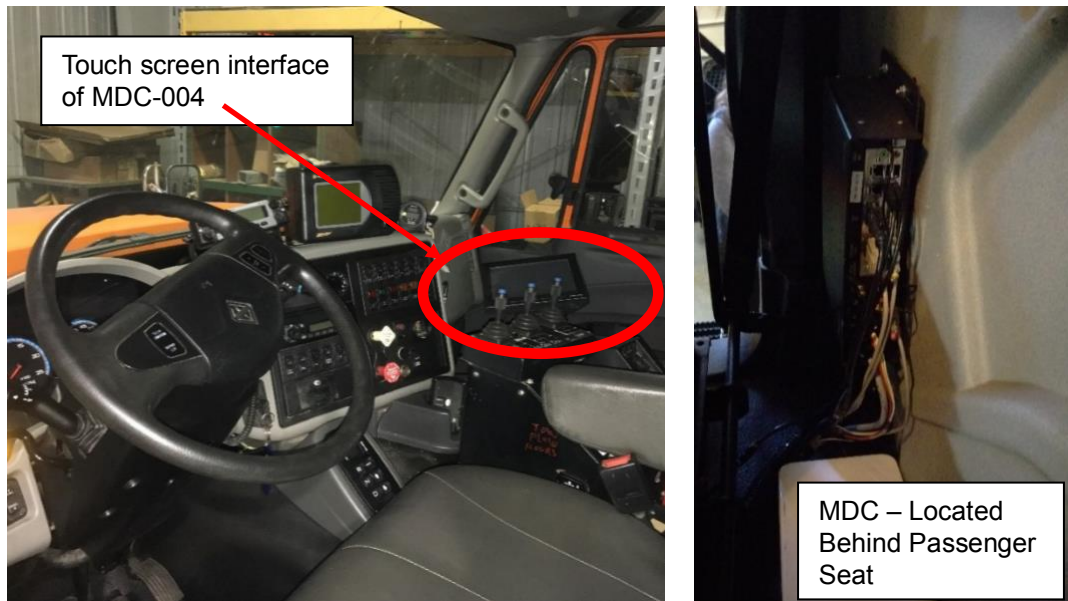


Figure 19. Location of Parsons AVL Hardware in MDOT Snow Plow

4.4.3 MDOT AVL/GPS System Software

MDOT utilizes two separate software packages that are described further within this section: one for the AVL/GPS system provided by Parsons, and a separate software interface for the MDSS functionality provided by Iteris.

4.4.3.1 MDOT AVL/GPS System Software

The AVL software package presents a map-based interface that allows MDOT staff to view the locations of snow plow vehicles in the field, which can be filtered in multiple ways (i.e. by region, by county, etc.). The interface allows for selecting specific vehicles on the map and viewing information about that specific vehicle. The AVL software can run automated reports that can assist maintenance staff to identify when issues may be occurring with AVL hardware. The reports can be custom-developed to provide alerts on items of interest for maintenance staff, which can assist in preventative maintenance of the vehicles. Through the software, MDOT staff can use a filter to view snow plow vehicles at specific garages and then view the date and time stamps of specific data elements.

Figure 20 presents a view of the AVL software package at a statewide level for MDOT. Figure 21 presents a vehicle level display that also presents dash-cam views of road conditions in real-time.

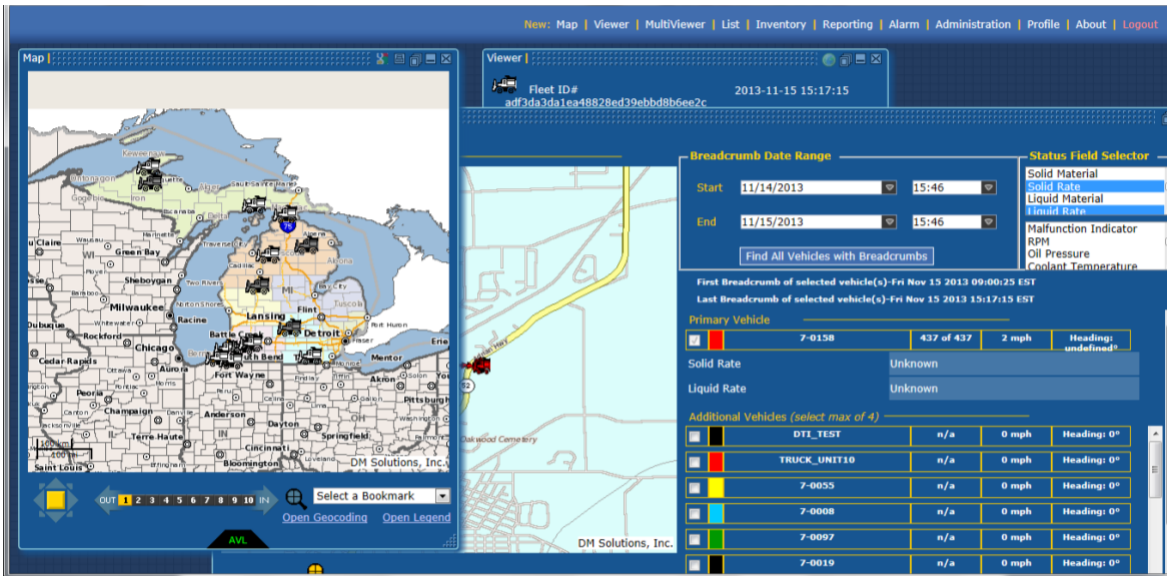


Figure 20. MDOT AVL/GPS System Interface Graphic from Parsons

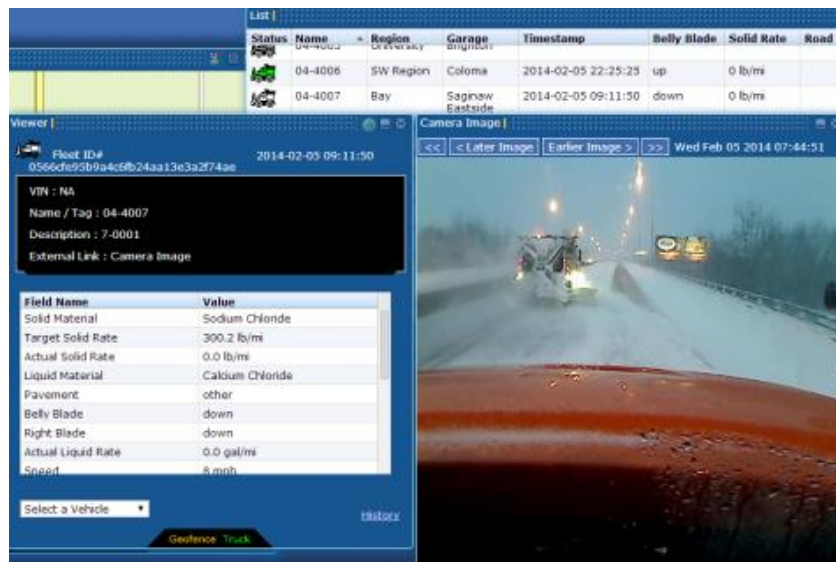


Figure 21. MDOT AVL/GPS Software Interface with Vehicle Camera Image

The most frequently used reports by MDOT staff include reports for blade usage, material usage, and speed compliance. The speed compliance report is an example of a custom-developed report for MDOT that can indicate the speeds of snow plows as they apply material. A recent MDOT study has found that 25 MPH is the ideal speed to ensure that salt remains on the road and does not scatter outside of the travel lanes. Reports on snow plow drivers can be generated for instances where speeds are detected in excess of 25 MPH. The reports can be used to discuss best practices with the drivers about maintaining travel speeds in the desired 25 MPH range.

The structure of this speed compliance report, and other reports within the AVL system, were requested by MDOT to be provided by the AVL vendor (Parsons) for future analyses by MDOT staff. These reports also help ensure the efficiency of snow plow operations.

4.4.3.2 MDOT MDSS Software

The MDSS software interface provided by Iteris is used for monitoring weather forecasts and determining the most efficient times and locations for roadway treatment. Multiple types of alerts can be presented on upcoming weather, road conditions, and where blowing snow would be predicted, along with maintenance alerts that provided treatment recommendations on material to be applied to specific roadways.

MDOT archives its previous treatment for the past 24 hours and can look ahead to the next 24 hours as well and see how past roadway treatment may be impacting recommendations, since a comparison of “no treatment” is presented alongside the current treatment by MDOT. It was also noted that the mobile application has been more useful to snow plow drivers than the laptop / PC-based version given that drivers do have mobile devices for viewing the interface in the field.

MDOT staff noted that the integration of the AVL functionality and vehicle locations within the MDSS software package provides MDOT maintenance supervisors and operations staff with the most effective tool for responding to winter weather events. MDOT staff noted that only a handful of states have performed the integration given the integration effort involved, but that it has proven to be effective for winter maintenance operations.

Images of the MDOT MDSS Software interface are presented in Figure 22 and Figure 23.

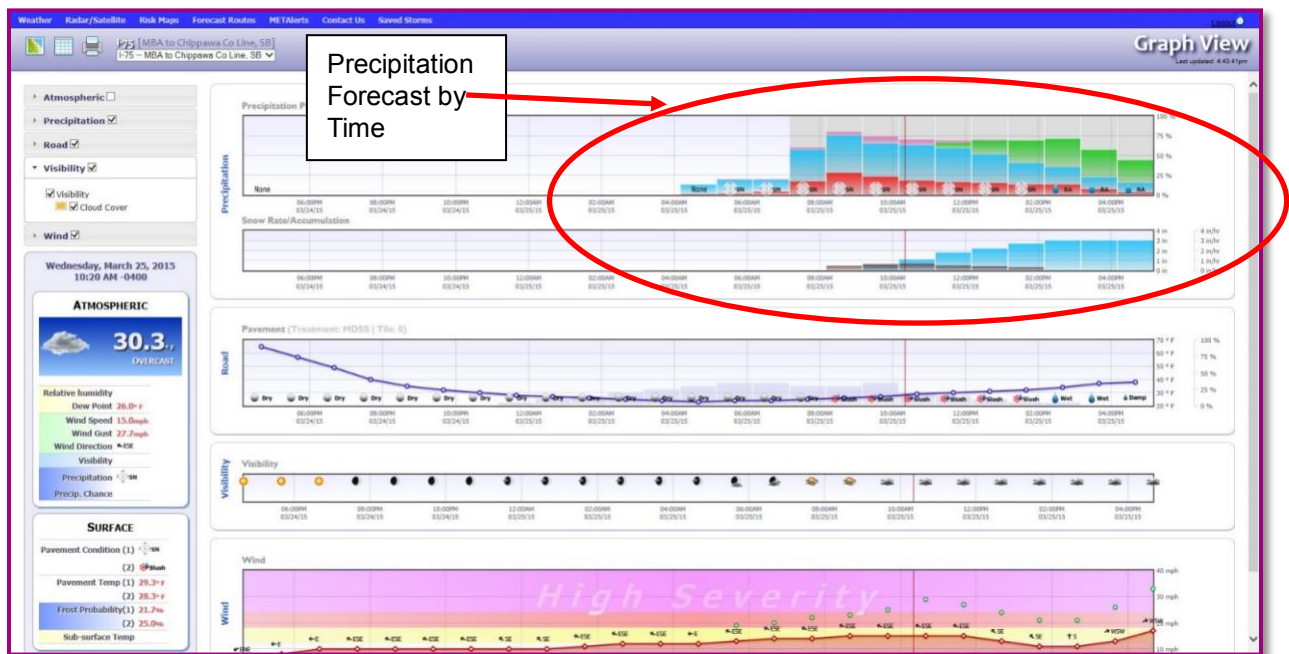


Figure 22. MDOT MDSS Screenshot of Weather Forecast

Time (GMT-0400)	Roadway: Treatment: None				Roadway: Treatment: MDSS				Wind				Precipitation				Vis Obs	Time (GMT-0400)								
	Temp (° F)	Pav. Cond	Frost Prob (%)	Maint. Rate	Temp (° F)	Pav. Cond	Frost Prob (%)	Maint. Rate	Dir	Speed (mph)	Gust (mph)	Wind Chill (° F)	Type	Precip Prob (%)	Liq Rate (in/hr)	Liq Acc (in)			Ice Rate (in/hr)	Ice Acc (in)	Sn Rate (in/hr)	Sn Accum (in)	Cloud Cover	Visibility (mi)		
Tue 8pm	38	Dry	0	---	38	Dry	0	---	26	21	75	WSE	10	---	19	---	0	0.00	0.00	0.00	0.00	0.00	0.00	10.00	---	Tue 8pm
Tue 9pm	34	Dry	0	---	34	Dry	0	---	27	20	76	ESE	9	---	18	---	0	0.00	0.00	0.00	0.00	0.00	0.00	10.00	---	Tue 9pm
Tue 10pm	31	Dry	0	---	31	Dry	0	---	26	21	81	ESE	10	---	16	---	0	0.00	0.00	0.00	0.00	0.00	0.00	10.00	---	Tue 10pm
Tue 11pm	29	Dry	5	---	29	Dry	5	---	26	21	81	ESE	11	---	16	---	0	0.00	0.00	0.00	0.00	0.00	0.00	10.00	---	Tue 11pm
Wed 12am	28	Dry	5	---	28	Dry	5	---	26	21	81	ESE	10	---	16	---	0	0.00	0.00	0.00	0.00	0.00	0.00	10.00	---	Wed 12am
Wed 1am	27	Dry	10	---	27	Dry	10	---	25	20	81	ESE	10	---	15	---	0	0.00	0.00	0.00	0.00	0.00	0.00	10.00	---	Wed 1am
Wed 2am	25	Dry	15	---	25	Dry	15	---	24	20	84	ESE	12	---	13	---	0	0.00	0.00	0.00	0.00	0.00	0.00	10.00	---	Wed 2am
Wed 3am	25	Dry	25	---	25	Dry	25	---	24	21	87	ESE	12	---	13	---	0	0.00	0.00	0.00	0.00	0.00	0.00	10.00	---	Wed 3am
Wed 4am	24	Dry	25	---	24	Dry	25	---	24	20	84	ESE	12	---	13	---	0	0.00	0.00	0.00	0.00	0.00	0.00	10.00	---	Wed 4am
Wed 5am	23	Dry	30	---	23	Dry	30	---	24	20	84	E	13	12	SN	20	0.00	0.00	0.00	0.00	0.00	0.00	10.00	---	Wed 5am	
Wed 6am	24	Dry	35	---	24	Dry	35	---	25	21	86	ESE	13	13	SN	20	0.00	0.00	0.00	0.00	0.00	0.00	10.00	---	Wed 6am	
Wed 7am	24	Dry	30	---	24	Dry	30	NaCl	225	26	21	84	ESE	14	21	SN	20	0.00	0.00	0.00	0.00	0.00	0.00	10.00	---	Wed 7am
Wed 8am	25	Dry	30	---	26	Dry	25	NaCl	150	27	24	86	ESE	15	24	SN	20	0.00	0.00	0.00	0.00	0.00	0.50	---	Wed 8am	
Wed 9am	27	SN	25	---	28	Slush	30	NaCl	150	27	24	86	ESE	15	24	SN	20	0.00	0.00	0.00	0.00	0.00	0.50	---	Wed 9am	
Wed 10am	29	SN	25	---	28	Slush	30	NaCl	150	27	24	86	ESE	15	24	SN	20	0.00	0.00	0.00	0.00	0.00	0.25	---	Wed 10am	
Wed 11am	30	SN	15	---	29	Slush	15	NaCl	150	27	24	86	ESE	15	24	SN	20	0.00	0.00	0.00	0.00	0.00	0.50	---	Wed 11am	
Wed 12pm	31	SN	10	---	30	Slush	15	NaCl	150	27	24	86	ESE	14	23	SN	20	0.00	0.00	0.00	0.00	0.00	0.50	---	Wed 12pm	
Wed 1pm	32	CompSn	5	---	32	Slush	10	NaCl	33	27	77	ESE	13	24	SN	20	0.00	0.00	0.00	0.00	0.00	0.50	---	Wed 1pm		
Wed 2pm	32	CompSn	10	---	33	Slush	5	NaCl	34	28	80	ESE	11	26	RA	70	0.01	0.00	0.00	0.01	3.0	5.00	HAZE	---	Wed 2pm	
Wed 3pm	32	CompSn	10	---	35	Wet	0	NaCl	35	29	80	ESE	11	27	RA	70	0.01	0.01	0.00	0.00	0.01	3.0	5.00	HAZE	---	Wed 3pm

Figure 23. MDOT Iteris MDSS Screenshot

4.4.4 Decision Making Process

The main impetus behind MDOT’s AVL and MDSS implementation was to provide a tool to allow maintenance garage supervisors to make more informed decisions on attacking winter storms using real-time operational data, current and forecasted weather information, and scientific models that predict how the forecasted weather would affect road conditions. MDOT also desired a system that could assist in asset tracking and speed compliance reporting. MDOT executive management expressed a desire to investigate AVL/GPS systems in early 2013 and requested operations and maintenance staff to review available system options. The MDOT Division of Operations Field Services leadership was responsible for initiating this project.

4.4.5 MDOT Data Collection and Utilization

AVL system data communicated from MDOT vehicles is stored on a server managed by Parsons as the AVL system provider. AVL system data is reported from vehicles to the central server once every minute. The data is available for review by MDOT staff through the AVL software interface. Data collected by the AVL system include:

- Vehicle location, speed and direction
- Air and pavement temperatures
- Plow/blade positions
- Wing plow and tow plow usage
- Types of material applied
- Material application rate and amount used
- Engine diagnostic data
- Dash cam images

MDOT chose to have the AVL vendor store the data on an off-site server due to challenges associated with MDOT IT security. MDOT still owns the data and can obtain it at any time. All data were warehoused since the beginning and were saved for the lift of the contract.

MDOT staff use the data from the AVL system and the MDSS for monitoring vehicle locations and road weather conditions, staffing and resources allocation and planning, material usage tracking, performance monitoring and reporting, research, among others. Measuring the efficiency of salting operations is one key measure that MDOT produces statewide by region and by County where AVL system data is installed. Figure 24 and Figure 25 show a statewide summary and the Grand Region summary for reference on FY 2017 direct force salt efficiency data. The key salt effectiveness measure MDOT has learned through previous research is that salt scatters outside the travel lanes as snow plows travel in excess of 25 MPH while applying salt to the travel lanes.

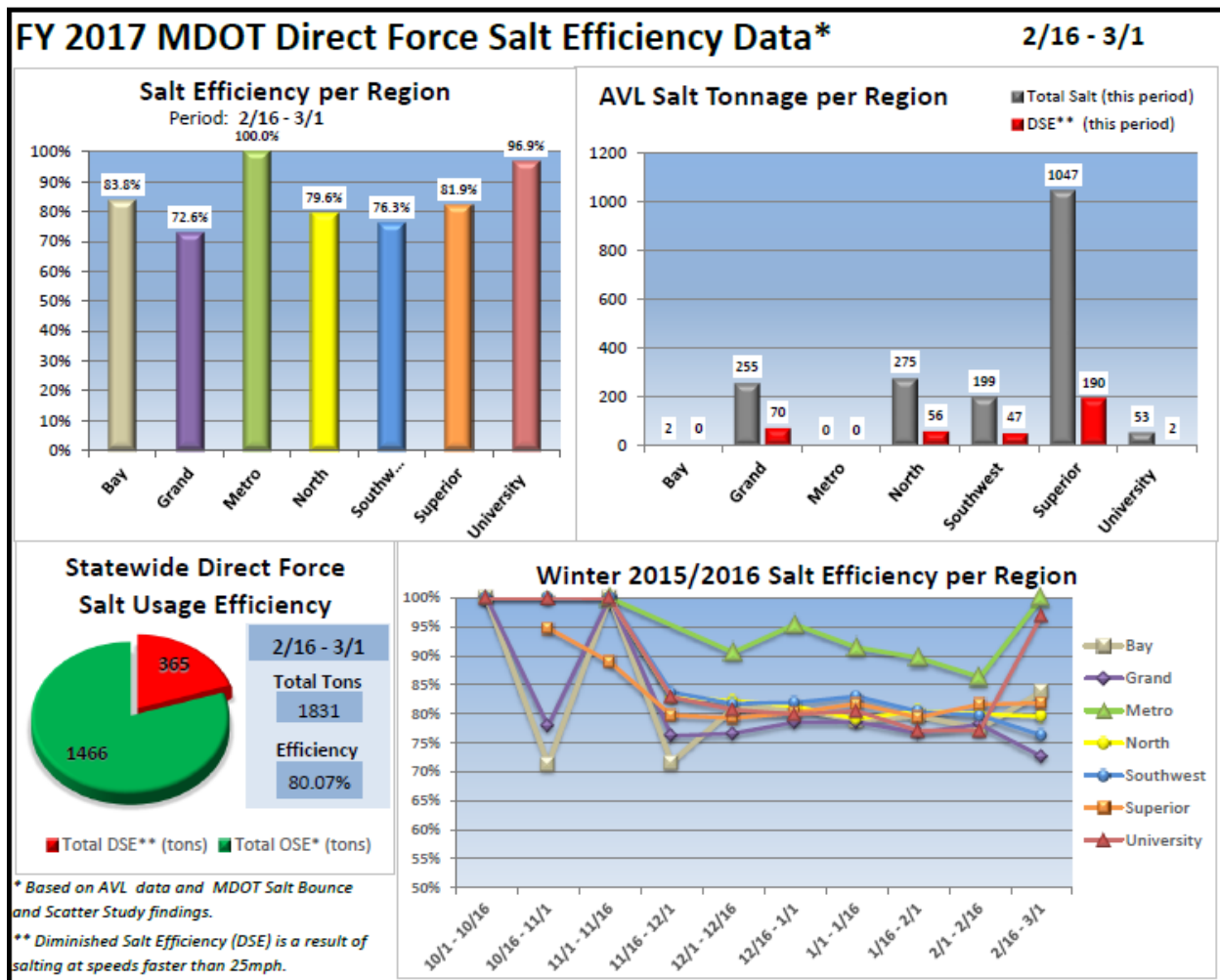


Figure 24. MDOT Salt Efficiency Data Statewide by Region with Direct Forces

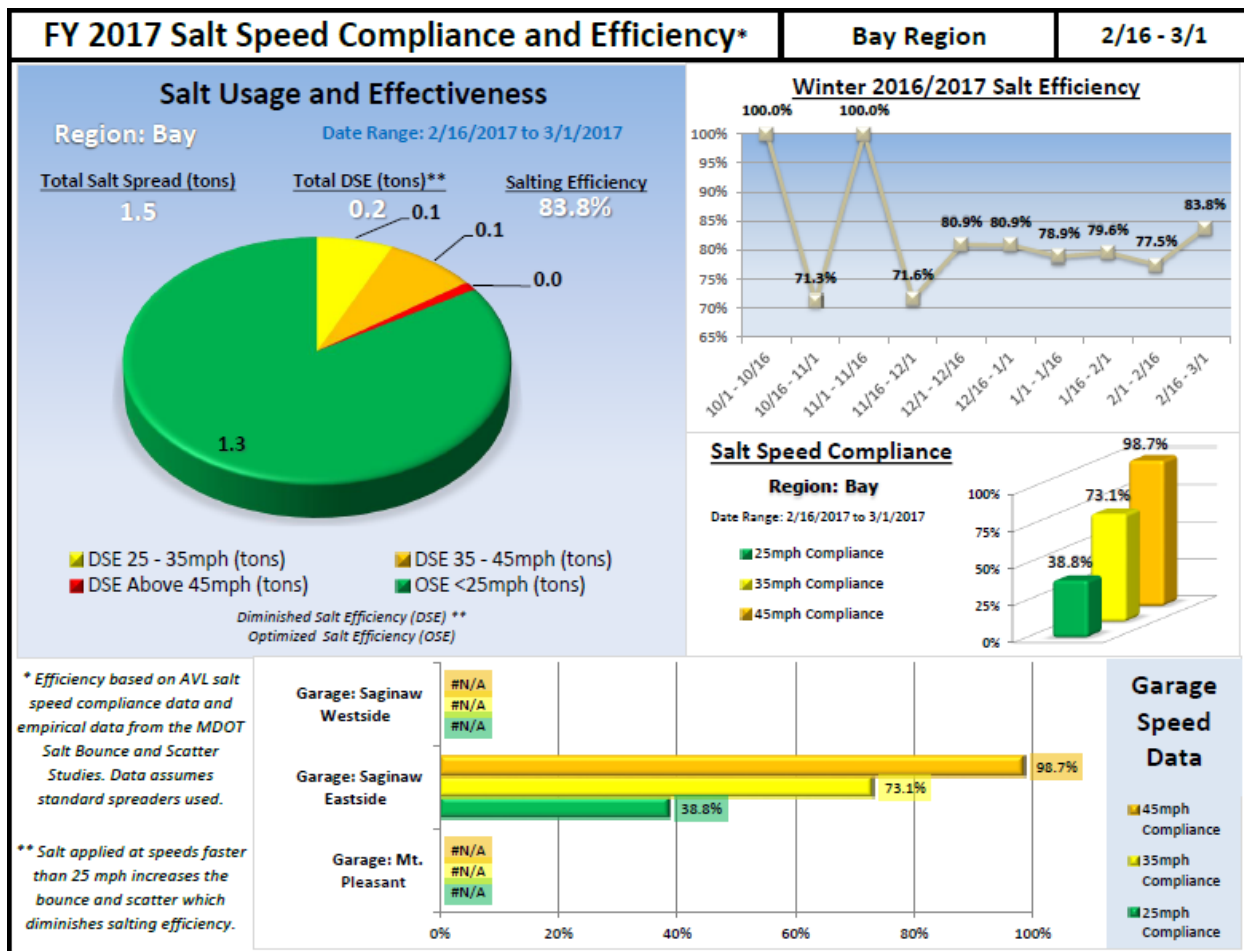


Figure 25. Grand Region Salt Efficiency Data and Speed Compliance Data

A summary of other ways in which MDOT utilizes the system data is presented below.

- The AVL system is used to track vehicle engine hours to schedule preventive maintenance for winter maintenance trucks.
- MDOT uses the AVL data to identify issues with system malfunctions, such as using missing data to investigate if antenna is not working properly or MDC is malfunctioning.
- The AVL data is used to track snow plow vehicle speed and location. Vehicle location information is also shared on the MiDrive website to the public.
- The AVL data is used to record types of material applied and application rates. MDOT supervisors use the AVL software to generate material usage reports.
- The AVL data is used for salting speed compliance reporting.
- The system data is also used for tracking blade usage.
- MDOT supervisors use the data for operational and resource planning according to the MDSS weather forecasts and treatment recommendations. MDOT supervisors monitor weather events, determine the optimal time to call in snow plow drivers, and determine the best course of material application.
- MDOT also uses the data for post-storm reviews. It allows MDOT to review the effectiveness of roadway maintenance activities and identify lessons learned, areas for improvement and best practice.
- Dash cam images are used by supervisors to view the conditions of the roadway or corridors as experienced by the snow plow driver.

- MDOT also uses the data for research. For example, MDOT was able to use the system data to conduct a research project to determine which speed was optimal for spreading materials such as salt, brine, sand, and other de-icing chemicals.
- System data are shared with MDOT TOCs. TOCs use the near real-time operational data from snow plows to observe roadway conditions and improve incident response.

Figure 26 and Figure 27 on the following page present a summary for FY 2017 that is at the MDOT Grand Region level. Figure 27 at the more detailed level can present how each County and Garage within the MDOT Grand Region is also performing with respect to their 5-year average.

While not every County and MDOT Garage in the state utilizes the AVL/GPS system, these reports illustrate how data gathered from the AVL/GPS system can be used to present performance measures on material usage and efficiency across multiple regions and counties over time.

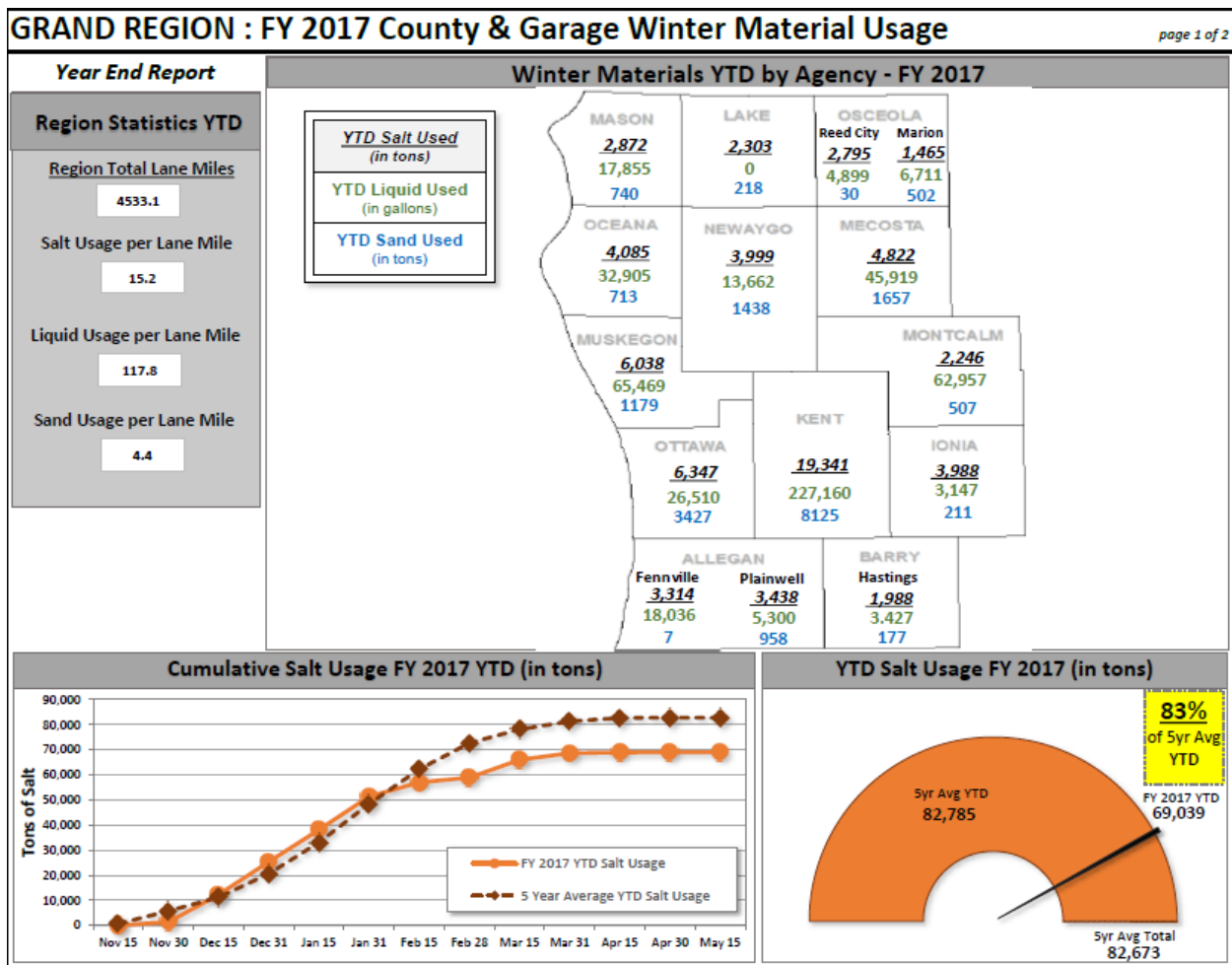


Figure 26. MDOT Grand Region County and Garage Material Usage

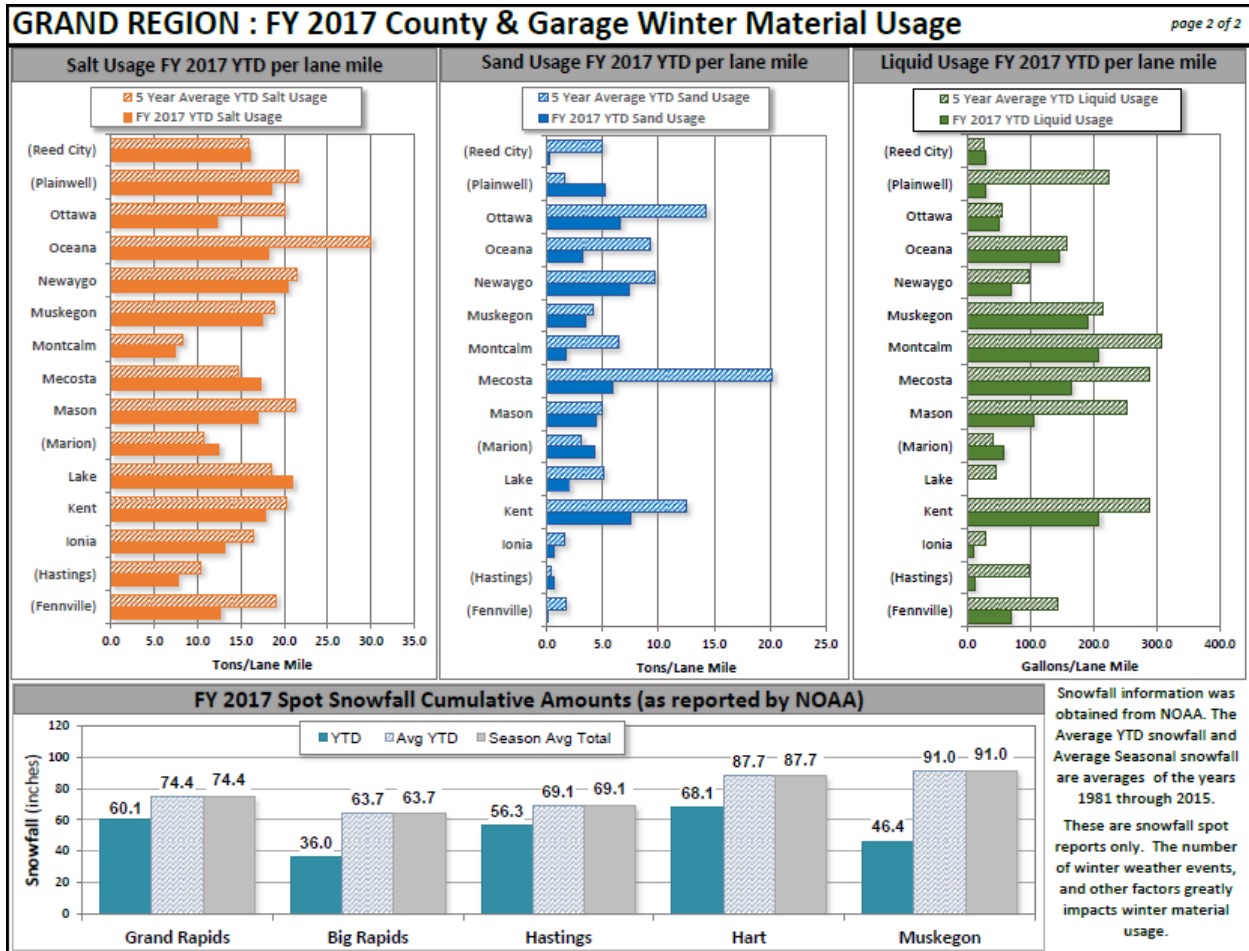


Figure 27. MDOT Grand Region Detailed Material Usage Reports for MDOT Counties and Garages

4.4.6 MDOT Training and Outreach

MDOT staff performed the installation of AVL/GPS hardware on as many MDOT vehicles prior to the 2013-2014 winter season as possible. Training was provided from the vendor on installation procedures to be followed by MDOT vehicle mechanics.

Training on the system functions and operations was provided by Parsons during initial system installation. Continued training sessions, both formal and informal, were provided annually. The MDSS vendor also provided in-person training to MDOT staff on the use of the MDSS system interface.

Continued training of MDOT snow plow drivers on proper use of the system can lead to increased accuracies of the material usage reported, as well as increases in the accuracy of the treatment recommendations coming from the MDSS system.

4.4.7 MDOT AVL/GPS Lessons Learned

The following lessons learned are offered based on the MDOT case study:

- Leveraging other agencies' experience in RFP and requirements development, procurement, installation and operations is extremely valuable.

- Specifications of the system in the RFP should not be too specific to limit agency's options and flexibility.
- Using an all-encompassing contract to hire one single vendor to be responsible for delivering a desired solution reduces agency staff resources required and helps integration of multiple systems; although this approach might increase the overall project cost.
- Support from executive management made procurement and roll-out quicker.
- Outreach to users, especially prior to installation, helped reduce resistance and promote buy-in.
- An aggressive installation schedule may hinder agency's ability and opportunity to perform desired level of user outreach.
- Adequate training is key to buy-in and successful operation. Having tech-savvy staff performing outreach, conveying key messages and supporting installation and operations helps alleviate concerns and promote buy-in.
- Different types of trucks and ages of trucks may require different cabling, connectors, mounting locations, etc. for installation.
- Ease for access and maintenance should be considered when selecting the mounting location for the AVL hardware. In addition, the AVL hardware should be located to minimize potential damage due to liquid, tools or other equipment.
- Battery draw can be a concern as there were many devices drawing power from the same battery. Installation of a battery shut off switch could be a solution. Understanding of the power requirements and consumption of individual devices helps better identify the problems and allows agencies to define and include specifications for power supply and consumption in RFPs.
- Timing of the AVL system installation should be arranged to avoid conflicting with winter seasons when the availability of winter maintenance vehicles may be limited.

4.4.8 MDOT AVL/GPS System Benefits

Key benefits of the AVL system as noted by MDOT include:

- Better and more efficient asset tracking
- More efficient tracking of material usage
- Speed tracking and compliance reporting
- Improved reporting efficiency with automated electronic reporting capabilities; reduction in paper reporting.

4.5 Tier 3 – Wisconsin DOT

4.5.1 Agency Overview

The Wisconsin DOT (WisDOT) Bureau of Highway Maintenance, in a partnership with its five WisDOT regional offices, is responsible for the maintenance of the state trunk and Interstate highway system. WisDOT contracts with each of the state's 72 county highway departments to perform snow and ice removal and control on all Interstates and State highways within each County. Though WisDOT provides funding to the Counties to perform winter maintenance activities, WisDOT does not own any of the snow plow vehicles or any of the equipment associated with the vehicles. Counties maintain the ownership of the vehicles and equipment resides on the vehicle. This partnership was set up more than 100 years ago and is unique in the nation.

Staff at WisDOT's five regional offices work closely with the county highway departments. Regional managers administer the contracts with the counties, and work with the counties to plan for maintenance activities and set priorities. Regional staff oversee county highway departments' maintenance expenditures, and are responsible for ensuring that the counties use resources efficiently and adhere to state guidelines for materials use. Regional staff also serve as a resource for the counties on state and

federal rules and regulations, and can provide training assistance. Figure 28 presents an overview of the WisDOT regions and counties of the state.⁶



Figure 28. WisDOT Regions and Counties

4.5.2 WisDOT AVL/GPS System Hardware

WisDOT displayed an early interest in AVL/GPS technology for winter maintenance operations, based on the state's involvement in the Clear Roads pooled fund program and in the MDSS pooled fund program. WisDOT winter maintenance of Interstates and state highways are performed by each of the 72 counties in the state, which procure their own snow plows and vehicle equipment for winter maintenance operations. WisDOT provides funding to the counties for snow plow equipment associated with the vehicles, specifically the AVL/GPS system.

The PreCise AVL/GPS system hardware is pictured in Figure 29. The AVL/GPS hardware is typically installed underneath the driver or passenger seats of the vehicle and connected to other in-vehicle equipment.

⁶ WisDOT 2016-2017 Annual Winter Maintenance Report. Available at: <http://wisconsindot.gov/Documents/doing-bus/local-gov/hwy-mnt/winter-maintenance/workers/2016-2017annualreport.pdf>

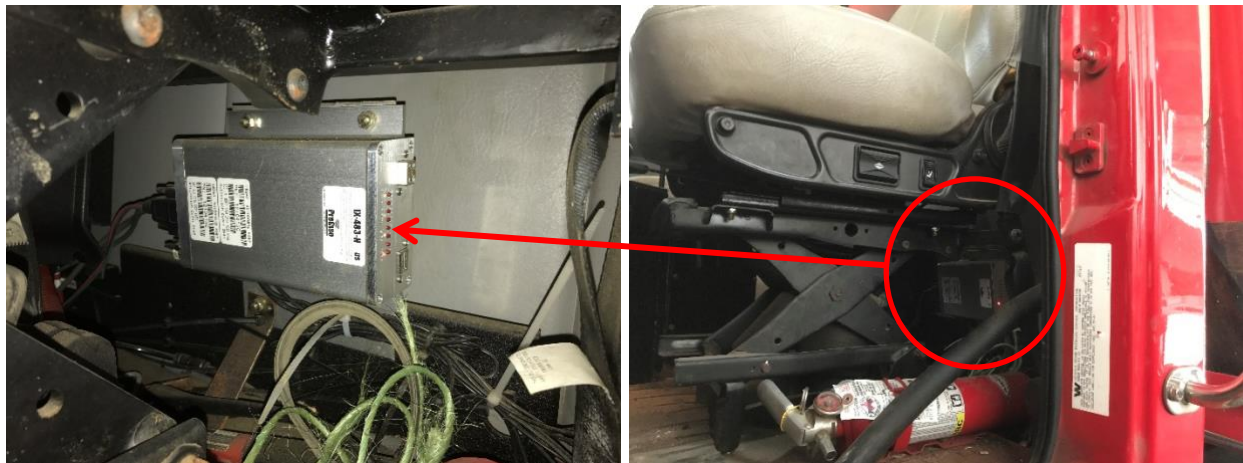


Figure 29. Location of WisDOT PreCise AVL/GPS Equipment in Sauk County Vehicle

The following in-vehicle equipment is integrated with the AVL/GPS system:

- Force America Spreader Controllers (mixture of 5100 and 6100 models)
- Air / pavement temperature sensors
- Plow position sensors (front, underbody and wing plows)
- Gate sensors
- Ground speed controllers

4.5.3 WisDOT AVL/GPS System Software

WisDOT primarily uses the AVL/GPS system software interface from PreCise for post-storm analysis to review how Counties have used salt / brine materials in response to winter weather. In the event that the review finds a discrepancy between certain areas of the County in terms of material amount or application, WisDOT will contact the Counties and present the findings to them for their review and comment. Detailed data and reports provided through the AVL / MDSS interfaces have been helpful to get “buy-in” from county commissioners responsible for the use of the AVL / MDSS interfaces to optimize winter maintenance operations.

4.5.4 Decision Making Process

WisDOT executive management expressed a desire to implement an AVL/GPS system statewide to both improve situational awareness and the efficiency of winter maintenance operations. WisDOT management staff worked to obtain federal funding under SAFETEA-LU for the procurement and implementation of an AVL/GPS system.

WisDOT then worked with the County Highway Commissioner from each county to gain buy-ins. Every County in Wisconsin employs a County Highway Commissioner who oversees all County highway maintenance operations. Within a County Highway Department, the Commissioner manages a team of roadway maintenance staff that includes: a County Patrol Superintendent who monitors vehicle operators and their use of snow plow equipment, and a County Foreman who maintains all vehicle equipment including the AVL/GPS system equipment.

Management level staff at WisDOT, including the Highway Maintenance and Roadside Management Section Chief, attended many County Commissioner Meetings to advocate the benefits of using AVL/GPS systems. Key benefits communicated with the Counties includes how an AVL/GPS system through the

use of MDSS could help optimize material usage and how the system could help with optimizing snow plow routes and resource allocation.

4.5.5 WisDOT Data Collection and Utilization

The following data elements are gathered by the WisDOT's AVL/GPS system:

- Vehicle identifier, time stamp, vehicle location, speed, direction
- Engine diagnostics (including engine on/off, vehicle engine data/codes, vehicle odometer, vehicle mileage and vehicle idle time)
- Type of material applied
- Material application rate
- Air and road surface temperatures
- Plow position (front, underbody and wing plows)

Data are transmitted to the PreCise data sever once per minute when vehicles are within cellular coverage range. All data are stored on the PreCise server, and WisDOT and county highway departments could access the data through the PreCise AVL software interface.

WisDOT chose to have the AVL vendor host the data storage on an off-site server to minimize internal staff commitment and resources required to develop, manage and maintain a database and reporting system. This approach also minimized WisDOT's exposure to IT risks. PreCise is responsible for archiving all data collected for a duration of five years. WisDOT owns all data, and WisDOT and county highway departments can access the data at any time. Historical data are available for playback via the web-based software interface and for download via text file or XML format. Historical data are also available via MDSS.

The AVL/GPS system data is also made available to the Wisconsin Traffic Operations and Safety (TOPS) Laboratory for planning, operational analysis, research, and training. The TOPS Laboratory, based at the University of Wisconsin-Madison, is an academic partner to WisDOT, collaborating on transportation operations, planning and research. The TOPS Laboratory archives data from a variety of winter maintenance data sources, including atmospheric and road surface weather data from the WisDOT Road Weather Information System (RWIS) for January 2006 to the present, WisDOT Bureau of Highway Maintenance Winter Storm Report System data for November 2013 to present, and a repository of WisDOT MDSS and aggregated snow plow AVL/GPS data from 2010.

4.5.6 WisDOT Training and Outreach

Installation of the current AVL/GPS equipment was performed by either county highway departments, PreCise, or third-party contractors. PreCise provided training to county technicians who were responsible for the installation. PreCise also provided on-site support for the installation on an as-needed basis under the requests by WisDOT or individual counties. In addition to installation training, PreCise also provided training on equipment maintenance and web-based software uses.

WisDOT established a training program to facilitate the implementation and utilization of the AVL/GPS system and MDSS. The AVL/GPS training is part of the Regional Operations/County Fall Training Sessions. These sessions are held annually in all WisDOT Regions in preparation for the upcoming winter season. WisDOT provided support and participated in some of these training sessions.

Two levels of MDSS training are provided by WisDOT. An introductory training covers the basics of MDSS and is designed for those who had never used it. The "main" MDSS training focuses on more advanced topics such as how to set up winter storm alerts and how to integrate MDSS into the decision-making process. At various times, this training has also included training on the PreCise website. Target

audience of the training sessions includes county patrol superintendents, state patrol, county highway commissioners, and WisDOT Region personnel.

4.5.7 WisDOT AVL/GPS Lessons Learned

Key observations and lessons learned from WisDOT's AVL/GPS system implementation are offered below:

- Regular communication with users (in this case individual Wisconsin counties) on the benefits of using the AVL/GPS system helps promote proper utilization.
- With AVL data, quality of the MDSS weather forecasts and treatment recommendations improves.
- The ability to view neighboring counties' weather forecasts and recommended treatment strategies in MDSS provides a better picture on winter storms and progression. It also proves a very helpful for resource planning and the timing of winter maintenance activities.
- Having peers at a region- or county-level to communicate and demonstrate the benefits of the system and best practices is more creditable and convincing than having the DOT Central Office staff presenting the information.
- The data and reports provided through the AVL and MDSS software interfaces illustrate evidence and help promote buy-in for system implementation and utilization.
- Changing material usage culture can be challenging. A combination of outreach, education, training, peer communication and evidence from field data provide support to influence field practice in type of material used and application rates.
- Understanding the ongoing costs for operations and maintenance is critical to the success and sustainability of the program.

4.5.8 WisDOT AVL/GPS System Benefits

WisDOT began collaborating with 34 counties on a pilot project for route optimization. Two of the 34 counties, Dane and Brown Counties, have begun evaluating benefits from the 2016-2017 winter. Preliminary numbers show:

- When routes are absorbed into larger routes through optimization, it creates savings of roughly \$85,000 annually per route.
- Brown County is saving \$1.2M this year in equipment costs, as route optimization effectively absorbed 165 new lane miles and eliminated the need to expand the fleet.
- Dane County was able to eliminate four additional trucks from its fleet after a second round of optimization. The further analysis was performed to incorporate new shop and shed locations.

WisDOT noted return on investment would be unique to each county, and WisDOT expected to experience significant savings related to operations, material usage, fuel consumption and increases in safety.

WisDOT also participated in an evaluation study to assess the benefits and costs of the AVL system over the 2010-2011 winter season.⁷ The evaluation focused on salt savings as a result of an improved vehicle operator compliance with winter maintenance guidelines. Measures of salt application by Counties with the AVL system installed were compared against salt applications by Counties without the AVL system, and the WisDOT winter severity index was utilized to account for the winter season that was observed.

⁷ Evaluation of Performance of Automatic Vehicle Location and TowPlow for Winter Maintenance Operations in Wisconsin. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2272, Transportation Research Board of the National Academies, Washington, D.C., 2012, pp. 136–143. Available at: <https://trrjournalonline.trb.org/doi/abs/10.3141/2272-16>

The report presented benefit-cost ratios for AVL system installation ranging from 1.05 to 1.89, depending on the cost of salt and assumption for normalized salt usage reductions. Furthermore, the ratios were considered to be conservative, because the savings in salt costs was the only benefit compared against all AVL system costs over an 8-year period. The inclusion of other benefits from AVL system usage (i.e. environmental benefits, route optimization, etc.) would increase the ratios beyond what was presented in the report.

4.6 Tier 3 – Nebraska DOT

4.6.1 Agency Overview

The Nebraska DOT (NDOT) is divided into eight Districts as shown in Figure 30.

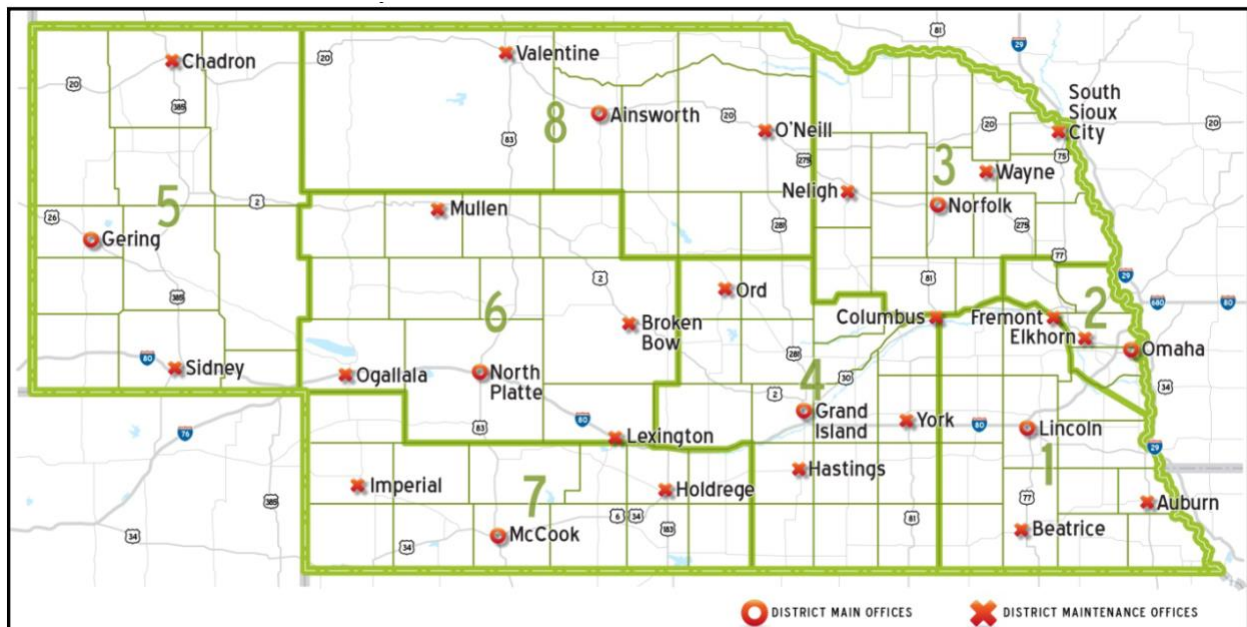


Figure 30. NDOT Districts

4.6.2 AVL/GPS System Hardware

NDOT installed an AVL/GPS system from Parsons prior to the 2015-2016 winter season. Approximately one-third of the fleet (about 225 vehicles) was equipped with the Parsons AVL System in 2015, and nearly all of the remaining vehicles were then equipped with AVL hardware in 2016.

The AVL/GPS system includes a touch screen in cab that can display weather radar images, locations of other trucks, MDSS treatment recommendations, material application rates, among others. An in-vehicle view of an NDOT snow plow equipped with the Parsons AVL/GPS system is shown in Figure 31. In new trucks, the mobile data computer hardware was mounted between the driver and passenger seat area behind the driver, as shown in Figure 32. Older trucks used different mounting locations. The hardware was installed so that wiring could be accessible to maintenance staff as needed from the passenger seat location.

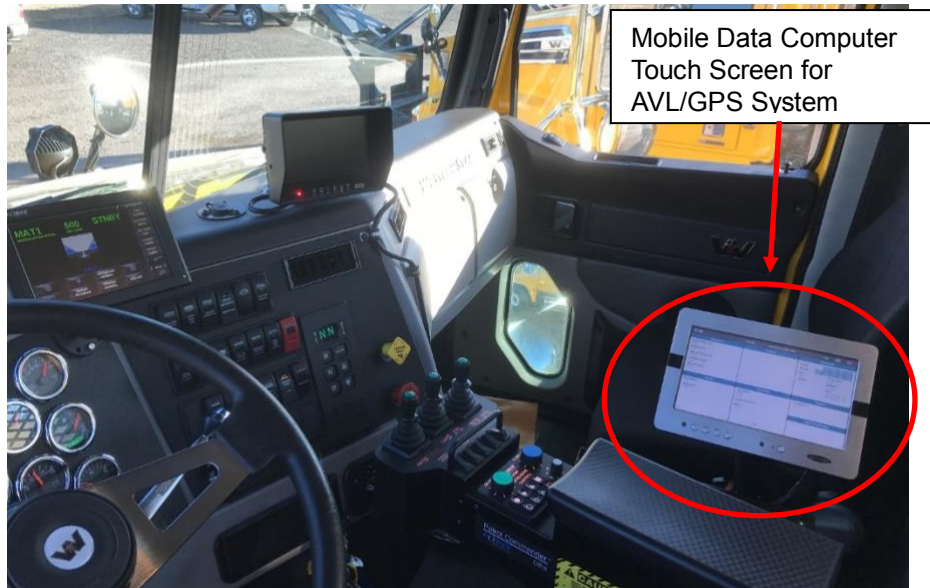


Figure 31. NDOT Snow Plow In-Vehicle Equipment



Figure 32. Location of NDOT AVL/GPS System Hardware

NDOT's contract for AVL system procurement, installation and integration was very similar to that of the Michigan DOT in which one Contractor managed the installation of the AVL system, and an MDSS software for all NDOT maintenance vehicles. NDOT felt the contract organization made the installation process smooth.

The AVL/GPS hardware was integrated with the following equipment and services:

- Spreader controllers
- Plow controllers
- RoadWatch pavement temperature sensors
- Front-facing vehicle dash-cams

- On-Board Diagnostics (OBD-II) port
- MDSS services

Spreader/plow controllers on NDOT's winter maintenance trucks were from various manufacturers, including: Force America, Certified Power, Cirus, Monroe and Raven. All spreader controllers were integrated with the AVL/GPS system with the exception of Monroe MC840 controllers, which was no longer supported.

Force America controllers were readily integrated. Certified Power controllers required costly data conversion hardware and different settings for a variety of spreader types and firmware versions. It has proven to be very challenging to get consistent data from Certified Power controllers.

4.6.3 NDOT AVL/GPS System Software

NDOT utilizes two separate software packages for the AVL/MDSS services: one for the AVL/GPS system provided by Parsons, and a separate software interface for MDSS provided by Iteris.

4.6.3.1 NDOT AVL/GPS System Software

The AVL software package, known as Parsons ATMS software, presents a map-based interface that allows NDOT staff to view the locations of snow plow vehicles. The interface allows for selecting specific vehicles on the map and viewing information about that specific vehicle.

The AVL software can generate automated reports that assist maintenance staff to identify when issues occur with the AVL hardware and vehicles. The reports can be custom-developed to provide alerts on items of interest for maintenance staff, which can assist in preventative maintenance of the vehicles. Through the software, NDOT staff can use a filter to view snow plow vehicles at specific garages and then view the date and time stamps of specific data elements. The absence of any data in the software reported from a vehicle is often a quick way to identify loss of cellular coverage, antenna problems, or malfunctioning AVL hardware. NDOT maintenance staff can then review that specific vehicle and perform the needed repairs, or request assistance from the AVL vendor as needed if replacement parts are required. The AVL software interface is shown in Figure 33.

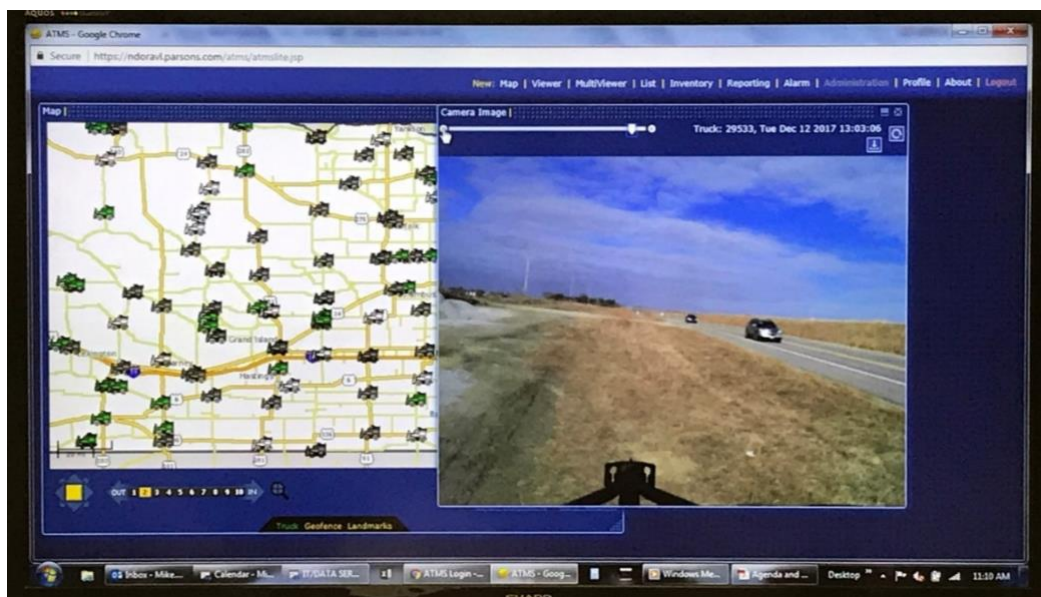


Figure 33. NDOT AVL/GPS System Software Interface

4.6.3.2 NDOT MDSS Software

The MDSS software interface provided by Iteris is used for monitoring weather forecasts and determining roadway treatment strategies in terms of times, locations, type and amount of material to use. Multiple types of alerts can be presented on weather, road conditions and blowing snow, along with winter maintenance treatment recommendations. The MDSS software interface can also be used to track and display vehicle locations and winter maintenance activities. Images from in-vehicle dashcams can also be viewed via the MDSS interface.

4.6.4 Decision Making Process

In 2014, NDOT followed a Systems Engineering process to determine how best to move forward with a new AVL/GPS system. This effort included interviews with NDOT Districts to review the past issues with the older AVL system, and determine what requirements could be developed for a new AVL/GPS system that might also include MDSS treatment recommendations and vehicle dashcams for reporting vehicle images of roadway conditions. Upon completion of the Systems Engineering analysis, NDOT began the RFP development.

Given the potential challenges with managing multiple contractors/vendors for implementing and integrating various systems desired for the AVL and MDSS services, NDOT developed an RFP that requested one prime vendor to serve as a single point of contact for managing the installation of in-vehicle hardware (AVL/GPS and vehicle dashcams), the integration of the AVL/GPS system with other in-vehicle technology, and the provision of MDSS services.

4.6.5 NDOT Data Collection and Utilization

NDOT collects the following data through the AVL/GPS system installed in its vehicles:

- Vehicle locations, speeds and headings
- Material application rate
- Type of material applied
- Pavement and air temperatures
- Dashcam images
- Engine diagnostics, including engine hours, odometer, speedometer, RPM, coolant temperature, fuel level, trip fuel, oil pressure, battery voltage, engine error codes, and idle time

The data polling rates for the AVL/GPS and the MDSS software interfaces were every 1 minute and 2 minutes, respectively.

NDOT does not store data on its server and relies on vendor to provide data storage solution. NDOT felt the key benefit is saving NDOT resources for developing and maintaining a data storage system. The decision of saving dashcam images for no longer than 24 hours was to limit exposure of NDOT to tort claims.

NDOT's primary interaction with the system is through MDSS in which they can view the locations of the snow plow vehicles overlaid on the MDSS software interface. District supervisors also use Parsons AVL/GPS software interface to confirm AVL data was being downloaded to MDSS. NDOT district supervisors and crew chiefs noted the AVL system is helpful for resource identification and relocation which helps improving winter maintenance efficiency. Vehicle locations can be viewed on the touch screen inside the snow plow. Crew chiefs use the information to identify available resources and make adjustments to route assignments and/or maintenance strategies based on field conditions, forecast weather, recommended treatment, and progress of winter maintenance activities.

Dashcam images are used by supervisors to observe field conditions. NDOT maintenance supervisors noted dashcam images were very helpful for observing field conditions, making winter maintenance decisions, and adjusting strategies.

In addition, weather radar information was displayed on the touch screens inside the vehicles. NDOT snow plow drivers noted the information was useful from drivers' perspective. It allowed drivers to observe storm paths and upcoming weather conditions, which helps them better understand winter maintenance instructions and decisions provided by supervisors.

4.6.6 NDOT Training and Outreach

NDOT initially received system training from the vendors of their AVL/GPS and MDSS systems (Parsons and Iteris). Training was provided to NDOT maintenance mechanics so they had the knowledge to perform basic maintenance on the system. Training was also provided to snow plow operators for the operations of the AVL/GPS system. Training on the AVL/GPS software interface was also provided to supervisors, covering how to use the interface to view vehicles and their status, view vehicle history and bread crumbs, and use the reporting features. Multiple levels of MDSS training were also provided to NDOT at the beginning of the implementation for basic users and supervisors. Refresher training for NDOT maintenance supervisors is also provided annually by the system vendors.

4.6.7 NDOT AVL/GPS Lessons Learned

Lessons learned that were gathered from the NDOT case study are presented below.

- Support from top level executives is critical.
- It is important to know how DOT intends to use the technology. Requirements and specifications should be developed based on needs identified by DOT winter maintenance staff.
- Requirements and specifications development takes time and should start with a systems engineering analysis. Taking time to engage district staff to understand their needs and go through systems engineering helps develop a better scope, which promotes project success.
- The RFP needs to clearly state the DOT's expectations of all aspects of the project, particularly related to integration of AVL and spreader controllers.
- Pilot projects help identify issues and opportunities.
- The turnkey contract mechanism reduces the needs for DOT resources for equipment installation, integration, and managing multiple vendors/manufacturers. The prime contractor will be the single point of contact for DOT and responsible for all issues.
- Including warranty in the contract is important.
- Expectations should be communicated to district winter maintenance staff well in advance and throughout the project.
- It is more effective having DOT winter maintenance staff to communicate benefits of the system to their peers. Similar communication from vendors may be viewed as sales pitches by DOT maintenance staff.
- A phased implementation may work well if some districts or maintenance areas are not ready to adopt the technology.
- Additional research is needed to improve the accuracy of spreader controller data gathered through spreader controllers and the AVL system.
- AVL/GPS implementation along with MDSS will bring major cultural changes to operational staff. It is important to identify the right people as champions, along with support from DOT management to support outreach, training and communication.

4.6.8 NDOT AVL/GPS System Benefits

Given the system was implemented on approximately 225 snow plow vehicles prior to the 2015-2016 winter and additional 600 vehicles were implemented before the 2017-2018 winter, NDOT would have

sufficient system data for the first time to conduct a quantitative evaluation of the system. NDOT envisioned the use of data analytics in coming years to capture and evaluate performance measures.

NDOT was especially interested in comparing material usage data based on the MDSS treatment recommendations against hand-written reports completed by NDOT District Supervisors. The comparisons would evaluate material usages for the entire winter season as well as for specific winter storms. The comparisons would provide a first real data point that NDOT can use to evaluate how the AVL/GPS and the MDSS systems have had an impact on material usage and overall operations efficiency. NDOT also planned to use the system data to generate and assess other performance measures, including: staff resource usage, operations costs, consistency between treatments, etc.

Benefits of the system as observed by field operations staff, particularly from maintenance supervisors and crew chiefs, are:

- The system provided increased situational awareness to winter maintenance staff. Supervisors and crew chiefs could obtain vehicle location information in real time, which helps in resource planning and allocation.
- Camera images provided road condition information from snow plow drivers' perspective, which provided additional information for supervisors' situational awareness.
- The system allowed the ability to check and monitor material application rates and types of material used.
- The MDSS treatment recommendations were especially helpful to less experienced drivers.

4.7 Colorado DOT

4.7.1 Agency Overview

The Colorado DOT (CDOT) is divided into five different regions as well as eight different maintenance sections as illustrated in Figure 34 and Figure 35, respectively. On average, CDOT spends roughly \$77 million on winter maintenance each season, and is also responsible for operating and maintaining the statewide heavy vehicle fleet of snow plows and the light vehicle fleet of other maintenance vehicles including safety service patrol vehicles. The annual operational budget for the combined fleets is approximately \$1 billion.

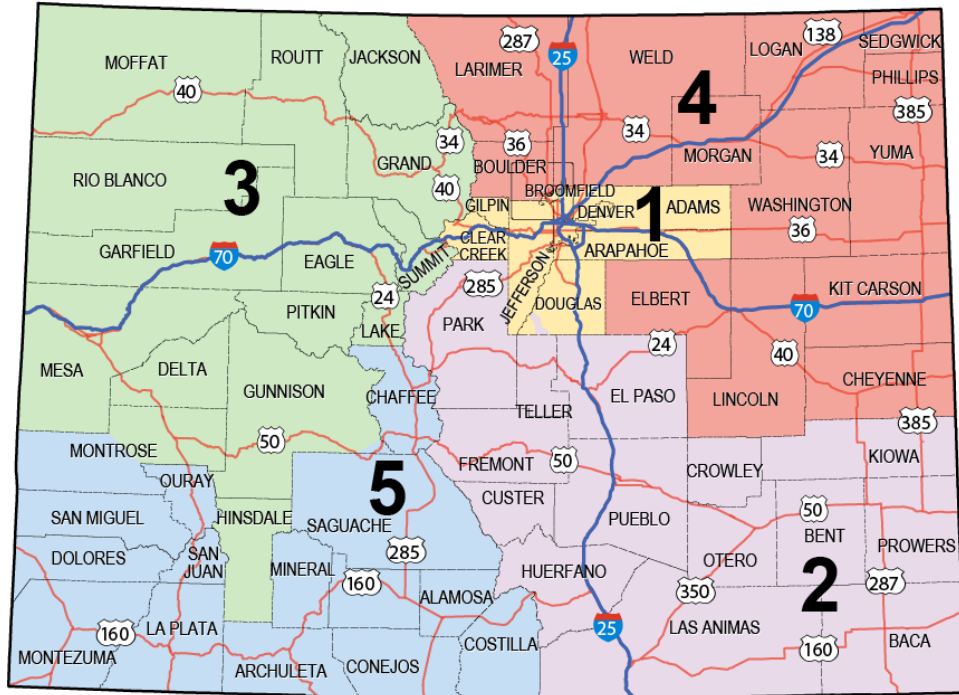


Figure 34. CDOT Regions⁸

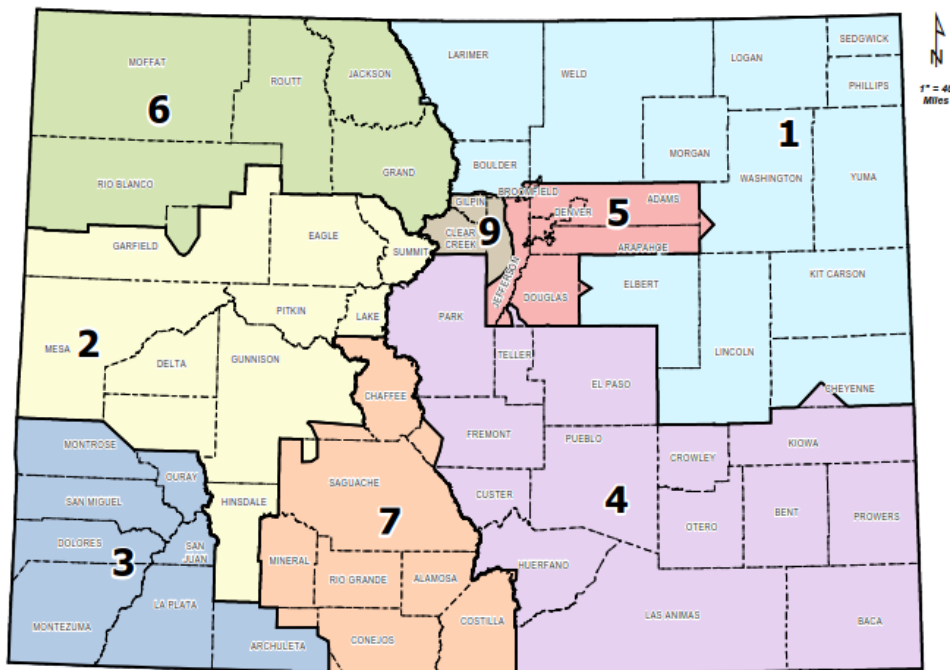


Figure 35. CDOT Maintenance Sections⁹

⁸ Source: <https://www.codot.gov/about/regions.html>

⁹ Source: http://dtdapps.coloradodot.info/staticdata/downloads/StatewideMaps/MaintSections_Small.pdf

4.7.2 CDOT AVL/GPS System Hardware

CDOT maintains a fleet of approximately 1,200 snow plow vehicles that are equipped with an AVL/GPS system by Zonar Systems, which features a ruggedized tablet within the snow plow that provides an interface for drivers to use for logging into their specific route. CDOT drivers utilize a pre-assigned ID card and tap it to the tablet to log into the tablet to perform various functions. Refer to Figure 36 for a view on the in-vehicle installation.

The tablet also performs a number of other tasks, namely electronic pre-trip and post-trip inspection reporting which has replaced paper reporting that was previously done by CDOT drivers. CDOT snow plow drivers physically bring the tablet to each of the areas of the truck with a yellow puck and tap the tablet to each puck, shown in Figure 37. All reports are sent electronically through the tablet to a central database for record keeping and identification of issues that may need maintenance on the vehicle.



Figure 36. CDOT Snow Plow and Zonar System Tablet Installation Location / Screen

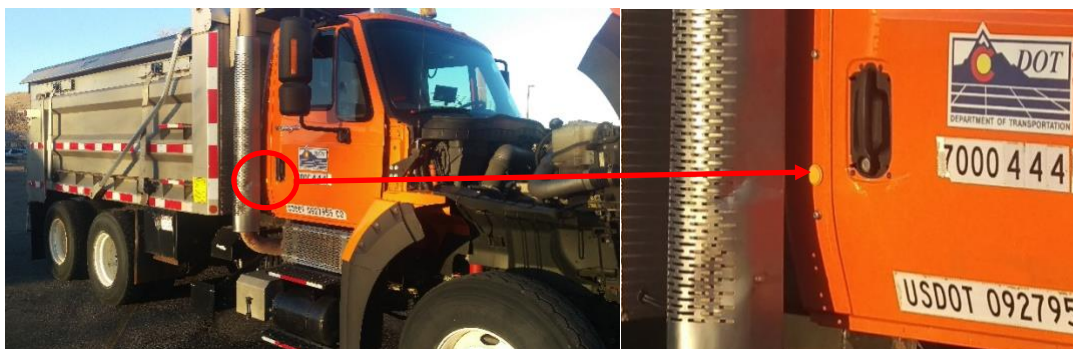


Figure 37. CDOT Snow Plow and Example Reporting Puck for Pre-Trip and Post-Trip Reports

Equipment on the CDOT snow plows integrated with the Zonar AVL system includes:

- Plow position sensors
- Spreader controllers for material application rate and type of material
- Air and pavement temperature sensors
- Humidity sensors
- Dashcams (8 units through a pilot project)
- Engine diagnostics

CDOT's snow plows primarily equipped with spreader control systems from Cirus, Certified Power, and Force America.

CDOT is currently conducting a project that may simplify the integration work required between in-vehicle components. The project is being conducted under CDOT's RoadX program that provides funding for new and innovative transportation projects in the state. Under the project, Verizon is partnering with two separate companies – Cradlepoint and Panasonic – to implement a system that would communicate real-time images and video from snow plow vehicles to a central office that could view roadway conditions and communicate back to the vehicle through in-vehicle equipment. Cradlepoint is providing an in-vehicle wireless communications router that is wirelessly connected to an in-vehicle dashcam provided by Panasonic, along with other in-vehicle equipment such as spreader controllers and temperature sensors.

The overall goal of the pilot project is to send and receive all data through the Cradlepoint router and improve the efficiency of in-vehicle communications. Depending on the overall success of the project, CDOT may roll it out on a larger scale in future years.

4.7.3 CDOT AVL/GPS System Software

The main software interface provided by Zonar is known as Ground Traffic Control, which is used by CDOT Administrators to assign other CDOT staff different levels of access to the software interface. This includes supervisors, mechanics, and drivers as users of the software to perform various functions. Ground Traffic Control is a web-based software interface. It allows users to view real-time analytics, generate reports, and configure alert features.

CDOT also uses the Iteris MDSS to assist in winter maintenance strategies. CDOT snow plow vehicles with the Zonar system receive MDSS weather forecasts and treatment recommendations. Snow plow operators can bring up the interface through a tap of the button on the right portion of the home screen. Drivers are still provided the independence to determine the level of treatment based on existing conditions and their overall judgement, given the diverse geography within the state that can make it difficult for weather forecasting services to predict the duration and intensity of winter storms for specific regions, areas or corridors.

4.7.4 Decision Making Process

In 2014, CDOT began the preparation of a Request for Proposals (RFP) document for a statewide AVL/GPS procurement to replace the AVL/GPS system installed previously. The overall goal of the procurement was to select one vendor to supply hardware and software for both the CDOT heavy vehicle fleet and light vehicle fleet. Improving the overall efficiency of fleet management and maintenance operations was the main focus for CDOT in preparing the RFP.

CDOT executive management expressed a desire to expedite the implementation of a system that was capable of achieving CDOT's main goal of improving fleet management and utilization efficiency and fuel efficiency. CDOT was able to leverage an existing master service agreement from the City and County of Denver to procure an AVL/GPS system for CDOT snow plow vehicles within a short period of time.

4.7.5 CDOT Data Collection and Utilization

Data collected by the CDOT AVL/GPS system on snow plows include:

- Plow position
- Material application rate and type of material used
- Pavement temperature and air temperature
- Humidity

- Dashcam images
- Engine diagnostics and alerts
- Inspection data

In addition to vehicle location data, the Zonar AVL/GPS system collects engine idle time, vehicle speed, vehicle health and diagnostics, inspection data and timestamps. Vehicle inspection is performed by the operator pre-trip. The operator will inspect each area of the vehicle which is marked with a yellow puck with an embedded RFID tag. The operator will scan the tag and respond to the inspection criteria using the tablet. Upon inspection, the operator will place the portable tablet into the vehicle mount where inspection information is transmitted to the software interface server via cellular transmission. Data required for the Federal Motor Carrier Safety Administration (FMCSA) compliance were retained for six months, per FMCSA requirements.

All data collected through the AVL/GPS system were stored on the Ground Traffic Control server. Data relevant to winter maintenance operations were also transmitted to and stored in Iteris MDSS. CDOT did not save any data generated from those systems on its server due to liability concerns.

4.7.6 CDOT Training and Outreach

CDOT's AVL system vendor (Zonar) provided a training session at the beginning of the system rollout. Training to CDOT staff at an administrative level on the software side of the system was also provided. Upon system implementation, CDOT continues providing training to snow plow operators on the system on an annual basis. CDOT acknowledged that more training up front would better facilitate buy-in and proper use of the system. In addition to the annual training, CDOT plans to conduct traveling road shows through the state to provide additional training and raise awareness in the future. CDOT would also like to perform additional training to managers, superintendents and supervisors to help them with interpreting reports and maximizing their knowledge of the system.

There was some reluctance among CDOT snow plow operators to accept the AVL system given concerns about the system potentially being used for disciplinary purposes. CDOT gained buy-in from operators over time as they realized that the AVL system could be used to protect them from claims of damage caused by CDOT snow plows. CDOT noted that to gain operators buy-in, support from supervisors as well as training to supervisors for proper use of the system is critical. When communicating with operators, it is essential to focus on communicating the benefits (such as for their protection from claims and personal safety) and making it clear that the system is not a tool for micro management or disciplinary actions.

4.7.7 CDOT AVL/GPS Lessons Learned

The following lessons learned are offered based on the CDOT case study.

- The needs and goals of an AVL/GPS program should be identified clearly in the early stage. Clearly identified needs and goals help develop system requirements and procurement document. They also help agency establish realistic expectations for the program. Past experience and experience by other agencies with implementation and utilization of AVL/GPS systems help in needs and goals identification.
- Automatic alerting features on vehicle diagnostic issues may create burdens to maintenance staff if the alerts are communicated with higher frequency. Agencies can work with maintenance staff and vendors to identify an approach for effective communication yet ensuring timing completion of corrective actions.
- Properly trained staff results in better usage of the system. Better usage of the system produces better quality data. Training should be provided to all levels of users, including maintenance

superintendents, supervisors, snow plow operators, mechanics/technicians, and system administrative staff (for software interface user management).

- Adequate training should be provided prior to system implementation. More training is beneficial and should be considered. Training not only promotes proper use of the system, it also facilitates buy-ins.
- If agency staff/trainers are utilized to provide training to system users, it is important that the trainers receive sufficient training and have adequate knowledge of the system and its operations.
- The integration between an AVL/GPS system and other technology in snow plow vehicles (such as spreader controllers and sensors) may not be straightforward. Agencies should anticipate issues and challenges, and be prepared to work with AVL/GPS vendors and other equipment manufacturers on the integration. Performing research and gathering information from other agencies and manufacturers helps agencies to better understand potential issues and solutions. It also helps in system and procurement requirements definition.

4.7.8 CDOT AVL/GPS System Benefits

Among the greatest benefits to the use of the system is an increase in situational awareness of how staff are responding to winter storms and an ability to present the response to executive management in real-time on vehicle locations. Other benefits identified by CDOT staff include:

- System generated maintenance alerts helps with proper diagnostic and repairs. This in turns saves money and promotes timely repairs.
- Alerts on long vehicle engine idle time helps reductions in idle time, fuel consumption and negative emission impacts.
- The system has abundant reporting features that help not only in situational awareness but also in improving resource management, staff management and operational efficiency.
- The system had positive impact on driver behaviors such as promoting speed compliance and minimizing improper use of the equipment.
- The system has been used to protect drivers from false/erroneous accusations by the public.

5. Best Practices and Recommendations

The purpose of the recommendations presented in this report is to help other state DOTs that may fit within the different Tiers described above make more informed decisions with respect to the implementation of AVL/GPS technology for winter maintenance activities. The recommendations are presented in the following sections based on the subject areas discussed with state DOTs during the interview stage of the project.

5.1 Planning and Decision Making

The following recommendations pertain to the decision making process involved in the planning and implementation stages of an AVL/GPS system.

Recommendation: Involve agency leadership and management throughout the project

Involvement from leadership at agency executive and district/region levels is key to successful planning, procurement and implementation. Buy-in and engagement from agency leadership helps in establishing and procuring an AVL/GPS program for winter maintenance operations. It supports communicating the importance of an AVL/GPS system to field maintenance staff in achieving agency's goals. It also supports timely installation and maintenance as well as encourages property use of the system. Without an internal support network, especially from the leadership, an AVL/GPS program will have little traction and will likely not progress in a positive way.

Best Practice

Each of the 24 WSDOT Maintenance Areas determined their own respective maintenance priorities related to vehicle maintenance. This led to some Areas placing less of a priority on the installation and maintenance of the AVL system. It also presented challenges to use of the system for gathering data on material usage and snow plow operations. Leadership for some Areas was very engaged and pushed for quick AVL implementation. As a result, those Areas had the AVL system installed very quickly. As an example, the Regional Maintenance Engineer for WSDOT Olympic Region sent out a memo to the maintenance staff within the region to communicate the use of the AVL/GPS system for winter maintenance as a high priority. This type of emphasis on the importance of properly using and maintaining the AVL system results in timely installation and proper utilization of the system.

Recommendation: Identify agency's needs, goals and objectives for an AVL/GPS system

The needs and goals of an AVL/GPS program should be identified clearly in the early stage. Clearly identified needs and goals help develop system requirements and procurement document. They also help agency establish realistic expectations for the program. Past experience and experience by other agencies with implementation and utilization of AVL/GPS systems help in needs and goals identification.

It is important to identify how an agency intends to use the technology. Agency's winter maintenance staff should be involved in needs identification, and requirements and specifications of the AVL/GPS system should be developed based on the identified needs and established expectations.

While the primary function of AVL/GPS systems is to provide location tracking and monitoring of snow plow vehicles to agency staff that supervise winter maintenance operations, AVL/GPS systems can enable an agency to achieve numerous goals and objectives, for example, increasing public transparency and increasing efficiency in vehicle maintenance/asset management.

An agency can utilize vehicle location data and other data in real-time from the AVL system so that vehicle location could be presented on a public-facing traffic information page. This can help to achieve the overall objective of increasing the public transparency of their winter maintenance operations.

Agencies can also increase vehicle maintenance efficiencies and improve asset management through collecting and transmitting vehicle diagnostic data via AVL/GPS systems. This capability can greatly increase the efficiency of vehicle technicians to perform remote diagnostic maintenance on snow plow vehicles, as well as routine preventative maintenance.

Recommendation: Assess the number of vehicles within the agency fleet that will require AVL/GPS system hardware and integration based on needs and financial flexibility

The deployment of AVL/GPS technology on a majority of the vehicle fleet can provide the agency with a greater situational awareness of how the agency is responding in real-time to winter storms. The literature review of a previous Clear Roads project (CR14-01) surveyed multiple agencies in 2015 and found that most agencies had equipped only part of their fleet with GPS/AVL equipment (an average of 35%), likely due to the cost and maturity of the technology at the time of system implementation. However, the 2017 survey results gathered as part of this project showed that more than half of the agencies had equipped more than 50% of their fleet with AVL/GPS technology as shown in Table 11 below. Many of the agencies surveyed in 2017 also noted they planned to continue expanding the technology to additional vehicles in the near future.

Table 11. Percent of Vehicle Fleet with AVL/GPS Technology from 2017 Survey

Percent of Vehicle Fleet with AVL/GPS Technology	0 to 15%	16% to 50%	50% to 99%	100%
Total Agencies	9 agencies	8 agencies	9 agencies	12 agencies

A majority of the state DOTs interviewed in late 2017 and 2018 had also equipped most or all of their winter maintenance fleet with AVL/GPS technology. One of the main benefits of the AVL/GPS system reported from agencies was a greater situational awareness of how DOTs are responding in real-time to winter storms. With more vehicles in a winter maintenance fleet that are equipped with the technology will come a greater awareness and ability to report to the general public on how the agency is responding to winter storms.

Recommendation: Conduct research and/or pilot projects to gain knowledge as well as identify issues and opportunities prior to full system implementation

Agencies can benefit from pilot testing prior to full system deployment. Pilot testing helps agencies understand the technology and its limitations. It helps agencies gain knowledge on the system and identify potential issues may encounter during installation, integration, operations and maintenance of the system. Experience and lessons learned from pilots also help develop a better project scope and specifications/requirements.

Similarly, research on AVL systems and equipment desired to be integrated is extremely valuable. This includes obtaining experience and lessons learned from other agencies. Research helps agencies gain a better understanding on AVL systems and other equipment, including how they can function individually as well as be integrated with other equipment. Agencies should also confirm research findings with vendors and manufacturers.

Best Practice

CDOT conducting AVL/GPS system demonstrations with various vendors in 2014 prior to the current system implementation. Those demonstrations provided insight into the capabilities of various systems and how they could achieve CDOT goals and objectives related to fleet management and winter maintenance. It also helped CDOT realize potential usage and benefits of the system. For example, early results from the demonstrations revealed that some snow plow vehicles had been idling with engines running for excessive periods of time, resulting in both excess fuel consumption and increased maintenance costs. The awareness of the issue resulted in the prevention of those instances in future maintenance operations, resulting in a large amount of operational savings to CDOT. Observations from those demonstrations prompted CDOT to reconsider their priorities to procure a system not only for winter maintenance operations but also for overall fleet management to improve fleet and fuel efficiency.

Best Practice

WSDOT began testing AVL/GPS technology in selected areas around 2007 through a pilot project. Over time, WSDOT expanded the AVL system implementation to other Regions around 2010. Due to the need to upgrade the existing AVL systems as well as establish a consistent approach with their AVL/GPS system on a statewide basis, WSDOT developed and issued a solicitation in 2015 to procure a vendor to provide AVL hardware and software for all WSDOT snow plows, sweepers and emergency response vehicles throughout the state. Knowing the potential challenges associated with the integration of the AVL system and spreader controllers from previous experience, WSDOT performed research in-house to gain a better understanding on the specifications of both the AVL systems and spreader controllers. WSDOT also worked with AVL vendors and spreader controller manufacturers to confirm their research findings. The research helped WSDOT with smooth integration of the AVL system and spreader controllers. It also enabled WSDOT staff to correctly interpret data from the system and devices.

Recommendation: Consider phased implementation to ease adoption of technology

For large scale, such as statewide, implementation, there may be districts or regions within an agency that are not ready to adopt the use of an AVL/GPS system due to prior experience, “big brother” perception, or skepticism. A phased implementation may work better in this case. Agencies can implement an AVL/GPS system on selected fleet or in selected areas/districts in the initial phase to gather benefits of the system utilization and build confidence. Outreach to districts/regions initially not ready for the technology needs to be followed to facilitate buy-in and subsequent system rollout. Positive experience and benefits realized from the initial implementation can alleviate skepticism, promote confidence and ease the adoption of the system in other districts or regions.

5.2 Procurement

The following recommendations pertain to the procurement of AVL/GPS systems for winter maintenance agencies.

5.2.1 Requirements and RFP Development

Recommendation: Use a Systems Engineering approach in the development of system requirements and specifications.

The development of system requirements and specifications takes time, and the process can benefit from taking a Systems Engineering approach. Agencies should take time to engage winter maintenance staff to understand their needs and go through systems engineering. The use of Systems Engineering helps develop a better scope, which promotes project success. This process typically begins with a Concept of Operations that can be understood by multiple agency staff, prior to developing more detailed system requirements and specifications.

This interdisciplinary approach assures that the system that is conceived early on at the concept level has a well-defined purpose to meet agency needs, and that the system requirements reflect input gathered from agency staff at multiple levels. The system requirements can also form the basis upon which an agency can perform acceptance testing on the system that is ultimately procured by the agency.

Best Practice

NDOT followed a Systems Engineering process to determine how best to move forward with a new AVL/GPS system. This effort included interviews with NDOT Districts to review the past issues with the older AVL system and to identify needs and potential solutions to address those needs. The high priority needs gathered from the interviews formed the basis for the system requirements for a new AVL/GPS system that would also include MDSS for treatment recommendations and vehicle dashcams for capturing vehicle images of roadway conditions. Upon completion of the Systems Engineering analysis and development of system requirements, NDOT began the RFP development.

Recommendation: Leverage other agencies' experience in requirements and RFP development

Given the use of wide deployment of AVL/GPS systems by multiple states over the past years, it can be beneficial to agencies to perform peer agency outreach during the development of system requirements and an RFP package. An informal survey of how other states currently use the AVL/GPS system technologies can allow an agency to gain additional knowledge on the potential benefits of an AVL/GPS system on winter maintenance operations. In fact, agencies can leverage knowledge, experience and lessons learned from other agencies for all aspects of their AVL/GPS program, including planning, decision making, RFP and requirements development, procurement, installation, operations, and maintenance.

Best Practice

MDOT surveyed other states using the technologies through the Clear Roads program, as well as other states in the Maintenance Decision Support System (MDSS) Pooled Fund Study, to gain additional knowledge on the potential benefits of an AVL/GPS system on winter maintenance operations. MDOT was also considering an agency-wide implementation of MDSS operations in addition to the AVL/GPS system deployment. One of the lessons gathered by MDOT was related to the challenges of maintaining separate contracts for both an AVL/GPS system and an MDSS provider, in addition to other contracts for cellular equipment, could create issues with the coordination required between multiple contractors. Based on this finding through the peer agency outreach, MDOT proceeded with the procurement of a single contractor that would be responsible and accountable for the management of both the AVL/GPS system and the MDSS system operations.

Recommendation: Clearly state agency's expectations in the RFP

An RFP needs to clearly state the agency's expectations of all aspects of the project, particularly related to integration of AVL and spreader controllers. The integration of AVL and spreader controllers can be complicated and challenging, especially if the agency has spreader controllers from multiple manufacturers. Clearly stated requirements and responsibilities in the RFP can minimize ambiguity and finger-pointing. They also help facilitate coordination and cooperation among all parties involved in system implementation and integration.

5.2.2 Methods of Procurement

Recommendation: Consider the use of a Request for Information (RFI) process to gather information on the current state of AVL/GPS system technology

The use of an RFI process can provide valuable information to the agency that could influence the subsequent steps taken in the procurement process. An RFI can provide an agency with a better understanding of the overall capabilities of AVL/GPS systems and can also help with developing a budgetary estimate for the deployment of an AVL/GPS system. Answers to key questions gathered through an RFI process can also be presented to multiple levels of agency staff to communicate what was learned through the process and how it could impact the next steps taken by the agency.

Best Practice

UDOT utilized an RFI in 2014 requesting information on system costs, types of technology, and other items of interest. Through vendors' responses, UDOT gained better knowledge of the overall capabilities of AVL/GPS systems and technology. Information gathered through the RFI also helped UDOT perform more realistic budget planning for procurement and system implementation. While valuable information was gained through that process on system capabilities, UDOT discovered that they would not be able to deploy a comprehensive AVL/Materials usage system on a statewide basis as desired from the onset based on the cost information vendors provided. This process helped influence UDOT's next steps of reviewing how best to proceed with AVL/GPS system procurement.

Recommendation: Use best value procurement for selecting an AVL/GPS vendor

The traditional low bid procurement method may be suitable for implementing an AVL/GPS system that requires less integration with other equipment or if the agency has well-defined specifications for the system. However, it may not be the best choice for more complex and/or large-scale implementation. Best value procurement allows agencies to evaluate vendors based on their costs as well as qualifications and past performance. This procurement method is recommended for Tiers 2 and 3 implementation where projects may include higher degree of risks and uncertainty, particularly related to the integration of an AVL/GPS system with spreader controllers and the delivery of the agency desired data management and reporting features. Best value procurement, along with the system requirements in the RFP, also allows an agency to verify vendors' ability to deliver an AVL/GPS system that complies with those requirements.

Recommendation: Consider the use of a turnkey contract for complex implementation

Using a turnkey contract to hire one single vendor to be responsible for delivering a desired solution reduces agency staff resources required and helps integration of multiple systems. The turnkey contract mechanism reduces the needs for agency resources for equipment installation, integration, and managing multiple vendors/manufacturers. The prime contractor will be the single point of contact for the agency and responsible for all issues. This contract mechanism is particularly useful for the implementation of a complex AVL/GPS project (Tiers 2 and 3). The turnkey contract mechanism can be considered if:

- The agency has limited staffing resources to manage and coordinate among multiple vendors/contracts,
- Spreader controllers from multiple manufacturers need to be integrated with the AVL/GPS system, or
- The agency has challenges getting needed support from spreader controller manufacturers.

It should be noted that the use of a turnkey contract likely increases the overall project cost.

Recommendation: Leverage existing contracting vehicles for expedited procurement

An alternative procurement method to an RFP process may exist for agencies that may not have the time or resources it may require to develop detailed system requirements and follow an RFP process. Some states interviewed through the case studies indicated that they were able to leverage existing pre-negotiated contracts to purchase the necessary hardware and software for their AVL/GPS systems. In some cases this could be leveraging an existing contract owned by other public agencies within the state, or it could be utilizing a larger multi-state contract that allows for an agency to purchase the desired AVL/GPS system hardware and software at pre-negotiated unit cost prices.

5.3 System Implementation

The following recommendations pertain to the implementation of AVL/GPS systems by winter maintenance agencies.

5.3.1 Installation

Recommendation: Arrange installation schedule to minimize impacts to winter maintenance operations

While the installation of AVL/GPS system hardware on snow plow vehicles can be completed either by in-house vehicle mechanics or by a contractor team hired by the agency, the timing of the installation is an important consideration that should be taken into account during procurement process or prior to installation.

Scheduling of AVL/GPS equipment installation and integration over non-winter months can better ensure vehicle availability. If agency staff are used for installation, this will allow for agency vehicle mechanics to better allocate their time and resources to help ensure a proper system installation. If installation is performed by the AVL/GPS system vendor and/or sub-contractors, scheduling the installation process over non-winter months will also help to ensure that the winter maintenance vehicles are available for the installation.

Recommendation: Install AVL/GPS equipment at protected locations with access for maintenance

Ease for access and maintenance should be considered when selecting the mounting location for the AVL/GPS hardware. In addition, snow plow operators may have additional tools or items inside the cab that could be hazardous to the AVL/GPS hardware. Such tools and items include: shovels, saws or chainsaws, axes, liquid chemicals, drinks, backpacks, etc. The AVL/GPS hardware should be located to minimize potential damage due to liquid, tools or other equipment.

Different types of trucks and ages of trucks may require different mounting locations, cabling, connectors, etc. for installation. Agencies should identify those scenarios and material needed and communicate with installers prior to installation. It is recommended to have a pre-installation meeting with installers, whether they are contractors or agency staff, to go over installation guidelines, standards and expectations.

Recommendation: Involve and train agency mechanics for AVL hardware installation

Regardless the AVL/GPS hardware installation is performed by agency staff or vendors/contractors, it is recommended to involve internal agency vehicle mechanics during the installation for their benefit of understanding how the equipment is installed. It is also beneficial to have the system vendor to demonstrate and train agency vehicle mechanics on the installation procedures. Involving agency vehicle mechanics in the installation process can help to create an atmosphere of ownership in the system among vehicle mechanics. It can also give them firsthand knowledge of how the equipment was installed and how it functions and interacts with other vehicle equipment, which can assist with future equipment maintenance and replacement.

5.3.2 Integration with Other Equipment

Recommendation: Anticipate issues and challenges associated with integration between other equipment and an AVL/GPS system

The integration between an AVL/GPS system and other technology in snow plow vehicles (such as spreader controllers and sensors) may not be straightforward. For example, if an agency has spreader controllers from multiple manufacturers, the integration between spreader controllers and an AVL system can be complicated and challenging. Agencies should anticipate issues and challenges, and be prepared to work with AVL/GPS vendors and other equipment manufacturers on the integration. Issues related to integration can be technical and institutional. As recommended previously, performing research and gathering information from other agencies and manufacturers helps agencies to better understand potential technical issues and identify solutions. It also helps in system and procurement requirements definition.

Agencies should also be aware of and be prepared for addressing institutional challenges associated with integration. Institutional challenges may include:

- Difficulties to coordinate with multiple parties (such as the AVL/GPS vendor, manufacturers of other equipment and installation contractors) and develop mutually agreed solutions.
- Inadequate or no customer support from equipment manufacturers due to age of the equipment or lack of interest on the manufacturers' side.
- Protection or legal considerations of proprietary technology or data.

Recommendation: Communicate with bidders regarding anticipated challenges with system integration during procurement

The best opportunity to communicate the complexity of the integration to the AVL/GPS system vendor is during the procurement process. Agencies can utilize an RFI process to gather responses and potential solutions from prospective bidders. Agencies can also include information regarding their current systems, desired integration outcomes, and anticipated challenges, along with system requirements and a detailed scope of work in an RFP. This can help to provide the AVL/GPS vendor with an understanding of the amount of work required to perform the integration.

5.3.3 Outreach and Buy-in

Recommendation: Perform regular outreach to maintenance field operations personnel

In addition to obtain buy-ins from agency executive and district/region leadership, it is equally important to obtain support from field maintenance operations personnel to ensure a smooth implementation and proper use of an AVL/GPS system. Field operations personnel are frontline users of the system and include maintenance supervisors and snow plow operators. Regular outreach and communication with those users should occur throughout the implementation process and continue during the operations phase. Outreach prior to system installation is also recommended as it helps reduce resistance and promote buy-in from field maintenance staff. In addition, expectations on proper use of the system should be communicated to winter maintenance staff in advance and throughout the system implementation and operations.

Outreach prior and during system installation should be planned carefully by taking into account not only staff schedule/availability but also installation schedule. If outreach activities are not planned accordingly, an aggressive installation schedule may hinder agency's ability and opportunity to perform desired level of user outreach.

Many of the agencies interviewed for the case studies indicated that identifying champions and/or peers to communicate the needs, purposes and benefits of an AVL/GPS system to field maintenance staff is an effective method. These project champions could be individuals at district management level, maintenance superintendents, or supervisors. Having champions or peers at a district or region level to communicate and demonstrate the benefits of the system and best practices is more creditable and convincing than having the DOT Central Office staff presenting the information. Similar messages delivered by vendors may be viewed as sales pitches by field maintenance staff and thus are less effective.

Recommendation: Communicate and demonstrate the purpose of the system to snow plow operators to alleviate concerns

The adoption of AVL/GPS systems by state DOTs in recent years has generally caused "Big Brother" concerns from some snow plow operators about the use of the system by supervisors to discipline drivers. Agencies interviewed for the case studies noted that these concerns have generally lessened over time as operators realize the system is used for a disciplinary purpose. However, it should be recognized that such concerns still exist.

To alleviate "Big Brother" concerns as well as promote proper use of the system, the communication should focus on positives of the system. For example, operators have found that an AVL/GPS system could provide evidence to protect them against false public complaints about property damages caused by snow plow operations.

Recommendation: Be prepared for dealing with winter maintenance cultural changes

AVL/GPS implementation on winter maintenance vehicles may bring cultural changes to operational staff. The impact on winter maintenance culture is more significant if the system is integrated with spreader controllers and used for material usage monitoring and reporting. Changing material usage culture can be challenging. Agencies should be prepared to utilize strategies that include a combination of outreach, education, training, peer communication and evidence from field data to influence field practice in type of material used and application rates. It is important to identify the right people as champions, along with support from DOT management to support adoption of the changes from field personnel through outreach, training, and communication.

5.3.4 Vehicle to Center Communications

Recommendation: Evaluate cellular providers to maximize coverage and supplement with other communications methods to fill the gaps

A majority of the agencies surveyed for the project reported the common use of cellular networks to communicate data between vehicles and central servers supporting AVL/GPS system software packages. The growth of cellular communications networks over the past decade has gradually reduced the gaps in coverage where snow plow vehicles operate to perform winter maintenance. This finding is consistent with that through a previous Clear Roads project that surveyed agencies in 2015.

Through the case study interviews, some DOTs reported that they were able to utilize multiple cellular providers given that some providers had better coverage in some areas of their state than others. This approach would be advantageous to states/regions where cellular coverage may be increasing to enable greater wireless coverage of those areas. Agencies may also utilize radio communications systems in more remote areas where cellular coverage is inadequate.

Best Practice

WSDOT utilizes cellular communications for its AVL/GPS system in most areas of the state. WSDOT's AVL vendor secures cellular data communications services based on cellular coverage in each area. WSDOT also utilizes a state-owned 700 MHz radio system to fill the communications gaps in two Regions that feature more remote areas of the state where cellular coverage is inadequate. This combination of cellular coverage and state-owned radio system has worked well for WSDOT.

5.3.5 Training

Recommendation: Provide training to all levels of system users before, during and after system implementation

A number of agencies interviewed for the case studies noted the importance of AVL/GPS system training for multiple levels of staff that will be involved with the system operations and maintenance. Properly trained staff results in better usage of the system. Better usage of the system produces better quality data. Training should be provided to all levels of users, including maintenance superintendents, supervisors, snow plow operators, mechanics/technicians, and system administrative staff (for software interface user management).

Adequate training is key to buy-in and successful operation. Training should be an on-going program. It should be provided prior to and during system implementation as well as during operations phase. On-

going training for both operations and maintenance is crucial to the success of an AVL program. Training should reach to the ground level staff involved in operations (operators) and maintenance (mechanics/technicians). More training is beneficial and should be considered. Also, having tech-savvy staff performing outreach, conveying key messages and supporting installation and operations helps alleviate concerns and promote buy-in.

Recommendation: Require AVL vendor to provide initial training to agency winter maintenance staff on system operations and maintenance

It is recommended that agencies require AVL/GPS system vendors to lead the Initial system training in the implementation process and provide agencies with the required understanding on system hardware and software functionality. Multiple types of training sessions can be requested from vendors. This can include installation training for agency mechanics so that they are able to perform basic maintenance on the in-vehicle hardware of the system. Training can also be requested for snow plow operators to understand how to interface with the in-vehicle equipment and detect any issues with system operations. Training can also be provided for maintenance supervisors on the AVL/GPS software interface, covering how to use the interface to view vehicles and their status, view vehicle history and bread crumbs, and use the reporting features.

Recommendation: Communicate the benefits of the AVL/GPS system operations as part of training to establish buy-in with the system among system users

Many agencies reported receiving some initial skepticism from snow plow operators about the use of an AVL/GPS system as part of a “big brother” concern about their movements being monitored for potential disciplinary actions. Communicating the benefits of an AVL/GPS system with snow plow operators as part of the training sessions can help gain “buy-in” from vehicle operators over time. The benefits for vehicle operators can include the ability to exonerate drivers from claims of vehicle or property damage reported by the general public. Agency goals and objectives for AVL/GPS system usage can also be presented so that snow plow operators develop an understanding on why the system is being installed (i.e. increasing public transparency, improving material usage efficiency, improving vehicle maintenance efficiency, etc.). Presenting these objectives to snow plow operators can help them to understand that the AVL/GPS system is not being used for disciplinary actions or other micro-management.

Recommendation: Conduct recurring training to winter maintenance agency staff to improve the agency's ability to achieve operational objectives

Recurring training sessions with winter maintenance agency personnel can help improve an agency's ability to achieve operational objectives. It also helps gain “buy-in” from staff on the overall value of the system. Recurring training is especially important for agencies that use AVL/GPS system data such as material usage for performance measures to evaluate operations efficiency.

Best Practice

WisDOT has established an ongoing training program to facilitate the utilization of both the AVL/GPS system and MDSS. The AVL/GPS training is part of the Regional Operations/County Fall Training Sessions, which are held annually in all WisDOT Regions in preparation for the upcoming winter season. WisDOT also provides support and participate in some of these training sessions. Through attending the trainings, WisDOT staff advocates and demonstrates the benefits of the AVL/GPS system usage, which has resulted in increases the efficiency of material usage, snow plow route optimization, and resource allocation.

Recommendation: Establish a “train the trainer” program to help retain system knowledge within the agency

A “train the trainer” program can ensure system knowledge resides within an agency. The train the trainer program also helps build a network to share knowledge and best practice as well as support on-going operations and maintenance of the system. If an agency is considering utilizing agency staff to provide training to system users, it is recommended to establish a train the trainer program for the AVL/GPS system. It is important that the trainers receive sufficient training and have adequate knowledge of the system and its operations.

5.4 Data Collection and Utilization

The following recommendations pertain to the collection, management and utilization of AVL/GPS system data by winter maintenance agencies.

5.4.1 Data Collection

Recommendation: Require AVL vendor to make system data available to the agency

Typically, an AVL/GPS system vendor will provide a software interface allowing an agency to view system data and generate various reports. Multiple agencies interviewed for the case studies noted the benefits of obtaining the system data from the AVL/GPS vendor. Obtaining system data from a vendor is typically through the use of an API provided by the vendor. The availability of the API allows for an agency to download select portions of raw vehicle data reported to the vendor’s data server and store that data in an internal agency database. This can include, for example, data attributes on vehicle latitude and longitude coordinates at a sufficient frequency which can then be used to display vehicle location on a public-facing traffic information webpage and/or mobile application.

In other cases, an agency may be able to perform an internal backup of the AVL data generated from their system. The storage of this data can allow for the agency to internally develop a software interface that can best meet the needs of agency staff that are responsible for winter maintenance operations.

5.4.2 Data Accuracy

Recommendation: Understand the limitations on material usage data accuracy

One of the most desired reporting features of an AVL/GPS system is the material usage reports. However, the accuracy of the material usage reports can be a challenge of working with the AVL/GPS system. Some of the challenges or practices that impact material usage reporting accuracy gathered through the case studies include:

- Inaccuracy of GPS measurements: WSDOT calculates material usage based primarily on the application rate and miles of vehicle traveled. WSDOT calibrates the material application annually. The mileage estimates are based on GPS measurements from the AVL system, not the odometer. WSDOT has experienced issues with the accuracy of the GPS measurements. This inaccuracy, in turn, led to an inaccuracy of the material usage calculations.
- Spreader/spinner is on when no material is spread: MDOT gathers the measure of material applied from spreader controllers, regardless of whether material is being applied. In Michigan, snow plow drivers may allow the vehicle spreader controller to operate throughout an entire driver shift to keep the vehicle augur from freezing up in cold temperatures, which results in a higher amount of material usage reported through the software.

5.4.3 Staffing and Resources for Data Management

Recommendation: Identify agency staffing and resources needed to support the management of the AVL/GPS System prior to system procurement

The agencies interviewed for the case studies discussed different approaches taken with respect to the staffing and resources required to support an AVL/GPS system. Items to consider in terms of resources include who performs data storage and management, how data is presented through central software, and other resources necessary for ongoing use of the AVL/GPS system. The approach taken to these items can vary based on the agency and should be discussed internally prior to proceeding with system procurement.

One common approach to addressing data management is to require the AVL/GPS system vendor to be responsible for all data management and storage of system data. The vendor can then be required to make the data available via web-based software interfaces which would need to be accessible when requested at any time by winter maintenance agency personnel. This approach can remove the need for agency coordination that would be needed with internal IT departments that might otherwise be responsible for managing AVL/GPS system data on internal agency computer servers. The approach may also provide cost savings in terms of staffing and resources required for developing and maintaining a data management and storage system.

Other agencies have chosen to supplement the use of the AVL/GPS system vendor's software package with internally developed software interfaces to support their winter maintenance operations. This approach can require the setup of a database to store AVL/GPS system data that can then be utilized for an internally developed software interface to present on the status of winter maintenance operations.

5.4.4 System Data Usage

Recommendation: Use real-time system data to make adjustments to resource allocation and maintenance strategies

Agencies can use the real-time system data to monitor winter maintenance activities. Based on weather forecasts, agencies can plan for resource allocation and maintenance strategies accordingly. Winter maintenance supervisors can also utilize the system to observe activities being performed in neighboring areas, assess the effectiveness and appropriateness of such winter maintenance activities, and make informed decisions and appropriate adjustments in strategies and resource utilization. The ability to view neighboring area weather forecasts and treatment strategies provides a better picture on winter storms and progression. It proves very helpful for resource planning and the timing of winter maintenance activities. It also allows for improved cross-regional coordination and resource sharing/allocation.

Best Practice

AVL system data is primarily by WSDOT Maintenance Supervisors and Superintendents for vehicle location monitoring and situational awareness during winter storms. Maintenance Supervisors and Superintendents use the real-time data to monitor winter maintenance activities and make adjustments to resource allocation and route assignments. WSDOT also uses the stored data for material usage reporting and post-event review/analysis as well as for review in the event of a tort claim of WSDOT liability in a traffic accident.

Recommendation: Integrate other road condition data with mobile observations from AVL/GPS systems

Most agencies in Tiers 2 and 3 integrate air and surface temperature sensors on snow plow vehicles with their AVL/GPS systems. Integrating mobile road condition data gathered from those sensors with data collected from RWIS stations and/or other real-time road condition data collection technology helps better situational awareness and facilitates improved winter maintenance practices. Many agencies also deployed traffic cameras for monitoring traffic conditions and assisting with traffic management. Agencies may also have cameras installed with RWIS stations or other locations. Those cameras along with real-time road condition data from RWIS and mobile observations help verify and confirm pavement conditions. The information can be helpful for determining as well as evaluating winter maintenance strategies.

Best Practice

UDOT has developed a Snow and Ice Performance Dashboard that has real-time statistics. UDOT integrates AVL data with RWIS data and data from non-invasive roadway grip sensors into the Snow and Ice Performance Dashboard. UDOT maintenance crews utilize the real-time statistics from the Dashboard to determine how effective the winter maintenance strategies are at maintaining good road conditions during a storm.

Recommendation: Establish a performance management program to document performance and benefits

There are many benefits of implementing AVL/GPS systems for winter maintenance operations. Having a proper performance management program in place to analyze data and systematically evaluate and document benefits of the AVL/GPS system is critical. It helps assess winter maintenance performance and identify opportunities for improvement. Agencies can use performance measures to identify best practices and demonstrate benefits to winter maintenance supervisors and snow plow operators to influence field practices. A performance management program also helps identify tangible benefits and provide justifications to agency executives and legislature on how the benefits relate to the costs, which helps sustain the on-going operations and maintenance of an AVL/GPS program.

Recommendation: Work with system vendors to develop agency desired data reporting features and performance dashboards

Although AVL/GPS system vendors can provide software packages allowing agencies to view valuable information and create multiple reports, the ability of vendor provided software packages may not always meet agencies' needs and expectations. Many agencies interviewed for the case studies use vendor provided software packages for data management and reporting without creating their own tools. Modifications to vendor provided software interfaces become necessary at times. Those agencies have found that most vendors were willing to work with agencies to enhance software packages and develop additional data management and reporting features to meet the agencies' needs. Vendors may see this as opportunities to enhancing their products with added features that may be desired commonly among winter maintenance agencies. Agencies should

Best Practice

MDOT utilizes data on vehicle speeds to assess how well snow plow drivers adhere to the recommended speed for roadway treatment through a speed compliance report. The speed compliance report was not a feature provided by the AVL vendor initially. MDOT expressed the desire and worked with the AVL vendor to custom-develop the report for MDOT through the AVL software interface that can indicate the speeds of snow plows as they apply material. Reports on snow plow operators can be generated for instances where speeds are detected in excess of 25 MPH. MDOT uses the reports to discuss best practices with snow plow operators about maintaining the recommended travel speeds.

Recommendation: Use internal resources to develop agency desired reporting features and performance dashboard

For agencies who have the resources and prefer to develop own tools for system data management and reporting, it is advantageous to use internal staff to develop tools with specific features that meet agencies' needs. Agency staff may have better understanding on the goals, objectives and needs of its AVL/GPS program. They may also be more knowledgeable regarding the performance management needs desired by the agency. In addition, tools developed by agency staff have a higher probability of being compatible and able to be integrated with agency's systems or software packages. Vendors, on the other hand, may be less interested in developing and adding features of the software that can only be used by few customers. Agencies should carefully review and investigate the options of using internal staff vs. vendors to determine the most advantageous way to develop or enhance tools to meet their needs.

Best Practice

UDOT is supported internally by GIS staff resources for developing and maintaining the GIS interfaces and database. UDOT had a team of two to three GIS staff members working on integrating the AVL data with the GIS database as well as developing additional products and analysis tools to assist with winter maintenance operations and performance management. UDOT GIS staff developed a Snow Plow Tracking Dashboard which draws from AVL data stored in the UDOT GIS database and shows the current UDOT snow plow locations, last plowed roadway segments, and additional metrics on the active plows. The interface is internal to UDOT Supervisors and Managers and can provide an overall snapshot of storm response on a statewide or regional scale.

UDOT also developed a Snow and Ice Performance Dashboard that has real-time statistics. UDOT maintenance crews utilize the real-time statistics to determine how effective they were at maintaining good road conditions during a storm. Several metrics go into creating the performance measure, including the intensity of the storm, length of time the storm is ongoing, resources allocated to the maintenance station covering the geographic area, field instrumentation on the RWIS units, and AVL data. The resulting information is utilized to measure storm performance, identify best practices and possibly re-allocate resources to better cover areas in need.

5.4.5 Data Sharing

Recommendation: Consider sharing vehicle location data with the general public

One of the most frequent comments and questions that a DOT gets from the public is “where are the plows.” Sharing snow plow vehicle location information and bread crumb trails to the public helps increase public transparency and promotes public trust.

Some agencies have taken additional steps to delay the reporting of vehicle location on a public webpage by 2-3 minutes. This step can alleviate snow plow operators’ concerns that real-time vehicle location could be used by individuals to plan specific attacks on snow plow vehicles. However, it is important to communicate the potential delay to the general public through a disclaimer on the reporting delay, in addition to notes about potential gaps in cellular coverage that may limit the ability to report on vehicle locations.

While there may be some benefit to sharing vehicle location for public transparency, this also has to be balanced with concerns regarding potential liability that departments may have with sharing vehicle locations. Some agencies reported potential liability concerns as a reason for not sharing the vehicle location on a public-facing webpage. Internal discussions within the agency can help to determine the best course of action on whether or not to share vehicle location information with the general public.

5.5 Operations and Maintenance

Recommendation: Obtain support and secure funding to sustain on-going operations and maintenance

Support from agency executives and management is crucial to the long-term sustainability of an AVL/GPS program. This support is also necessary to secure funding for on-going operations and maintenance of the program. In addition to gather support from leadership and management, it is important to understanding the staffing resources and costs required for on-going operations and maintenance of the program. For agencies maintaining their AVL/GPS systems with limited or without vendor support, it is important not to underestimate the maintenance involved to keep the system working correctly.

Appendix A – Summary of Survey Responses

Available separately; contact the Clear Roads administrative contact (see <http://clearroads.org/contact-us/>) for access.

Appendix B – Case Study Interview Summary: Utah DOT

PROJECT 16-01: UTILIZATION OF AVL/GPS: CASE STUDIES

SUMMARY OF UTAH DOT IN-PERSON INTERVIEWS

Overview

Interviews were conducted by Ming-Shiun Lee and Dan Nelson of AECOM and coordinated with Tim Ularich of the Utah Department of Transportation (UDOT) on November 27 and 28th, 2017.

UDOT Staff Interviews

Meeting attendees throughout the day on Mon. Nov. 27th included the following individuals:

- *Tim Ularich, Deputy Maintenance Engineer*
- *Brandon Klenk, Methods Engineer*
- *Kevin Griffin, Director of Maintenance*
- *Jeff Casper, Equipment Operations Manager*
- *CJ Connor, Maintenance Programs and Contracts Manager*
- *Troy Starley, Equipment Specialist*
- *Wendy Kemp, Procurement Specialist*
- *Rodney Andrews, Equipment Specialist*
- *Nicole Godfrey, Equipment Systems Specialist*

Meeting attendees throughout the day on Tues. Nov. 28th included the following individuals:

- *Tim Ularich, Deputy Maintenance Engineer*
- *Jason Davis, Director of Operations*
- *Kevin Griffin, Director of Maintenance*
- *CJ Connor, Maintenance Programs and Contracts Manager*
- *Kaitlyn Marousis, GIS Analyst*
- *Adam Radel, GIS Program Manager*
- *Greg Searle, Region 3 District Engineer*
- *Michael Cole, Area Supervisor*
- *Chad Hansen, Station Supervisor*

UDOT Executive Level Interviews

Group met at the UDOT Headquarters in West Valley City to discuss how UDOT proceeded through the procurement process of their AVL/GPS system. UDOT determined in 2014 to install AVL/GPS technology in winter maintenance vehicles in an effort to increase the public transparency of their operations by providing snow plow locations to the general public via a public UDOT traffic information page and mobile application.

As part of the AVL/GPS procurement process, UDOT sent out a Request for Information (RFI) in 2014 to industry providers of AVL equipment requesting information on system costs, types of technology, and other items of interest. The responses to the RFI indicated that financially UDOT would not be able to deploy the AVL systems on a statewide basis as it had been desired.

Around that time, UDOT learned about a pre-negotiated contract that Verizon had entered into in 2011 with the Western States Contracting Alliance (WSCA), which is currently managed by the National Association of State Procurement Officials (NASPO). As a member of the WSCA, UDOT would be able to utilize that contract to purchase the associated hardware and software required for their AVL/GPS system.

UDOT had previously tested a pilot program with a PreCise AVL/GPS system in 2012. Some issues encountered at that time related to sensor reliability and difficulty in data utilization. Upon further review of the system in 2014 though, UDOT found that they could implement their entire fleet of winter

maintenance vehicles with the Verizon AVL system and still accomplish the objective of public transparency while staying within the available project budget.

In the spring of 2015, UDOT requested Verizon to perform a demonstration of the overall system on approximately 50 winter maintenance vehicles. Verizon performed the hardware installations on the vehicles and demonstrated the functionality and reliability of the system over a two-month period for UDOT. The vehicles were monitored by UDOT through the software package (NetworkFleet) by UDOT staff and features of the software were observed to confirm that the system was functioning properly.

Upon successful completion of the demonstration, UDOT purchased additional Verizon hardware that was then installed by a Verizon team of subcontractors in all 508 Class 8 winter maintenance vehicles prior to the 2015-2016 winter season. Since that time, additional UDOT maintenance equipment and Incident Management (Safety Service Patrol) vehicles have been equipped with Verizon units. UDOT staff have been trained to perform the installation of Verizon hardware on new winter maintenance vehicles and other maintenance equipment (i.e. sweepers, loaders, skid steers, mini-excavators, graders, etc.).

Key challenges associated with UDOT's decision-making and deployment include:

- Financial constraint was the biggest barrier.
- Due to financial constraints, UDOT had to find a balance between plow location data vs. material usage data. The need for public transparency on plow locations outweighed tracking of material usage through AVL.
- The concern about "Big Brother" watching from drivers has been lessened but still persists for some.
- Involvement from Districts and Regions is key to success. Exposing technology to people helps buy-in and implementation. UDOT worked with staff in each region to gain buy-in to the system. In addition to providing continued training, UDOT holds monthly meetings with District Engineers to identify and discuss innovations.

Key benefits identified by the UDOT executives include:

- Ability to provide records of plow locations and activities, which help achieve public transparency.
- AVL data helps address liability issues and resolve tort claims.
- AVL data provides assistance in route planning and prevents gaps in plowing routes.
- AVL data with RWIS data provides real-time road conditions information which integrated in UDOT's Snow and Ice Performance Dashboard.
- The system facilitates better resource sharing and cross-regional coordination.
- AVL data supports performance management. AVL data enables UDOT to make performance measures available to the public, which in turn promotes public trust.
- Truck diagnostics have helped UDOT mechanics optimize their time by allowing for truck error code access to perform a preliminary diagnostic on mechanical issues.

UDOT noted their future plan related to expanding the system capabilities and to winter operations. The future plan includes:

- Integrating AVL system with spreader controllers to gather material usage data.
- Further development and enhancement of performance measures and management program.
- Investigating and implementing connect vehicle technologies.
- Equipping DSRC to snow plows to help with signal priority and I2V communications.

UDOT Supervisor / Manager Level Interviews

Group met at the UDOT Headquarters in West Valley City to discuss how UDOT staff interact with the AVL/GPS system. Vehicle maintenance staff that attended discussed the benefits that they have observed in reading the vehicle diagnostic codes that are communicated through the AVL software package (NetworkFleet). Staff receive automated alerts when these codes are detected, which provides valuable information on the appropriate maintenance actions needing to be taken. It was noted that in some cases, the codes have saved maintenance technicians from having to travel multiple hours to where snow plow drivers have stopped operating because of the vehicle error codes presented to them on the vehicle dashboard.

This capability is made possible through connection of the Verizon AVL hardware with the existing vehicle's On-Board Diagnostics (OBD-II) port, which allows pre-defined vehicle codes to be sent as alerts through the NetworkFleet software package to alert UDOT staff that vehicle maintenance is needed in a specific area. This was noted as a major benefit of the system by UDOT managers and supervisors when discussing how they have used the NetworkFleet software. Given the long distance of some snow plow routes that travel through remote areas on UDOT highways, supervisor / maintenance staff would have to travel for multiple hours to address a problem that can now be diagnosed and addressed remotely from the garage.

UDOT Maintenance Supervisors also use the NetworkFleet software package to have automated reports generated for specific system users on items of concern, namely vehicle idling for extended periods of time or high speeds of travel in excess of pre-defined speed values on specific routes. These reports can be presented by supervisors to specific drivers as informational reports, which have had an observed positive impact on driver behavior. The information can also be used for training, retraining and coaching of new or targeted drivers.

UDOT also noted that the system allows for more efficient resource sharing and relocation to fight major (particularly localized) storms.

UDOT Maintenance staff noted another benefit of the Verizon NetworkFleet system has been the use bread crumb trail reports to address public complaints about the lack of snow clearance on specific roads or reported damage to parked vehicles by snow plows. UDOT supervisors at a regional or area level are able to quickly run a report in a specific area over the range of time that the public complaint was received. UDOT staff can then respond to the public complaint by presenting an image of when the snow plows had cleared snow along a specific roadway, or whether they were present along a roadway when damage had occurred to a parked vehicle.

It was noted that the general public has been pleased with UDOT's responsiveness to the public's complaints, even in cases where a UDOT snow plow was found to be liable for damage caused to a parked vehicle. The ability to use the AVL data and bread crumb trail of where vehicles have been in past snow storm events has also helped to accomplish the overall goal of increasing public transparency with respect to winter maintenance operations.

Installation of the system was smooth, and UDOT didn't experience any issues. Additional wires and customized installation, however, was required on older trucks that did not have ODB-II ports. UDOT didn't experience any issues with maintenance of the system either. UDOT noted some issues with other equipment on the snow plows:

- UDOT experienced issues with plow sensors and gate sensors due to rusty or loose connections of wires. Nevertheless the sensors were very reliable with approximately 2 to 3 failures over more than 500 units over the past years.
- There were still gaps with cellular coverage. Verizon had the best coverage, but 75% to 80%.

UDOT uses the AVL system data to monitor and report the following performance measures:

- Snow and Ice Dashboard, which includes RWIS data and non-invasive "roadway grip" sensors to determine effectiveness of plowing operations
- New GIS based dashboards are being developed for Public Consumption.
- They also used the records from past storms to over serve past performance and identify contributing factors (e.g. types of material and equipment used). This helps UDOT to improve operations.

UDOT IT /Data Management Level Interviews

Group met at the UDOT Headquarters in West Valley City on Tues. Nov. 28th to review how UDOT IT and GIS staff currently support the AVL/GPS system.

Previous support efforts have included the automated presentation of snow plow vehicle locations on the UDOT traffic information webpage at: <http://udottraffic.utah.gov/RoadWeatherForecast.aspx>. It was noted that this was made possible by Verizon sharing its Application Programming Interface (API) with UDOT. This allowed UDOT GIS staff to capture data attributes reported to Verizon on vehicle latitude and longitude coordinates at a sufficient frequency (once every 30 seconds during winter months, 2 minutes during summer as plow locations are turned off for the public interface). These latitude and longitude points are then used to display the vehicle location on the UDOT traffic information webpage and mobile app.

Additional steps were taken by UDOT staff to delay the reporting of vehicle location on the webpage by 2-3 minutes to alleviate driver concerns that real-time vehicle location could be used by individuals to plan specific attacks on the snow plow vehicles. UDOT staff noted that some of the reasons to choose the Verizon system over other vendors were:

- Verizon was the most cost effective way to get statewide coverage of all Class 8 Snow Plows. The also offered an API to migrate data to a public interface and provide vehicle diagnostics to help mechanics.
- Verizon had the best cellular coverage in the state of Utah.

When the general public accesses the traffic information page either through a computer or mobile device, they are presented with the following disclaimer which helps users to understand why there may be some observed inaccuracies in the route taken by snow plow vehicles:

"The snowplow location feature on the UDOT Traffic displays information about actively working UDOT-only snowplows throughout the state of Utah. Plow location information is updated every 3-5 minutes. This information is provided to help travelers make smarter decisions about where and when to travel. Please note that areas without cellular phone coverage will not show plow movements, even though plows may be working. Plow location information is provided for awareness and is not intended to redirect plow resources. Every attempt has been taken to ensure the data is as accurate as possible, however data discrepancies may appear at any time."

Verizon stores UDOT AVL data on its server for one year. UDOT also downloads and stores the data in its GIS database. Staff resources for developing and maintaining the GIS interfaces and database were not an issue. Most of the resources were dedicated to the initial development of the GIS database and making vehicle location information available on the webpage. UDOT's goal was to aim for automation of the system.

Issues with data accuracy were identified by UDOT staff. Data inaccuracy was mainly due to:

- Downtown areas due to urban canyons
- Canyon areas where cellular coverage was spotty
- Data was not detailed enough with a 30-second polling rate

UDOT GIS staff are currently developing an algorithm that would automate the process of using the software package to gather a bread crumb trail that would be used to respond to public complaints about either a lack of snow plowing along roadways or potential damage to parked vehicles caused by UDOT snow plows. Currently, this is a manual process where Region or Area Supervisors will access the NetworkFleet software and search for bread crumb trails around the location and time of the complaint about winter maintenance operations. The automated process will reduce the amount of time spent by UDOT staff in searching for information to be used in responding to public complaints.

UDOT Technician / Driver Level Interviews

Group traveled to Region Three garages in Orem, UT to visit with technicians and take pictures of UDOT snow plow vehicles. UDOT is split into four regions that generally cover the northern, central, southern, and metro areas of the state. Within each region, UDOT winter maintenance staff are structured into the following general positions:

Region District Engineer: Responsible for overseeing all Areas within the region in terms of response to winter storms. This supervisor may be responsible for allocating some of the region's resources to other regions of the state in the event of severe weather impacting that specific region.

Area Supervisor: Responsible for monitoring how multiple Maintenance Stations within their respective area have allocated resources to plow roads within a specific area of that region. Reports to District Engineer and communicates with Station Supervisors as needed during winter events.

Station Supervisor: Responsible for overseeing multiple snow plow drivers performing along their assigned snow plow routes within that part of the Area within the Region.

It was noted that District Engineers and Area Supervisors use the NetworkFleet software package on a more frequent basis than Station Supervisors, who also are active in plowing snow during winter weather events. Area Supervisors noted the ability to monitor vehicle locations to enable sharing and relocating resources was extremely useful. In addition to monitor vehicle locations, Area Supervisors felt the system was very useful for:

- Verifying snow maintenance activities
- Coupled with UDOT cameras, verifying and confirming pavement conditions

UDOT staff noted that drivers might have high level of resistance to the AVL system initially but the concern has been mostly alleviated now. Showing the vehicle locations on the public webpage didn't create issues or damages to drivers, which helps alleviate the concern.

Appendix C – Case Study Interview Summary: Washington State DOT

PROJECT 16-01: UTILIZATION OF AVL/GPS: CASE STUDIES SUMMARY OF WASHINGTON STATE DOT IN-PERSON INTERVIEWS

Overview

Interviews were conducted by Ming-Shiun Lee and Dan Nelson of AECOM and coordinated with Joe Schmit of the Washington State Department of Transportation (WSDOT) on December 19th, 2017.

WSDOT Staff Interviews

Meeting attendees on Tues. Dec. 19th included the following individuals in person and via teleconference:

- *Joe Schmit, Technology Resource Manager, Maintenance Operations Division*
- *James Morin, Snow and Ice Program Manager*
- *Andrea Fortune, Maintenance Policy Branch Manager*
- *Kimberly Williams, WSDOT Purchasing Manager*
- *Oai Tang, Maintenance and Operations Specialist*
- *Keisha Chinn, GIS and Data Systems Manager*
- *Peter Burkhard, Technology Resource Program Specialist*
- *Additional IT Support Staff (via phone)*
- *Additional Maintenance Superintendents and Supervisors (via phone)*

Group met at the WSDOT Materials Laboratory in Olympia, WA to discuss how WSDOT staff have implemented their AVL/GPS system. The group participated in the interview included staff representing executive management, maintenance managers, supervisors, technicians, IT and research. Brent Schiller and Joe Schmit of WSDOT provided an overview on the early history of WSDOT with AVL/GPS technology, which began as a pilot project in Tacoma, WA where the WSDOT was initially using PreCise AVL system in combination with pre-existing Force America spreader controllers. Over time, WSDOT allowed for other Regions to install PreCise hardware for integration with existing Force America spreader controllers, while some WSDOT Regions installed Location Technologies (LT6) as an AVL/GPS provider around 2010. The LT6 hardware installed on WSDOT vehicles was utilizing 2G cellular technology as a means of center-to-field communications.

WSDOT was notified by PreCise around 2014-2015 that an upgrade of the vehicle's IX-302 AVL hardware would be required in order to prevent disruption of WSDOT's center-to-field communications with those vehicles while in operations. This was due to a phasing-out period of the 2G cellular technology.

Given that new PreCise hardware would need to be procured, and that different AVL systems were being used by different Regions, WSDOT saw this as an opportunity to procure and upgrade the system as well as to establish a consistent approach with their AVL/GPS system. As such, WSDOT developed and issued an RFP to procure a vendor to provide AVL hardware and software for all WSDOT snow plows throughout the state. The solicitation only requested the vendor to provide AVL hardware and meet a hardware / software specification that was included, and the solicitation occurred in early 2015. Location Technologies was selected by WSDOT through the review process, and they provided the requested quantities of AVL hardware to WSDOT within a short amount of time after being selected. The procurement also expanded the AVL installation to sweepers and emergency response vehicles. Vendor demonstration was not included in the procurement. Instead, WSDOT relied on its prior

experience with the pilots as well as peer exchange to gain knowledge on vendor qualifications from other states experience.

WSDOT noted that the procurement process was very smooth given the unique nature of how the state was able to purchase AVL equipment in this manner. The Transportation Equipment Fund (TEF) is a revolving fund within WSDOT which provides vehicles and equipment to WSDOT programs so that they can accomplish their missions. The fund is a non-appropriated program responsible for the acquisition, management, support, and disposal of a wide variety of state vehicles and support equipment, which also includes the agency's wireless communications equipment. Funds within the TEF were utilized to purchase the LT6 AVL hardware needed for the snow plows within the WSDOT fleet.

The main driving forces for the AVL system implementation included:

- Real-time tracking of vehicle locations and material usage to support and improve operational efficiency
- Supporting and minimizing tort liability
- As an advisory tool for improving resources planning and adjustments

WSDOT then coordinated with local contractors within each of the six WSDOT regions, who were already responsible for the up-fitting / assembly of WSDOT snow plows with spreader controllers and other on-board equipment, to perform the installation and integration of the AVL hardware per the recommended instructions from Location Technologies. These contractors also perform the required maintenance of the AVL system and coordinate with Location Technologies as needed for hardware repair and / or replacements.

For center-to-field communications, WSDOT utilizes cellular communications in most areas of the state, which is primarily Sprint as the vendor, although Verizon is utilized in some Areas where it provides greater and more reliable coverage. As part of the contract, Location Technologies secures cellular communications services and bill WSDOT monthly. WSDOT also utilizes a state-owned 700 MHz radio system to fill the communications gaps in two Regions that feature more remote areas of the state and do not have adequate cell coverage. The combination of cellular and state-owned radio system works well for WSDOT. WSDOT noted the costs of cellular communications were half of that prior to the statewide procurement.

WSDOT has integrated the vehicle's snow/ice spreader controllers and air/pavement temperature sensors on the vehicle with the LT6 AVL hardware unit. WSDOT vehicle technicians reported some issues with the integration of existing Force America 6100 model spreader controllers with the LT6 AVL hardware. WSDOT staff were unable to configure the data polling rate initially and this led to a time-out issue with the communication of data from the spreader controller. WSDOT noted Force America was willing to work with them on the issue through a firmware upgrade to the controller which resolved the issue. Joe Schmit also noted that air and pavement temperature sensors may be providing faulty readings to the AVL equipment if the sensors were improperly installed and / or maintained by Area vehicle technicians. WSDOT mostly uses Vaisala temperature sensors and some RoadWatch sensors. The majority of the temperature sensors were tied into spreader controllers. WSDOT is currently testing a PreCise wireless sensor.

WSDOT experienced issues with integrating plow position sensors with the AVL system. WSDOT was working on identifying causes to resolve data consistency issues. WSDOT was also investigating the

possibility of integrating plow hydraulic sensors with spreader controllers and using hydraulic sensors for plow position indicators.

The LT6 AVL hardware was not integrated with the vehicle's OBD-II port to gather vehicle diagnostic information, given that as a separate effort the WSDOT Fleet & Equipment Operations, commonly referred to as the Transportation Equipment Fund (TEF), was implementing Verizon NetworkFleet on vehicles to collect, track and report vehicle diagnostics back to Area Maintenance Superintendents.

Joe Schmit also noted that the WSDOT TEF is the state fund that is responsible for the acquisition, asset management, upkeep, and logistical support of the state's 500 snow plow vehicles and the AVL/GPS system. The TEF is a revolving fund within WSDOT that provides vehicles and equipment to WSDOT programs so that they can accomplish their missions. For winter maintenance operations, the TEF program provides funding for snow plow vehicle support and AVL/GPS system maintenance through 35 equipment repair facilities and 130 fuel stations across the six WSDOT Regions within the state.

WSDOT is split into six Regions that cover different parts of the state. Within each region, WSDOT winter maintenance staff are structured into the following general positions:

Region Maintenance Engineer: Responsible for overseeing all Areas within the Region in terms of response to winter storms. May be responsible for allocating some of the Region's resources to other Regions of the state in the event of severe weather impacting that specific region.

Area Maintenance Superintendent: Responsible for monitoring maintenance supervisors within each of the respective 24 Areas of the state, and how each Area is responding to winter storms within that Area / Region. Reports to Region Maintenance Engineer and communicates with Maintenance Supervisors during winter events.

Area Maintenance Supervisor: Responsible for overseeing multiple snow plow drivers performing along assigned snow plow routes within that part of the Area within the Region.

It was noted that Area Maintenance Superintendents and Supervisors maintain communication with each other utilizing vehicle radio equipment. Snow plow drivers within an Area may be called upon to divert from their planned route to assist with snow clearance along other roads as needed.

It was also noted that each of the 24 Areas within the state determines their own respective maintenance priorities related to vehicle maintenance. This can lead to some Areas placing less of a priority on the installation and maintenance of the AVL system than other Areas, which can present challenges to the use of automated reports that gather data on material usage and snow plow operations. Leadership for some Areas was very engaged and pushed for quick AVL implementation. As a result, those Areas has the AVL system installed very quickly.

Joe Schmit provided a memo developed within the Olympic Region that provided an example for how Region Maintenance Engineers can set the use of an AVL system as a priority within a Region. This type of emphasis on the importance of properly maintaining the AVL system can enable a higher confidence in the automated reporting of material usage coming out of the LT6 AVL system. In turn, this can lead to improvements in the use of reports on material usage to increase the overall efficiency of material usage by each WSDOT Region.

Location Technologies provided WSDOT two views of the AVL data: a web map view and a reporting engine that includes user tools. Through the LT6 software interface, WSDOT staff can generate pre-defined reports that provide information on vehicle operations and material amounts utilized per vehicle within an Area. Currently, WSDOT only utilizes a "General Activity" and Material Summary"

report from the software. WSDOT noted the most desired reporting feature of the system was the material usage reports. WSDOT noted the biggest challenge was the accuracy of material usages. Joe Schmit noted material usage was calculated based primarily on application rates and miles of vehicle traveled. He noted that in the past, mileages used for material usage calculation were based on GPS not odometers. WSDOT experienced issues with GPS accuracy in the past. As a result, material usage calculation was not close to accurate. Joe Schmit noted that reports on material use would eventually be able to provide a quality baseline of material usage, as issues related to AVL system installation and its usage are resolved over time.

Joe Schmit noted that in addition to vehicle location data, the AVL system collected the following information:

- Material name and type
- Pre-wetting or not
- Application rate
- Pavement surface and air temperatures
- Plow position (up/down) – front plow only

WSDOT performed an internal backup of the AVL data generated from the LT6 AVL system, and has created an in-house web-based software interface that displays the locations of WSDOT snow plows throughout the state for use by Area Maintenance staff. WSDOT noted that LT6 made its Application Programming Interface (API) available for the purposes of getting key AVL system attributes, such as GPS coordinates, vehicle ID numbers, and material names, to enable the vehicle location and other attribute reporting on the in-house software interface. WSDOT polled the data from Location Technologies server every minute. This data is stored on a high availability server and would be saved for at least seven years. AVL data was primarily used by WSDOT Maintenance Supervisors and Superintendent for vehicle location monitoring and situation awareness. The stored data were used primarily for material usage reporting and occasionally for post event review/analysis and for review in the event of a tort claim of WSDOT liability in a traffic accident.

One of the primary benefits that WSDOT has observed with the AVL/GPS system is the overall savings to WSDOT in terms of tort liability in the event of claims of damage by WSDOT snow plow vehicles. James Morin noted that if WSDOT snow plows are found to be at any amount of fault in the event of a traffic accident with another vehicle or vehicles, WSDOT is entirely responsible for the financial coverage of vehicle repairs and other damages incurred from the accident. With the ability to provide detailed breadcrumb trails on where WSDOT snow plows have traveled and when, this has significantly reduced the annual average of payments made by WSDOT resulting from tort claims. WSDOT paid an average of \$2 million for winter maintenance related tort claims in the past. After the installation of the AVL system, the average went down to \$500,000 per year.

One of the other main benefits that WSDOT has observed with the AVL/GPS system is the improved operational awareness of maintenance superintendents as they respond to winter storms. This has been noted by Maintenance Superintendents and Region Maintenance Engineers that have used either the LT6 software interface and / or the in-house developed WSDOT interface for viewing vehicle locations and making operational adjustments based on situations.

Joe Schmit explained the organizational structure related to the WSDOT AVL program. The WSDOT Central Maintenance Office managing funding and coordinate with Regions. The Central Office does not set policies and relies on Regions' buy-in to support the AVL program. As such, outreach and buy-in

from Regions is crucial to the success of the program. An added challenge to this de-centralized structure was the difficulty of achieving statewide consistency.

Joe Schmit noted that one of the main challenges with the hardware installation and wiring process was that there was no standard procedure followed in a consistent manner across WSDOT Regions. The information provided by Location Technologies did not include explicit wiring requirements. WSDOT needed to perform additional investigation on the specifications of the AVL device and spreader controllers to understand the wiring requirements. Once the wiring requirements were defined, the installation went through smoothly. One of the basic installation requirements was to ensure the visibility of the power and communications indicator lights on the front of the AVL device. This allows drivers to perform a visual check of the AVL hardware to confirm an operational status prior to beginning snow plow operations, and is a primary check for AVL equipment repair and replacement. Another requirement was to ensure the AVL device was installed at a location that was accessible for maintenance.

A lesson learned offered by WSDOT was that WSDOT did research in house to ensure smooth integration of the AVL system and spreader controllers. The research helped WSDOT staff understand the specifications of both the AVL system and spreader controllers. It also enabled WSDOT staff to interpret data from the systems/devices. WSDOT also contacted vendors of the AVL system and spreader controllers to confirm their research findings.

WSDOT also noted issues with the antennae for the AVL system. The GPS antenna for LT6 hardware carries current, but it would short out if it was not installed correctly. WSDOT has now standardized on a dual GPS / cellular antenna after experimenting with multiple types of antennae over the years. The procurement of LT6 AVL system hardware excluded the antennae from the manufacturer given the ability of WSDOT to provide the antennae for the system.

Joe Schmit also noted that a high staff turnover rate in some WSDOT Regions and Areas is one of the reasons for keeping the operation of the AVL/GPS system as simple as possible. Training becomes very important to address the high rate of staff turnover. The main responsibility for WSDOT snow plow drivers with respect to AVL operations is to monitor the power indicators on the AVL hardware within the vehicle before they begin their snow plow route, and to report on faulty hardware when detected. This reduces the amount of work to be performed by snow plow drivers related to AVL operations that may be new to the work, and simplifies the overall driver training procedures.

WSDOT noted the importance of training, for both operations and maintenance training. The training program was geared to the ground level staff involved in operations (drivers) and maintenance. WSDOT also had a "train the trainer" program to ensure knowledge resided in each Region and many Areas. The Train the Trainer program also helped build a network to share knowledge and best practice as well as support on-going operations and maintenance of the system.

Other challenges include different WSDOT Areas placing different priorities above that of properly installing and maintaining the AVL/GPS system perhaps due to staffing and other vehicle repair issues that may be straining resources.

Appendix D – Case Study Interview Summary: Michigan DOT

PROJECT 16-01: UTILIZATION OF AVL/GPS: CASE STUDIES

SUMMARY OF MICHIGAN DOT IN-PERSON INTERVIEWS

Overview

Interviews were conducted by Ming-Shiun Lee and Dan Nelson of AECOM and coordinated with Melissa Longworth of the Michigan Department of Transportation (MDOT) on November 30th, 2017.

MDOT Staff Interviews

Meeting attendees throughout the day on Thurs. Nov. 30th included the following individuals:

- Benjamin Hodges, MDOT Maintenance Supervisor
- Mark Crouch, MDOT Maintenance Coordinator
- Matt Pratt, MDOT Maintenance Coordinator
- Greg Perry, MDOT Operations Engineer
- Tim Croze, MDOT Manager of Maintenance Services
- Justin Droste, MDOT Asset Management Engineer
- Melissa Longworth, MDOT Region Support Engineer
- Ming-Shiun Lee, AECOM Project Principal Investigator
- Dan Nelson, AECOM Project Lead Researcher

Group met at the MDOT Grand Ledge Garage to interview Ben Hodges and understand primarily the AVL and MDSS application. Ben Hodges described his use of the Iteris MDSS software interface to monitor weather events and snow plow activity. As maintenance supervisor, the use of MDSS helps determine the most optimal time to call in snow plow drivers and determine the best course of material application. Ben also utilizes AVL software provided by Parsons to download material usage reports and salting speed compliance reports.

Matt Pratt and Mark Crouch discussed the types of snow plow equipment that are integrated with the AVL system for data reporting. These include DickeyJohn ControlPoint spreader controllers, RoadWatch pavement temperature sensors, wing plow sensors, tow plow sensors, and front-facing vehicle dash-cams. MDOT staff identified the locations of the components on a few snow plow vehicles in the garage after the meeting. MDOT staff noted that vehicle camera images are taken once a minute and those pictures then appear within the AVL / MDSS software interfaces for review by MDOT maintenance supervisors.

Lessons learned during the installation process were discussed and are summarized below:

- The AVL hardware on the vehicle was initially mounted in the center console area where it was susceptible to damage from liquid spills due to its proximity to cup holders. Hardware was re-located to behind passenger seat.
- Cell / GPS antennae were initially run through an area along side of the vehicle where the cables were susceptible to damage. Re-routing of the cables addressed the issue.
- Process of equipment installation and training of staff was condensed in a short amount of time to get system operational prior to winter weather. Additional time to train vehicle mechanics on equipment installation and garage supervisors on how to use the software would have eased the roll-out of the system.

As far as hardware is concerned, some drivers disliked the monitors in the truck. They felt there were already lots of equipment in the truck and drivers had many things to do. Some also felt that they could

use smartphones to achieve the same functionality with radar tracking. MDOT also noted the desire to have an automatic dimming feature for monitors.

Group then traveled to the MDOT Operations Field Services Division office in Lansing to meet with Greg Perry and view how MDOT uses the two different AVL and MDSS software packages. The AVL software package presents a map-based interface that allows MDOT staff to view the locations of snow plow vehicles in the field, which can be filtered in multiple ways (i.e. by region, by county, etc.). The interface allows for selecting specific vehicles on the map and viewing information about that specific vehicle. MDOT staff noted that the map-based interface is not as user-friendly as other Windows-based interfaces, and requires training on how to navigate through various features. It was also noted that snow plow locations are also shared with the MiDrive website that presents traffic and roadway information with the general public. There is a small lag of three to five minutes of when vehicle locations are reported.

AVL training was provided during initial system installation. Formal and informal training was also provided annually. MDSS vendor also provided in-person training to MDOT staff.

AVL system data was polled every minute. The data was stored and managed by Parsons. MDOT didn't store the data on its own server due to challenges associated with security and other requirements of the MDOT system. MDOT still owns the data and can obtain it at any time. All data were warehoused since the beginning. Only 12-month data was kept as "active" and the remaining data was archived but still accessible. The AVL system data is shared with and can be accessed by MDOT Transportation Operations Centers (TOCs) and MDOT ITS Data Use Analysis and Processing (DUAP) program. The data is also fed into the MDSS.

MDOT staff then demonstrated the Reports feature of the AVL software to show how MDOT maintenance can identify when issues may be occurring with AVL hardware. MDOT staff can use a filter to view snow plow vehicles at specific garages and then view the date and time stamps of specific data elements, which can quickly identify when a GPS antennae may not be functioning, or when vehicle equipment may not be sending information back to the AVL hardware on the vehicle. MDOT maintenance staff can then review that specific vehicle and perform the needed repairs or request assistance from the AVL vendor as needed if replacement parts are required. Other reports frequently used by MDOT staff include reports for blade usage, material usage, and speed compliance.

MDOT worked with Parsons to enhance the reporting features, including enhancing the existing reports as well as developing additional reports useful to MDOT. Melissa Longworth described other reports that could be developed including salting speed compliance reports which help to verify how efficient drivers are at applying salt along roadways. A previous MDOT study has found that 25 MPH is the ideal speed to ensure that salt remains on the road and does not scatter outside of the travel lanes. The structure of this report, and other reports within the AVL system, were requested by MDOT to be provided by the AVL vendor (Parsons) for future analyses by MDOT staff. These reports also help to ensure the efficiency of snow plow operations. MDOT also extracts raw data directly from the AVL software interface for separate analyses and internally developed reports on statewide and regional performance related to snow plow operations.

Greg Perry then demonstrated the MDSS software interface provided by Iteris that is used for monitoring weather forecasts and determining the most efficient times and locations for roadway treatment. Multiple types of alerts could be presented on upcoming weather, road conditions, and where blowing

snow would be predicted, along with maintenance alerts that provided treatment recommendations on material to be applied to specific roadways. MDOT archives its previous treatment for the past 24 hours and can look ahead to the next 24 hours as well and see how past treatment may be impacting recommendations, since a comparison of no treatment is presented alongside the current treatment by MDOT. It was also noted that the mobile application has been more useful to snow plow drivers than the laptop / PC-based version given that drivers are mobile in the field.

MDOT staff noted that the integration of the AVL functionality within the MDSS software package provides MDOT maintenance supervisors and operations staff with the most effective tool for responding to winter weather events. Melissa Longworth noted that only a handful of states have performed the integration given the integration effort involved, but that it has proven to be effective for winter maintenance operations.

Tim Croze and Justin Droste of MDOT discussed the overall procurement process that MDOT followed with their AVL/GPS system. MDOT executive management expressed a desire to investigate AVL/GPS systems in early 2013, and MDOT operations and maintenance staff surveyed other states through the Clear Roads and MDSS Pooled Fund studies on lessons learned in the overall process. Among the lessons learned were that the use of separate contracts for AVL and MDSS, in addition to other contracts for cellular equipment, could create issues with the coordination required between multiple contractors.

MDOT released an RFP in spring of 2013 and requested a single point of contact from a Contractor that would be responsible for managing both the AVL and MDSS systems, as a means of ensuring accountability in the integration of the two systems by the selected Contractor. MDOT expressed its desire for the integration of the two systems from the beginning of the contract start date and allowed the Contractor to determine the most optimal plan for delivering the integration for MDOT maintenance operations. Through frequent meetings and communication with the Contractor and its project team, MDOT achieved the desired outcome of implementing the system prior to the 2013-2014 winter season.

Key procurement experience and lessons learned include:

- The procurement followed the MDOT best value procurement process. Proposals were reviewed by a Joint Evaluation Committee (JEC).
- The RFP was developed under an aggressive schedule. For the RFP and requirements development, MDOT leveraged the requirements developed by the Wisconsin DOT and the MDSS Pooled Fund program.
- Specifications should not be too specific to limit options and flexibility.
- The MDOT contract with one single vendor might increase the cost but help reduce staff resources for coordinating with multiple vendors, and it also helps integration of multiple systems as desired.

Key benefits of the AVL system as noted by MDOT include:

- Better and more efficient asset tracking
- More efficient tracking of material usage
- Speed tracking and compliance reporting
- Improved reporting efficiency with automated electronic reporting capabilities; reduction in paper reporting.

One of the next steps that MDOT envisions with the MDSS software interface is the creation of a Reports module that would be able to run the same kind of reports that MDOT runs through the AVL software package. This will reduce the amount of staff time spent running two separate software packages and improve the efficiency of MDOT maintenance supervisors in reviewing past winter weather events. MDOT also desires to implement automated reports within the MDSS software package to reduce the amount of time spent completing paperwork that snow plow drivers at the end of their respective shifts.

Other lessons learned gathered from MDOT through the interviews are summarized below.

- Outreach to users, especially prior to installation, helped reduce resistance and promote buy-in.
- Having tech-savvy staff performing outreach, conveying key messages and supporting installation and operations helps alleviate concerns and promote buy-in.
- Adequate training is key to buy-in and successful operation.
- Support from executive management made procurement and roll-out quicker. On the flip side, due to the aggressive schedule as directed by executive management, desired level of user outreach could not be performed.
- Different types of trucks and ages of trucks may require different cabling, connectors, mounting locations, etc. for installation.
- Battery draw can be a concern as there were many devices drawing power from the same battery. Installation of a battery shut off switch could be a solution.
- Resources dedicated to system maintenance should be considered.

Appendix E – Case Study Interview Summary: Wisconsin DOT

PROJECT 16-01: UTILIZATION OF AVL/GPS: CASE STUDIES SUMMARY OF WISCONSIN DOT IN-PERSON INTERVIEWS

Overview

Interviews were conducted by Ming-Shiun Lee and Dan Nelson of AECOM and coordinated with Al Johnson of the Wisconsin Department of Transportation (WisDOT) on December 11th and 12th, 2017.

WisDOT Staff Interviews

Meeting attendees throughout the day on Mon. Dec. 11th included the following individuals:

- *Al Johnson, Winter Maintenance Engineer*
- *Mike Adams, RWIS Program Manager*
- *Sharon Bremser, Statewide Bureaus Consultant Supervisor*
- *James Hughes, Highway Maintenance and Roadside Management Section Chief*
- *Chris Ohm, Bureau of Highway Maintenance*

Meeting attendees throughout the day on Tues. Dec. 12th included the following individuals:

- *Al Johnson, Winter Maintenance Engineer*
- *Mike Adams, RWIS Program Manager*
- *Pat Gavinski, Sauk County Commissioner*
- *Rob, County Patrol Superintendent*
- *Manuel, County Snow Plow Driver*
- *Tony, County Vehicle Maintenance Supervisor*
- *Cory, County Vehicle Technician*
- *Anthony, County Vehicle Technician*

WisDOT AVL/GPS System Management Level Interviews – Dec. 11th

Group met at the WisDOT Division of Transportation System Development (DTSD) Offices in Madison to discuss how WisDOT has implemented and utilized their AVL/GPS system. WisDOT noted that their winter maintenance operations are different from a lot of states in that winter maintenance activities on all Interstates and state highways are performed by counties. WisDOT allows each of the 72 counties in the state to procure their own snow plows and equipment that are used for winter maintenance operations on Interstates and state highways. WisDOT provides funding to the counties, but does not technically own any of the snow plow vehicles or any of the equipment associated with the vehicles. This arrangement of winter maintenance operations has been in place between the state and the counties for nearly 90 years.

WisDOT displayed an early interest in AVL/GPS technology for winter maintenance operations, dating back to about 2002, based on the state's involvement in the Clear Roads pooled fund program and in the MDSS pooled fund program as well. WisDOT was also able to observe how Dane County, which includes the City of Madison, had become the first County in the state to implement an AVL system on their County vehicles.

In February 2008, a severe winter storm hit southeastern Wisconsin and dropped about 20 inches of snow in the Madison area. During the storm, state agencies were slow to recognize the scale of the storm and the extent of the emergency, as thousands of motorists were stranded on northbound I-39 between Madison and Janesville in both Dane and Rock Counties. A post storm review identified that WisDOT and counties could not communicate the location of winter maintenance assets in a timely manner that would have improved the overall incident response to stranded motorists. Given the value

that an AVL system for these and Counties would have aided in the overall incident response, WisDOT determined to provide funding for an AVL/GPS system for all County vehicles throughout the state.

WisDOT procured funds through a federal earmark under SAFETEA-LU for the statewide AVL/GPS system procurement for winter maintenance. The funds were used for reimbursing counties for the costs that they would incur for the procurement and installation of the AVL/GPS system.

WisDOT staff then traveled to the various counties to present how counties could procure and install an AVL/GPS system that would be consistent throughout the state. This included the use of Force America equipment for spreader controllers, and the use of PreCise MRM (Mobile Resource Management) as the vendor / manufacturer of AVL/GPS equipment. The decision of choosing Force America spreader controllers was based on the Dane County system and their experience, as well as the ability for WisDOT to use the Dane County procurement for statewide procurement. In 2009, Force America acquired PreCise MRM, which became a subsidiary of the Force America Company.

All Wisconsin counties were then responsible for the procurement and solicitation process of AVL/GPS equipment, in the same way that they were already responsible for the procurement of winter maintenance vehicles and snow plow equipment. Every County in the state currently employs a County Highway Commissioner that manages all County highway maintenance operations, a County Patrol Superintendent that monitors vehicle operators and their use of snow plow equipment, and a County Foreman that maintains all vehicle equipment, including the AVL/GPS system equipment.

Since the initial rollout of the AVL/GPS system, there are approximately 400 County snow plows that have been equipped with AVL/GPS system technology across nearly all of the Counties in the state. These snow plows are responsible primarily for maintaining state highways and Interstates within the counties. Other snow plows that maintain County roads do not have the AVL/GPS system installed on them.

A second phase of the project was initiated in 2014-2015 to upgrade the cellular equipment from its previous 2G network capability to a 3G network capability. This involved the replacement of the PreCise hardware that was installed within County vehicles. The upgrade provided increased speeds in the vehicle's reporting of real-time data which improved the ability of County Patrol Superintendent to monitor vehicle locations and their response to winter weather storms.

WisDOT Supervisor / Manager Level Interviews – Dec. 11th

Group continued to meet at the WisDOT DTSD Offices in Madison to discuss how WisDOT staff interact with the AVL/GPS system. Al Johnson noted that WisDOT primarily uses the AVL/GPS system software interface from PreCise for post-storm analysis to review how Counties have used salt / brine materials in response to winter weather. In the event that the review finds a discrepancy between certain areas of the County in terms of material amount or application, WisDOT will contact the Counties and present the findings to them for their review and comment.

WisDOT also prepares an Annual Winter Maintenance Report that presents a summary of how the Counties and the state as a whole performed in response to winter weather. This report can illustrate how Counties are performing in relation to neighboring Counties with respect to material usage and a number of other measures for winter maintenance.

Al Johnson noted that the WisDOT had also been involved at an early stage with MDSS testing and development, and once the AVL/GPS system had been installed on County vehicles, WisDOT entered into an agreement with Iteris for the connection of real-time data from the existing AVL/GPS system into an MDSS software interface. The MDSS interface provides County Patrol Superintendents with a weather forecast over the coming 24 hours that will indicate where and when winter maintenance is recommended. MDSS can also provide analytical tools for post-storm analyses by WisDOT for review as needed. The ability to use MDSS was also one of the main motivations for the AVL/GPS implementation in all Counties, as well as the state's prior research on best management practices pertaining to material usage.

Al Johnson also demonstrated how WisDOT can use the PreCise AVL software interface to view the locations of various vehicles by County. Specific vehicles could be selected for further detail to determine how many miles had been driven and how much material that vehicle had been using over a specific period of time. The AVL software interface also provides a bread crumb trail to help locate the route taken by snow plow operators. It was noted that the AVL software user interface was not as user friendly to navigate as the MDSS software interface that WisDOT does also access and monitor.

Jim Hughes attended the meeting to discuss his role as a state level advocate for the use of AVL/GPS systems by Counties to improve their usage of materials ranging from sand to salt to liquid brine. WisDOT staff will attend as many County Commissioner meetings as possible, usually scheduled in the summer and the winter, and Jim notes that these meetings are the best opportunities for WisDOT to communicate with Counties on how AVL/GPS can benefit those counties. It was noted that some counties have been slow to "buy-in" to the use of the AVL/GPS system for helping to optimize material usage, through the use of the MDSS interface, or to help with optimizing snow plow routes.

Jim has noted that the detailed data and reports provided through the AVL / MDSS interfaces have been helpful to get "buy-in" from county commissioners responsible for the use of the AVL / MDSS interfaces to optimize winter maintenance operations. County Highway Commissioners have also been able to speak to one another and demonstrate the benefits of the system and best practices, which can sometimes be more convincing than having WisDOT staff presenting the information.

WisDOT also noted although Counties contract for winter maintenance vehicles and AVL/GPS equipment, WisDOT purchases the salt and liquid brine material and delivers to each county highway department.

The group discussed the topic of displaying winter maintenance vehicle locations on a traffic information page for the general public. WisDOT does not currently provide this information to the public and noted the potential liability concerns due to all winter maintenance activities were performed by counties.

It was also noted that PreCise arranges the cellular carrier of preference for the system based on the best cell coverage available. While there are still some coverage gaps in rural areas of the state, WisDOT in general is satisfied with the cellular coverage throughout the state.

Sauk County Highway Department Interviews – Dec. 12th

Group met at the Sauk County Highway Department in West Baraboo, WI on Tues. Dec. 12th to review how Sauk County maintenance staff currently support the AVL/GPS system. Within each County, there are the following general positions with regard to highway and winter maintenance:

County Commissioner: Responsible for overseeing all highway maintenance activities in the County, including response during winter storms. Communicates with WisDOT as needed with requests for information on the AVL/GPS system.

County Patrol Superintendent: Responsible for monitoring how multiple vehicles and drivers are operating within the County. Will review the recommended material treatment from MDSS software interface and then communicate the appropriate application rate to County snow plow drivers over radio. Reports to County Commissioner on winter maintenance operations.

County Foreman: Responsible for maintenance of AVL/GPS system equipment and requesting spare parts from the vendor.

Sauk County noted that two technicians were dedicated for AVL/GPS installation: one person handled the installation on new vehicles and another for older vehicles. No installation issues were experienced to date.

An initial concern from counties regarding MDSS treatment recommendations was that if they would be required to follow the recommendations strictly. Mike Adams of WisDOT noted that the treatment recommendations are viewed as guidance for County Patrol Superintendents in communicating the appropriate application rate with snow plow drivers. This clarification by WisDOT has eased some concerns in Counties that might view the recommendations as direction for how to treat roadways.

Counties have also been able to view MDSS recommendations for neighboring counties to gain a better picture on winter storms and progression. Based on the MDSS information, Sauk County could talk to their neighboring counties to get updates on current weather and treatment plans in effect. In addition, Counties have access to and can pull data for post-storm reviews, asset management, and many other purposes. Data is available to the Traffic Operations and Safety (TOPS) Laboratory for planning, operational analysis, research, and training.

Generally snow plow drivers felt the technology helps improve operations. A snow plow driver noted that one of the more positive features of the AVL system has been the ability for them to program an alarm that is provided to the driver when exceeding a speed threshold, or when exceeding a material threshold during snow plow operations. The primary task of maintaining focus on the snow plow route during winter storms, in addition to other equipment and sensors on the plow, can cause the driver to lose sight of their current speed or treatment level. Alarms can also be customized to provide warnings on other items if requested as well.

The County Patrol Superintendent also noted that the MDSS software interface has become more reliable this current year with the incorporation of RoadWatch pavement temperature sensors. WisDOT had previously disconnected all vehicle sensors from reporting data to the central MDSS software due to patent litigation issues in the past years. WisDOT chose not to pay a licensing fee per truck for the data connection, and some Counties saw a drop in the reliability of the MDSS forecasts and recommendations due to the loss of real-time vehicle sensor data on air and pavement temperatures. However, WisDOT has now re-enabled this connection and the County Patrol Superintendent has reported a positive improvement in the performance of the MDSS software.

The County foreman and vehicle technicians noted that County vehicles were not sending vehicle diagnostic data to the AVL system through the OBD port on-board the vehicle. There was some concern by County staff about potential negative issues this integration may have caused to the AVL system. WisDOT noted that the AVL software interface through PreCise can be used for some diagnostic checks related to vehicle battery voltages and could provide additional data if there was a connection made between the on-board diagnostics port of the vehicle and the AVL system.

The County Patrol Superintendent was asked if there were any concerns of snow plow operators about the use of the AVL system to monitor the locations of snow plow drivers. It was acknowledged that

there were some driver-level concerns about the system being used by superintendents to monitor every route taken by drivers and used as a disciplinary tool against drivers. However, the concerns went away once drivers realized the system was not being used in a disciplinary manner, and more for weather forecasting and planning for winter maintenance operations.

The group noted that the following equipment have been integrated with the AVL/GPS system: ground speed controllers, plow position sensors, spreader controllers/application rates, and air/surface temperature sensors. It was noted that the previously installed RoadWatch Air/Surface Temperature Sensors were near the end of life and their quality has deteriorated over time. Force America has newer sensors, both wire and wireless models. Installation and integration of the wired model has been straightforward for County staff that handle the installation.

Appendix F – Case Study Interview Summary: Nebraska DOT

PROJECT 16-01: UTILIZATION OF AVL/GPS: CASE STUDIES

SUMMARY OF NEBRASKA DOT IN-PERSON INTERVIEWS

Overview

Interviews were conducted by Ming-Shiun Lee and Dan Nelson of AECOM and coordinated with Ty Barger and Mike Mattison of the Nebraska Department of Transportation (NDOT) on December 13th and 14th, 2017.

NDOT Staff Interviews

Meeting attendees throughout the day on Wed. Dec. 13th included the following individuals:

- *Mike Mattison, AVL/GPS Project Manager*
- *Sean Mulligan, Parsons Project Manager*
- *Larry Simmons, Parsons Project Support*
- *NDOT District 1 (Lincoln) Plow Operators*
- *NDOT District 2 (Omaha) Plow Operators*

Meeting attendees throughout the day on Thurs. Dec. 14th included the following individuals:

- *Mike Mattison, AVL/GPS Project Manager*
- *Dale Butler, NDOT District 2 District Operations and Maintenance Manager*
- *Kelly Doyle, NDOT District 7 District Operations and Maintenance Manager*
- *Kyle Schneweis, NDOT Director*
- *Moe Jamshidi, NDOT Deputy Director, Operations*
- *Tom Sands, NDOT Operations Manager*
- *Rita Kucera, NDOT Procurement Specialist*

NDOT IT Operations Level Interviews – Dec. 13th

Group met at the NDOT Offices in Lincoln to discuss how NDOT currently operates and maintains its AVL/GPS system software packages. NDOT installed an AVL/GPS system from Parsons prior to the 2015-2016 winter season. Approximately one-third of the fleet (about 225 vehicles) was equipped with the Parsons AVL System in 2015, and nearly all of the remaining vehicles were then equipped with AVL hardware in 2016. Some of the older NDOT maintenance vehicles will be phased out of the fleet in the near future, and newer vehicles will come equipped with the Parsons AVL hardware.

The Parsons Team, led by Parsons with Iteris and other vendors, was hired by Nebraska DOT in 2015 to manage the installation of all AVL hardware, as well as to provide MDSS software for all maintenance vehicles. To address the AVL hardware installations, Parsons hired a local sub-contractor to travel through the state and perform the installation and integration of the hardware with existing spreader controllers, plow controllers, and air / pavement temperature sensors. Vehicle dashcams were also installed and integrated with the AVL hardware to provide still images of road conditions once every 60 seconds back to the AVL software interface. NDOT's contract for AVL system procurement, installation and integration was very similar to that of Michigan DOT.

NDOT felt the contract organization made the installation process smooth. It was challenging to schedule installation initially. The contractor (Parsons) stepped up to provide detailed schedule and equipment information to facilitate scheduling of installation, as well as reminders prior to installation to ensure vehicle availability. The effort helped improve scheduling and getting system installed as planned. NDOT left the AVL/GPS equipment mounting locations to the discretion of the installers with general guidance from Parsons.

Larry Simmons noted that one of the main challenges they encountered was the integration of multiple brands of spreader controllers with the AVL hardware. Some controllers were no longer supported by the manufacturer that had provided them to NDOT, and some manufacturers could not provide the necessary support to assist in understanding how best to perform the integration of the spreader controllers with the Parsons AVL hardware. Another issue encountered was manufacturers provided incorrect information on software version of controller boxes, chips, etc. Larry Simmons noted that a previous effort of the Clear Roads program to develop a “Plug-and-Play” standard for how in-vehicle electronics communicate data with other devices would alleviate this problem in future deployments that may occur in other states.

NDOT also experienced low-band radio interference caused by MDCs. The issue was resolved by changing circuitry of the MDC board. However, Signal to noise ratio was still an issue that reduced FM radio reception, and drivers were generally not happy about it. NDOT performed an informal test that was not a standard type of test, and found signal degradation in some frequencies. This issue has not been resolved.

NDOT staff also noted their experience with integrating Parsons AVL/GPS system with various spreader controllers on their snow plows:

- Force America: worked pretty well. No substantial issues experienced.
- Certified Power: GL400 controller was an older technology and was very challenging to integrate. NDOT didn’t have good experience with customer services either.
- Monroe: NDOT had about 40 trucks with Monroe controllers. The equipment was five years old and support has been discontinued. NDOT ended up replacing them with Force America controllers.
- Raven: NDOT had a smaller number of Raven controllers. Those controllers were about 15 years old and would likely be retired in the near future. As such, NDOT did not test out the integration.

NDOT staff was also trained by Parsons to have the knowledge to perform basic maintenance on the system.

The AVL/GPS system has three antennae: GPS, cellular and Wi-Fi. NDOT’s AVL/GPS system utilizes cellular communications. There are gaps in cellular coverage in parts of the rural areas. NDOT chose cellular carriers based on coverage by area with inputs from NDOT Districts. Cellular communications for the system is currently provided by three carriers, Verizon, Viaero, and US Cellular.

In terms of data storage and retention, the NDOT system includes:

- Two years of data archiving period
- Two-week of data available for immediate access
- Parsons keeps all data for the life of the contract
- Dash cam images are kept for a 24-hour period
- Iteris/MDSS stores all data provided to MDSS, and NDOT has immediate access to the last 72 hours of data.
- NDOT can store data for storms for longer period (i.e. the life of the contract).

NDOT does not store data on its server and relies on vendor to provide data storage solution. NDOT felt the key benefit is saving NDOT resources for developing and maintaining a data storage system. The decision of saving dash cam images for no longer than 24 hours was to limit exposure to tort claims.

NDOT Technician / Driver Level Interviews – Dec. 13th

Group met at the NDOT Offices in Lincoln to discuss how NDOT District Crew Chiefs and snow plow drivers are impacted by the AVL system / MDSS operations, and to take pictures of NDOT snow plow vehicles. NDOT is split into eight Districts, and within each District, NDOT winter maintenance staff are structured into the following general positions:

District Engineer: Responsible for overseeing all winter maintenance and other construction activities within the District.

District Operations and Maintenance Manager (DOMM): Responsible for monitoring how multiple Superintendents within the District are responding to winter weather with winter maintenance operations. Reports to District Engineer and communicates with Superintendents as needed during winter events. Uses MDSS software interface for observing weather and treatment recommendations.

District Superintendent: Responsible for overseeing multiple District Supervisors within the District and keeping in touch with them about MDSS treatment recommendations and responses to winter weather.

District Supervisor: Responsible for overseeing one or multiple Crew Chiefs and winter maintenance workers that plow snow along pre-defined routes within that part of the District.

District Crew Chiefs: Responsible for communicating with and overseeing other snow plow drivers, and for reporting to District Supervisors / Superintendents and DOMM's as needed.

District Crew Chiefs discussed their overall experience with the AVL/GPS system, which mainly comes through their interaction with the MDSS interface in the vehicles. Trucks equipped with the AVL/GPS system have a touch screen in cab that can display weather radar images, locations of other trucks, MDSS treatment recommendations, material application rates, among others. The NDOT District 2 Crew Chief was supportive of the AVL system given his use of the MDSS treatment recommendations for understanding the proper amount of material for defined routes within the district. The AVL system also helped relocate available resources to improve efficiency of winter maintenance activities. Drivers also thought the weather radar information displayed on the touch screen was useful. The NDOT District 2 Crew Chief did note that the size of the touch screen buttons on the in-vehicle tablet provided for the purpose of entering inputs on existing weather conditions were not large enough so that only one touch would be needed to enter the information. In some areas, the touch screen buttons were large enough, but in others, they were much smaller.

District operators were asked about whether or not there were “big-brother” concerns during the initial deployment of the AVL system. The NDOT District 1 and 2 operators noted that these concerns gradually went away when drivers realized that the AVL system was not being used in a disciplinary manner.

The practice of using MDSS treatment recommendations varies by District. Some Districts were more receptive to the MDSS recommendations; while others still tended to use staff's own judgement. NDOT District 2 was one of the Districts more receptive to MDSS. Material application rates for the NDOT District 2 drivers were determined by supervisors using a combination of the MDSS recommendations and crew inputs. The NDOT District 2 crew chief noted that a driver might be questioned by a NDOT District Supervisor if the amount of material used on a route was significantly different from the MDSS recommendations for that route. Given that drivers are provided the flexibility to determine what the proper treatment should be, they can communicate reasons for the difference with their supervisor after the end of their shifts.

The NDOT District 1 Crew Chief noted other concerns related to the in-vehicle dashcam that is used to capture images once every 60 seconds and send the images back through the AVL system. In some instances, an image may appear to show that the vehicle was stopped at a location, when the vehicle was turning around on their plow route. These images might be questioned by a NDOT District Supervisor if they felt it was necessary to be addressed with the drivers.

NDOT Supervisor / Manager Level Interviews – Dec. 14th

Group met at the NDOT Offices in Lincoln to discuss how NDOT District 2 and District 7 Supervisors interact with the AVL/GPS system. The NDOT District Supervisors interviewed noted that they felt the AVL/GPS system and the dashcam images were very useful. Their primary interaction with the system is through MDSS in which they can see the locations of the snow plow vehicles overlaid on the MDSS software interface. District supervisors use the system to check and monitor material application rates and usage. They will monitor long-term weather forecasts and log into MDSS when winter weather is forecasted within the next couple of days.

The group also reviewed the Parsons ATMS software and the MDSS software interfaces to illustrate the use of the system by District Supervisors. It was noted the data polling rates for the Parsons ATMS and the MDSS software were every 1 minute and 2 minutes, respectively. NDOT District Supervisors used the Parsons ATMS software to confirm AVL data was downloading and check dashcam images to observe field conditions. As for the MDSS software, NDOT District Supervisors noted that they were responsible for data entry regarding roadway characteristics to allow MDSS algorithms to provide better outputs. These data entry inputs included daily traffic volumes, pavement types, and hours of operation for NDOT snow plow operators. These inputs are all factored into the type and amount of materials recommended through the MDSS software package.

NDOT has integrated the on-board AVL hardware with the snow plow vehicle's On-Board Diagnostics port (OBD-II) port, which allows pre-defined vehicle codes to be sent through the AVL software package to alert NDOT staff that vehicle maintenance is needed on specific vehicles. NDOT supervisors have not utilized this feature as extensively, but they do monitor when vehicle codes are provided for certain vehicles.

NDOT provided a brief history on their experience with AVL/GPS system installations. NDOT had initially installed an AVL/GPS system on a few test vehicles for vehicle location tracking, prior to becoming involved with the MDSS pooled fund study. Over time, additional AVL hardware would be installed in NDOT vehicles, and in 2009, NDOT procured approximately 100 AVL/GPS hardware units for installation in NDOT snow plows in all 8 NDOT Districts throughout the state. This installation included MDSS treatment recommendations that were being provided to NDOT District Supervisors and snow plow operators as well.

Problems were reported by some of the NDOT Districts with respect to the reliability of the AVL hardware and its performance in winter weather. Other problems were reported with respect to the accuracy of the winter weather forecasts, which negatively impacted the accuracy of the treatment recommendations. Given the issues that were encountered, drivers and supervisors that had tried to use the MDSS recommendations stopped using the AVL/GPS and MDSS systems altogether. The NDOT Districts that continued to use the system despite some of the early problems were District 2 (Omaha), District 6 (North Platte), and District 7 (McCook).

In 2014, NDOT followed a Systems Engineering process to determine how best to move forward with a new AVL/GPS system. This effort included interviews with NDOT Districts to review the past issues with the older AVL system, and determine what requirements could be developed for a new AVL/GPS system

that might also include MDSS treatment recommendations and vehicle dashcams for reporting vehicle images of roadway conditions.

NDOT then released an RFP in April 2016 that requested one prime vendor to serve as a single point of contact for managing the installation of all in-vehicle hardware (AVL/GPS and vehicle dashcams in all NDOT Districts) and for providing MDSS treatment recommendations to NDOT Districts 2, 6, and 7. NDOT also requested a demonstration of the AVL system prior to beginning with the procurement of AVL hardware for the entire fleet.

The RFP for the turnkey procurement included a detailed scope of work and system requirements for vendor provided equipment, installation, MDSS system, integration, communications, data hosting/storage, warranty, testing, operations and maintenance, training, and deliverables. To ensure receiving quality products as well as services, the contract was bid as a professional services contract, as opposed to a low-bid procurement. Vendor proposals were evaluated on three areas: Vendor's qualifications and past performance; technical approach; and costs. The contract was for a period of five years with an option to renew for five additional one year periods.

NDOT selected Parsons in May 2016 as the prime contractor that would eventually provide AVL/GPS hardware, and manage Iteris as a sub-contractor responsible for the MDSS treatment recommendations. A local sub-contractor managed the installation of all AVL hardware on NDOT snow plows. NDOT noted that the arrangement of contractors worked very well for the project, and that they had received excellent support from Parsons and Iteris during the training of NDOT staff. About 225 snow plow vehicles were equipped for the 2016-2017 winter season, and since then, nearly all of the NDOT snow plow fleet (approx.. 600 vehicles) have been equipped with AVL hardware and vehicle dashcams for the coming 2017-2018 winter season.

NDOT noted the following benefits and lessons learned from this turnkey contract:

- The turnkey contract mechanism reduced the needs for NDOT resources for equipment installation, integration, and managing multiple vendors/manufacturers. Parsons was the single point of contact for NDOT and was responsible for all issues.
- Including warranty in the contract was important.
- Asking vendors to price items/system components individually and provide unit price gives DOT flexibility for equipment and service selections.
- The scope of work and requirements were developed based on needs identified from NDOT Districts. Scope and requirements development takes time and starts with systems engineering.
- The RFP needs to clearly state the DOT's expectations of all aspects of the project, particularly related to integration of AVL and spreader controllers.
- Due to some Districts were not ready for MDSS, a phased implementation for both equipment and software worked well.
- Accuracy of spreader controller data was still an issue. Additional research would be desired. NDOT planned to compare the data from material usage reports manually completed by NDOT staff with the data from the system. NDOT noted that neither sources could be considered accurate.

Given the negative experiences that some NDOT Districts had in the previous AVL system installation, NDOT envisions a gradual rollout of treatment recommendations to Districts 1, 3, 4, 5, and 8 over the coming years. NDOT has developed a working group that is composed of project champions from each

NDOT District who have bought into the positive impact that the treatment recommendations from MDSS can have on snow plow operations. These project champions from each District can then communicate the positive impacts with others in their own District that might be skeptical of the technology from their previous experiences with the older AVL system. NDOT has witnessed the positive impact that this arrangement has had on the gradual buy-in from those NDOT Districts with respect to the AVL/GPS system and to MDSS treatment recommendations.

As for the potential use of the AVL system in the future, NDOT was considering the integration of backup cameras with on-board touchscreen display. NDOT would also consider using the system that provides location and weather information for summer maintenance operations such as for striping, pavement sealing, etc. Other potential uses of the system included: providing coordinates of locations with problems (e.g. locations where snow fences are needed) and for asset inventory (e.g. locations of guardrails).

NDOT does not share the snow plow location information to the public currently. NDOT staff noted the uncertainty regarding public interpretation of the vehicle locations was the primary concern, such as questions related to why NDOT has so many snow plows; why snow plows are not moving or in garages when it is snowing, etc.

NDOT Executive Level Interviews – Dec. 14th

Group met at the NDOT Central Office in Lincoln on Thurs. Dec. 14th to review the history and processes followed in the installation of the AVL/GPS system for NDOT.

NDOT noted that a pilot was conducted in three NDOT Districts for a year. All trucks in those three Districts were equipped with AVL and MDSS. Upon completion of the pilot, NDOT executives met with DOMM's from all districts and collectively decided to procure AVL and MDSS on a statewide basis. NDOT felt MDSS was especially helpful to less experienced drivers.

NDOT envisions the use of data analytics in future years to compare the system's treatment recommendations for the winter season and various winter storms against hand-written reports completed by NDOT District Supervisors on how much material was used by plow operators. This will provide a first real data point that NDOT can use to evaluate how the AVL/GPS and the MDSS systems have had an impact on material usage and overall operations efficiency. Additional winter seasons will also need to be evaluated to determine what effect the technology is having material usage by NDOT Districts. It was noted that the Winter Severity Index (WSI) would be used as a baseline to compare winter storms against one another, since some storms are more severe and require more material than others. Other performance measures could include: staff resource usage, operations costs, consistency between treatments, etc. NDOT also envisions the data will be used to support operations strategies and resource allocation. The data will be able to help NDOT identify best practices and facilitate better discussion regarding winter maintenance. NDOT could also use the data to study optimal locations for salt storage/loading facilities and for route optimization.

NDOT also discussed how the MDSS working group has had a positive effect on the gradual rollout of treatment recommendations to all NDOT Districts. The NDOT has requested that at least one vehicle within each District follow the treatment recommendations during the 2017-2018 winter season. Additional snow plow operators may request the use of the treatment recommendations in future winter seasons after hearing of positive reports on the system's operations.

NDOT discussed that they may share vehicle locations in real-time on the state 511 traffic information page along with vehicle dashcam images in the coming years to increase public transparency of winter

maintenance operations. NDOT would like to restrict the reporting of images so that the general public does not see an image of the truck parked in a garage, or stopped at a location off the roadway. Another general concern raised was with respect to data storage and retention of vehicle dashcam images. The Iowa DOT was noted as a model to follow in the sharing of vehicle locations and images.

One key lesson learned by NDOT was ensuring that the RFP written for the project is written well enough to ensure that any challenges encountered can be addressed by the project team. The issue of the difficult integration of multiple brands of spreader controllers with the AVL hardware was cited as one example, in which NDOT expected the Contractor (Parsons) to address the problem given their role as the overall project manager. NDOT was able to work with the Contractor and spreader controller manufacturers to resolve many of these issues.

NDOT also noted the importance of buy-in on AVL/GPS and MDSS systems from executive management at top levels of an agency, since that serves to support the operations of NDOT District Supervisors and other staff throughout an agency. Without buy-in from top levels, agency employees at other levels would be less apt to buy-in to the system as well, which would negatively impact the credibility of the system and use of data gathered from the system for data analytics efforts. In addition, NDOT identified a champion in each district to facilitate buy-in from district staff and help provide training.

NDOT Executives summarized the following key successes and lessons learned:

- AVL/GPS implementation along with MDSS will bring major cultural changes to operational staff. It is important to identify right people as champions along with support from District Engineers.
- Taking time to engage district staff to understand their needs and go through systems engineering helps develop a better scope, which promotes project success.
- It is more effective having NDOT staff to communicate benefits of the system to their peers. DOT staff may feel such communication from vendors as sales pitches.
- Support from top level executives is critical.

Appendix G – Case Study Interview Summary: Colorado DOT

PROJECT 16-01: UTILIZATION OF AVL/GPS: CASE STUDIES SUMMARY OF COLORADO DOT IN-PERSON INTERVIEWS

Overview

Interviews were conducted by Ming-Shiun Lee and Dan Nelson of AECOM and coordinated with Kyle Lester of the Colorado Department of Transportation (CDOT) on January 9th and 10th, 2018.

CDOT Staff Interviews

Meeting attendees throughout the day on Tues. Jan. 9th included the following individuals:

- *Kyle Lester, Director of Highway Maintenance*
- *Paul Fox, Heavy Fleet Administrator*
- *John Lorme, Region 1 Superintendent*
- *Al Martinez, Region 1 Deputy Superintendent*
- *David Johnson, Winter Operations Manager*
- *Chris Volkert, Equipment Asset Manager*
- *Jeff Tatkenhorst, Region 9 Highway Maintenance Superintendent*
- *Mike O’Neill, Region 1 Deputy Director of Maintenance*

Meeting attendees throughout the day on Wed. Jan. 10th included the following individuals:

- *Kyle Lester, Director of Highway Maintenance*
- *Ryan Rice, TSM&O Division Director*
- *John Lorme, Region 1 Superintendent*

CDOT IT Operations Level Interviews

Group met at the CDOT Maintenance Training Offices in Golden, CO on Tues. Jan. 9th to discuss how CDOT has implemented AVL/GPS technology for their vehicle fleet. CDOT maintains a heavy vehicle fleet of approximately 1,800 vehicles, which includes about 1,200 snow plow vehicles. These vehicles have an AVL system provided by Zonar Systems that features a ruggedized tablet within the snow plow that provides an interface for drivers to use for logging into their specific route. CDOT drivers utilize a pre-assigned ID card and tap it to the tablet to log into the tablet to perform various functions. The tablet also performs a number of other tasks, namely electronic pre-trip and post-trip inspection reporting which has replaced paper reporting that was previously done by CDOT drivers.

The main software interface provided by Zonar is known as Ground Traffic Control, which is used by CDOT Administrators to assign other CDOT staff different levels of access to the software interface. This includes supervisors, mechanics, and drivers as users of the software to perform various functions. One lesson learned early on in the deployment was the high frequency with which users were notified of vehicle diagnostic issues requiring maintenance. When an issue was detected, an email notification was sent to supervisors and mechanics. As a result, a huge amount of notifications were generated and sent to those users regardless if the issues were newly detected or previously communicated. To reduce the amount of notifications yet help users keep tracking of issues need to be resolved, CDOT worked with Zonar to create a weekly report that provided a single report with all vehicle diagnostic issues. Major diagnostic issues are assigned a red flag and still provided via email to mechanics whenever they are detected. Mechanics are then required to address red flag issues and progress of completion is tracked until completion.

CDOT has also recently provided the location of snowplows on a public facing website to increase the public transparency of winter maintenance operations, available at: <http://www.cotrip.org/snowplow.htm#/snowplow>. The locations of the snow plows are made available through the sharing of the Application Programming Interface (API) by Zonar with CDOT, so that CDOT can request latitude / longitude coordinates of vehicles and display them on a map of the state. Bread crumb trail points on where snow plows have been is also shown when clicking on a snow plow icon on the map. Snow plows would disappear from the public facing website after 15 minutes of inactivity (i.e. when the ignition is turned off). CDOT was still exploring different solutions to determine inactive vehicles.

A separate AVL system has also been installed on the CDOT light vehicle fleet which is provided by Verizon known as NetworkFleet. Light vehicles operated by CDOT are not required under federal regulations to have the same pre-trip and post-trip reporting, thus Verizon NetworkFleet is an AVL system used by light vehicles whereas Zonar is implemented on heavy vehicles.

In addition to vehicle location data, the Zonar system collects engine idle time, vehicle speed, vehicle health and diagnostics, and inspection data and timestamps. Data required for the Federal Motor Carrier Safety Administration (FMCSA) compliance were retained for six months, per FMCSA requirements. For light duty vehicles, Verizon made the data available in a more user-friendly environment for a period of 90 days. Only raw data were accessible after the 90-day period. Data related to winter maintenance operations were stored in MDSS. CDOT did not save any data generated from those systems on its server due to liability concerns.

Group also discussed cellular coverage in areas of the state which still has some unacceptable gaps in coverage where snow plows do operate. CDOT has noted that this is a drawback to the reliance on cellular technology, which may cause long periods of time between updates on vehicle location and other information. CDOT has noted this on its public facing webpage so that the general public is aware of the potential delay in the update of vehicle locations.

It was noted that Zonar Systems works exclusively with AT&T as a cellular network provider. Although different cellular providers may have stronger coverage in other areas of the state, CDOT noted that some areas of the state are difficult in terms of elevation and climate, which are not conducive to the use of any kind of cellular network coverage.

Group noted that the Zonar AVL system, like many other AVL systems, is reliant on third-party mapping sites, such as Google, for integrating maps into its software interface. This may result in errors generated from alert-based reporting that is a feature of the Zonar. For example, alerts are generated for snow plow vehicles traveling over 50 MPH along a roadway segment. If a snapshot of the vehicle location is taken while that vehicle is traveling 40 MPH but crossing over / under a road with a 20 MPH speed limit, a high-speed alert will be generated and sent to a superintendent. CDOT staff have learned to spot these types of errors in the system over time.

Other alerts can be generated from the Zonar system on idle times in excess of a number of hours and vehicle health reports in terms of vehicles that have not had pre-trip or post-trip reports completed. CDOT has learned how to balance the thresholds of these alerts to generate the appropriate number of alerts for mechanics and for superintendents. CDOT staff spoke highly of the idle time alerts, which they felt helped to correct excess fuel consumption and reduce maintenance costs early on in the AVL system

testing process. It was estimated that the overall savings on these two items in the first year of the system's use exceeded the overall costs of the AVL system installation for the fleet.

CDOT staff spoke about Cirus spreader controllers on newer maintenance vehicles that have been integrated with the Zonar AVL system. The integration process between Zonar and Cirus was initially hampered by the length of time required for both sides to come to an agreement on a Memorandum of Understanding (MOU) that would protect the intellectual property of both companies. A separate truck building company used by CDOT for up-fitting the vehicle chassis and all equipment was able to bring representatives of both Zonar and Cirus together to determine how best to complete the integration process. In term of the AVL equipment installation, CDOT noted that a pre-build meeting was conducted with the truck building company to ensure installation standards. CDOT did not experience any issues with the AVL equipment installation.

These newer vehicles are also presenting automated treatment recommendations on the Zonar tablets through a separate agreement between Zonar and Iteris related to MDSS system operations for CDOT. Snow plow operators are still provided the independence to determine the level of treatment based on existing conditions and their judgements, given its diverse geography within the state that can make it difficult for weather forecasting services to predict the duration and intensity of winter storms for specific regions, areas or corridors.

One of the lessons learned from superintendents and managers is for the agency to best understand what they want from the AVL system to meet their agency's needs. CDOT noted that the needs and goals for the AVL/GPS program were not clearly identified initially. They now have a better understanding of their needs through the implementation and utilization of the system. CDOT also emphasized the importance of training and noted that properly trained personnel resulted in good results and better usage of the system. Another lesson learned was to have more training performed at the beginning of the program. CDOT performed some training at the beginning of the program but felt that more training up front would facilitate buy-in and proper use of the system. It was also noted that CDOT staff at an administrative level on the software side of the system were still learning the system at the time when supervisor and operator training sessions where carried out. CDOT staff with the software administrative rights were unable to demonstrate the smooth usage and operations of the software, which resulted in speculation in system usefulness and user resistance.

CDOT conducts training to snow plow operators on the system annually. CDOT felt that making recordings of the training available would be helpful for new snow plow operators. In addition to the annual training, CDOT planned to conduct traveling road shows through the state to provide additional training and raise awareness. CDOT would also like to perform additional training to managers to help them with interpreting reports and maximizing their knowledge to the system.

CDOT Supervisor / Manager / Technician Level Interviews

Group continued to meet at CDOT Maintenance Training Offices in Golden, CO on Tues. Jan. 9th to discuss how the Zonar AVL/GPS system was procured for winter maintenance operations.

CDOT is split into eight different maintenance sections throughout the state. Within each section, CDOT winter maintenance staff is structured into the following general positions:

Section Superintendent: Responsible for overseeing winter maintenance activities within the section in terms of response to winter storms. May be responsible for allocating some of the section's resources to other sections of the state in the event of large winter weather storms.

Section Supervisor: Responsible for monitoring how multiple vehicle operators within the section have allocated resources to plow roads within a specific area of that section. Reports to Superintendents and communicates with vehicle operators as needed during winter events.

Vehicle Operators: Responsible for overseeing multiple snow plow drivers performing along their assigned snow plow routes within the section.

The group acknowledged that there was some reluctance among vehicle operators to accept the AVL system equipment given concerns about the system potentially being used for disciplinary reasons. It was noted that CDOT gained buy-in from drivers over time as drivers realized that the Zonar AVL system could be used to protect them from claims of damage caused during winter storms by CDOT snow plows. CDOT noted that to gain operators buy-in, support from supervisors as well as training to supervisors for proper use of the system is critical. When communicating with operators, it is essential to focus on communicating the benefits (such as for their protection from claims and personal safety) and making it clear that the system is not a tool for micro management or disciplinary actions.

Among the greatest benefits to the use of the system is an increase in situational awareness of how staff are responding to winter storms and an ability to present the response to executive management in real-time on vehicle locations. Other benefits identified by CDOT staff include:

- System generated maintenance alerts helps with proper diagnostic and repairs. This in turns saves money and promotes timely repairs.
- Alerts on long vehicle engine idle time helps reductions in idle time, fuel consumption and negative emission impacts.
- The system has abundant reporting features that help not only in situational awareness but also in improving resource management, staff management and operational efficiency.
- The system had positive impact on driver behaviors such as promoting speed compliance and minimizing improper use of the equipment.
- The system has been used to protect drivers from false/erroneous accusations by the public.

In addition to the above benefits, CDOT would like to establish a performance management program to systematically evaluate and document the benefits of the AVL/GPS and fleet management system. A performance dashboard was highly desired. CDOT noted that due to lack of sufficient data to measure improvements, cost savings and other measurable improvements have not been assessed. CDOT indicated likely performance measures and goals would include:

- Reduction in equipment down time
- Increase in reliability
- Reduction in repair costs
- Fuel savings
- Road surface friction

The subject of treatment recommendations through MDSS was discussed with the group. Prior to 2014, CDOT procured an AVL/GPS system (from iwapi) along with MDSS under one contract. Since 2014, the MDSS services were procured under a separate contract with Iteris. CDOT currently has a number of fixed weather stations providing air and pavement temperatures back to a central office for the determination of treatment recommendations. Vehicle operators are still provided the independence to determine the level of roadway treatment based on existing conditions, given the differing number of climates and regions within the state that can make it difficult for weather forecasting services to predict the duration and intensity of winter storms.

CDOT is conducting a pilot study on using friction sensors in lieu of pavement/air temperature sensors. CDOT felt that pavement friction provides a better picture on road surface conditions. Upon successful testing, CDOT plans to integrate friction sensors with the AVL system and expand the installation statewide. Data from friction sensor will be input into MDSS.

CDOT also discussed an ongoing project being conducted under the agency's RoadX program that provides funding for new and innovative transportation projects in the state. Under the program, Verizon is partnering with two separate companies – Cradlepoint and Panasonic – to implement a system that would communicate real-time images and video from snow plow vehicles to a central office that could view roadway conditions and communicate back to the vehicle through in-vehicle equipment. Cradlepoint is providing an in-vehicle wireless communications router that is wirelessly connected to an in-vehicle dashcam provided by Panasonic, along with other in-vehicle equipment such as spreader controllers and temperature sensors. The overall goal of the pilot project is to send and receive all data through the Cradlepoint router and improve the efficiency of in-vehicle communications. Depending on the overall success of the project, CDOT may roll it out on a larger scale in future years.

CDOT Executive Level Interviews – Wed. Jan. 10th

Group met at the CDOT Headquarters offices in Denver to discuss the history and processes followed in the installation of the AVL/GPS system for the CDOT heavy and light vehicle fleets.

Prior to 2014, CDOT had previously implemented an AVL/GPS system provided by Iwapi on a number of snow plow vehicles throughout the state. Each maintenance section decided on the quantity of vehicles within that section to equip with an AVL/GPS system. This resulted in some sections having more vehicles equipped with an AVL/GPS than others. While the system had provided benefits to some sections of the state with an increased awareness of winter maintenance operations, a larger statewide view of how multiple sections were responding to winter storms was not possible with different levels of acceptance by different sections of the state.

Implementation of an AVL/GPS system on CDOT fleet was driven by a desire to implement a system that could assist in fleet management and operations. CDOT primary needs for such a system included:

- An automated feature to reduce administrative burden for pre and post trip inspection.
- A robust vehicle diagnostic program to support vehicle health monitoring and preventive maintenance.
- A fuel management program to improve fuel efficiency and fleet utilization.

An AVL/GPS system was an element of a fleet management system that CDOT desired to implement. CDOT began the preparation of a Request for Proposals in 2014. The overall goal of the procurement would be to select one vendor to supply hardware and software equipment for both the CDOT heavy vehicle fleet and light vehicle fleet.

CDOT also had been conducting a number of small AVL/GPS system demonstrations in 2014 with various vendors that were interested to demonstrate their system's functionalities to CDOT in advance of any future procurement. AVL vendors included Zonar and Verizon NetworkFleet among others, provided their systems for demonstration free of charge. These demonstrations provided some insight into the capabilities of the current systems and how they could achieve CDOT goals and objectives related to fleet management. Early results from the demonstrations revealed that some vehicles had been idling with engines running for excessive periods of time, resulting in both excess fuel consumption and increased maintenance costs. The awareness of the issue resulted in the prevention of those instances in future maintenance operations, resulting in a large amount of operational savings to CDOT. This prompted CDOT to reconsider their priorities and realize an opportunity for improving fleet and fuel efficiency.

Upon review of the various systems being demonstrated in late 2014, Colorado DOT executive level managers decided to accelerate the installation timeline of AVL/GPS technology on CDOT snow plows beyond the previously planned timeline as part of the RFP process. Colorado state law allowed CDOT to leverage an existing master services agreement already in place between Zonar and the City and County of Denver, which enabled CDOT to procure a Zonar AVL system for the heavy vehicle fleet that could perform both vehicle monitoring and automated pre-trip and post-trip vehicle inspections. CDOT used a separate existing contract with Verizon to procure a NetworkFleet system for the light vehicle fleet, which did not have the same requirements for pre-trip and post-trip reporting.

Although the procurement process resulted in two different AVL/GPS systems, CDOT was able to meet the accelerated timeline and deploy the Zonar AVL system on its heavy vehicle fleet for use in 2015. CDOT was also able to justify the higher cost of the Zonar AVL system based on the overall fleet management costs managed by the agency. CDOT currently manages a combined heavy and light vehicle fleet with an estimated value of about \$1 billion, and viewed the overall costs related to fleet management as greater than that of the winter maintenance operations estimated at about \$77 million for the current winter season.

Zonar's previous clients included commercial vehicle fleets and other agency fleets, but they were relatively new to winter maintenance operations performed by state governments. As such, CDOT has been working with Zonar to address specific issues related to winter maintenance operations that were new to Zonar. Such issues included: integration with various spreader controllers, SAP software and dashcam, as well as development of specific reports for operations and performance management. CDOT was also encouraged by the willingness of Zonar to work with CDOT to perform additional integration of their AVL system with other systems, namely vehicle spreader controllers and an existing SAP system currently used by CDOT for employee timesheets and issuing work orders on items requiring maintenance, such as roadside guardrail or other roadway assets managed by CDOT.

However, delays to the integration process arose from the length of time required to develop Memorandums of Understanding (MOUs) that were requested from legal teams of both Zonar and SAP. The MOUs were requested to protect the intellectual property developed by both companies from potentially being shared with competitors through the exposure of those systems to each other in the process of working for CDOT. Although discussions had taken place between Zonar and SAP, CDOT eventually instructed Zonar not to proceed further with an MOU given the length of time it was taking to come to an agreement between both companies.

Additional challenges resulted from other MOUs requested of Zonar prior to integrating with spreader controller manufacturers. This integration process was eventually assisted by a local company that CDOT was utilizing for up-fitting of trucks ordered by CDOT with winter maintenance equipment. The company brought Zonar field staff together with Cirus Controllers as a manufacturer of some of CDOT's existing spreader controllers. Integration testing by the truck company of the communications between the systems resulted in an accelerated completion of the integration that otherwise would not have been possible. At the moment, Cirus controllers have been integrated with Zonar on about 200 snow plow trucks, with newer snow plow vehicles being upfitted by the trucking company with that integration already performed.

CDOT noted that these and other challenges with Zonar have caused CDOT to re-assess how they should proceed with AVL/GPS system technology on both their heavy and light vehicle fleets in future years. With the current contract with Zonar expiring in 2019, a new RFP is likely to be developed in 2018 that will present a refined set of CDOT objectives with respect to on-board AVL/GPS technology and integration with other systems. The RFP would likely place the responsibility of AVL/GPS system integration with other systems with a single vendor that would be accountable for the overall installation that would achieve CDOT's desired level of system integration.

CDOT recognized the Zonar system had a lot of potential and capabilities. They acknowledged that CDOT has not utilized the system to its full capabilities and continued exploring its potential and capabilities. However, CDOT also noted the lack of staff has been a key challenge that hindered their ability to explore the system capabilities within a desired timeline.



research for winter highway maintenance

Lead state:

Minnesota Department of Transportation
Research Services
395 John Ireland Blvd.
St. Paul, MN 55155