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Automated Vehicle Location (AVL) technology involves automatically determining and transmitting the geospatial location of a vehicle. In winter maintenance applications it has been used in an integrated fashion with data from other sensors on weather and pavement temperature as well as data on the quantity of material applied on the roadway to improve efficiency, safety, and mobility. This report summarizes the results of a two-day workshop that was organized with the goal of determining the scope and nature of the implementation of AVL technology in transportation agencies. The workshop provided a forum for information exchange in terms of sharing ideas and discussing lessons learned from AVL technology implementations and operational improvements. Presentations from eleven different agencies that implement AVL technology in winter maintenance provided data on some key parameters that need to be considered when implementing this technology. In addition, presentations from different transportation agencies provided information on lessons learned from and ideas for future implementation and operational improvements of AVL technology.

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Advanced Highway Maintenance and Construction Technology Research Center

Department of Mechanical and Aerospace Engineering
University of California at Davis

Workshop on Automated Vehicle Location (AVL) Technology for Winter Maintenance – A Summary

Bahram Ravani, Ph.D., Principal Investigator
And
Kristopher Wehage

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California Department of Transportation

Division of Research, Innovation and System Information

ABSTRACT

Automated Vehicle Location (AVL) technology involves automatically determining and transmitting the geospatial location of a vehicle. In winter maintenance applications it has been used in an integrated fashion with data from other sensors on weather and pavement temperature as well as data on the quantity of material applied on the roadway to improve efficiency, safety, and mobility. This report summarizes the results of a two-day workshop that was organized with the goal of determining the scope and nature of the implementation of AVL technology within transportation agencies. The workshop provided a forum for information exchange in terms of sharing ideas and discussing lessons learned from AVL technology implementation and operational improvements. Presentations from eleven different agencies that implement AVL technology for winter maintenance provided data on some key parameters that need to be considered when implementing this technology. In addition, presentations from different transportation agencies provided information on lessons learned from and ideas for future implementation and operational improvements of AVL technology.

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LIST OF ACRONYMS AND ABBREVIATIONS

Acronym	Definition
AHMCT	Advanced Highway Maintenance and Construction Technology Research Center
ASOS	Automated Surface Observing System
AWOS	Automated Weather Observing System
AVL	Automated Vehicle Location
Caltrans	California Department of Transportation
DOT	Department of Transportation
CANbus	Controller Area Network bus
DRISI	Caltrans Division of Research, Innovation and System Information
GIS	Geographic Information System
HUD	Head-Up Display
IMO	Integrating Mobile Observations
ISO	International Standards Organization
IT	Information Technology
ITS	Intelligent Transportation Systems
MDSS	Maintenance Decision Support System
MMS	Maintenance Management System
OBD	On-Board Diagnostic
RFID	Radio Frequency IDentification
RWIS	Road Weather Information System
SAE	Society of Automotive Engineers
UC-Davis	University of California-Davis
WARS	Winter Automated Reporting System

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EXECUTIVE SUMMARY

This report summarizes the findings of a workshop on Automated Vehicle Location (AVL) technology in winter maintenance operations organized by the Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center at the University of California-Davis (UC-Davis) through sponsorship from the California Department of Transportation (Caltrans). The AVL technology involves automatically determining and transmitting the geospatial location of a vehicle. In winter maintenance applications it has been used in an integrated fashion with other sensors providing data on weather and pavement temperatures as well as data on the quantity of material applied on the roadway. The aim of the workshop was to provide a forum for peer exchange of information among participants and identification of best practices and areas where the most benefits have been gained from the use of AVL technology. Through a series of presentations from the Departments of Transportations from several states as well as some cities and other organizations, the workshop provided an understanding of the ways AVL technology is being used for winter maintenance. The discussions and interactions with the participants also provided data on what some of the best practices are as well as parameters to consider in implementing AVL technology for winter maintenance. Such information is important for Caltrans to develop proper planning for the use of AVL technology for winter maintenance operations.

The workshop presentations clearly indicated that AVL technology has reached a mature state, and has been implemented by several transportation agencies to enhance their winter maintenance operations. Although the level of AVL implementation varied among the agencies that gave presentations, some common key considerations and take-ways were:

1. Early in the effort, adopters need a clear vision of the goals and business case for the level of service expected from the system.

2. Adopters need buy-in at both management and operational levels.

3. A good path forward begins with a pilot study that allows for learning through trial-and-error before transitioning into full implementation within the winter maintenance fleet.

4. Due consideration should be given to implementation at different levels in terms of the type of data to be collected, data analysis and storage requirements, and sharing and the communication of the information.

5. The implementation plan should be agile in order to adapt to continuous changes in new technology and variations in supply chain or vendors.

INTRODUCTION

This report summarizes the findings of a workshop on Automated Vehicle Location (AVL) technology in winter maintenance operations organized by the Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center at the University of California-Davis through sponsorship from the California Department of Transportation (Caltrans). The aim of the workshop was to provide a forum for a peer exchange of information among participants and the identification of best practices and areas where the most benefits have been gained from use of AVL technology. The participants consisted of representatives from several states' Department of Transportations (DOTs), researchers, and other stake holders with experience in AVL technology as well as interested groups within the Caltrans organization. The workshop lasted two days and resulted in networking and the exchange of knowledge. The following research questions were posed to the participants:

1. What are the experiences of other state DoTs and transit organizations is using AVL technology in winter maintenance?
2. What are some of the benefits and challenges in using this technology?
3. What are the common equipment or devices, material, and vendors that offer reliable AVL technologies?
4. What are some of the best practices in using AVL technology in winter maintenance operations?
5. What are some of the shortcomings of commercially available systems and services in this area?
6. What are some of the workflow and implementation issues?
7. How can the use of AVL and winter maintenance equipment provide for a more sustainable winter maintenance program?

Automated Vehicle Location (AVL) technology involves determining and transmitting the geographic location of a vehicle using automatic means. Global Positioning System (GPS) technology is usually used in combination with mobile data communication. Since the 1990s such systems have been utilized by transit agencies and are sometimes combined with computer aided dispatching technology. They have also been utilized for fleet management, vehicle theft protection, first responders, and, more recently, by public transportation system providers such as Uber and Lyft.

The aim of the workshop was to provide a forum for a peer exchange of information among participants and identification of the best practices and areas where the most benefits have been gained from use of AVL technology.

Through a series of presentations from several states' Departments of Transportations as well as some cities and other organizations, the workshop provided some level of understanding of the ways AVL technology is being used for winter maintenance. The discussions and interactions with the participants also provided data on what some of the best practices are as well as parameters to consider when implementing AVL technology for winter maintenance. Such information is important for Caltrans to develop proper planning for implementing AVL technology for winter maintenance operations.

Background

AVL technology has been implemented in transit agencies in various forms for more than two decades. A study published in 1999 [Casey 1999] reported 61 transit agencies with operational AVL technology at the time. This study used data from the transit operator for the Portland, Oregon metropolitan area, and evaluated running time improvements, as well as waiting and travel time benefits for bus riders. The conclusions of this study were positive in all these areas, indicating initial improvements in the reliability of the transit operations. In another study also published in 1999 [Peng, Beimborn, Octania, and Zygowicz 1999] the use of AVL in small and medium size transit agencies was evaluated. This study included the cost and benefit of the AVL technology both to transit users and transit operators. AVL technology has also proven useful in several other areas; for example, its usage in school buses [Rhoulac 2005] allowed for providing updated information on household arrival times and bus routes to parents. It has also been used in first responder's applications (see, for example, [Portillo 2008]). Although AVL technology was first successfully implemented in fleet management, its integration with Geographic Information Systems (GIS) has opened a wide variety of applications in Intelligent Transportation Systems (ITS).

In the area of winter maintenance, Pennsylvania DOT has made a major commitment to using AVL technology. In 2014-15 they did a pilot study that included AVL technology installed in 119 plow trucks. They used AVL technology to log and share data in real-time for each truck, including showing the location of a truck and the dispensing level of its material spread. Since then, they have expanded their pilot study to include many more trucks and vehicles.

APPROACH

Key personnel from transportation agencies who had experience in implementing and using AVL technology for winter maintenance were invited to be presenters for the workshop. The invited presenters submitted abstracts or outlines of their presentations. These submissions formed the basis of developing the agenda for the workshop.

Agenda

The final agenda for the workshop was:

Automated Vehicle Location (AVL) Technology for Winter Maintenance

A Peer Exchange Workshop

Thursday, October 27th – Day 1

9:00 AM	Introduction and Announcements	Prof. Bahram Ravani, AHMCT-UC-Davis
9:10 AM	Opening Remarks	James L. Appleton, Division Chief, DRISI, Caltrans
9:25 AM	Overview: Caltrans Winter Operations	Chris Smith, Chief, Winter Operations Branch, Caltrans
9:45 AM	Overview of the PennDOT AVL Program	Jon Fleming, Pennsylvania DOT
10:15 AM	Overview of the Idaho State AVL Program	Steve Spoor, Idaho DOT
10:45 AM	Break	
11:00 AM	AVL at the Iowa DOT (Webinar)	Tina Greenfield, Iowa DOT
11:30 AM	Panel Discussion	
12:30 PM	Lunch	
1:30 PM	Overview of the Washington State AVL Program (a Webinar Presentation)	Joe Schmit & James R. Morin, Washington DOT
2:00 PM	Deployment of Two Road Weather Management Solutions	Paul Pisano, US DOT
2:30 PM	Coffee Break	
2:45 PM	An Overview of the Minnesota State AVL Program	Joseph Huneke, Minnesota DOT
3:15 PM	Fleet Management Analytics	Kyle Lester, Chris Volkert, & Al Martinez, Colorado DOT
3:45 PM	Panel Discussion	
5:00 PM	End of Day 1	

Friday, October 28th – Day 2

9:00 AM	AVL at the City of West Des Moines	Kevin Hensley, City of West Des Moines
9:30 AM	Implementation and Application of AVL Technology at the Ministry of Transportation	Max Perchanok, Ontario Ministry of Transportation, Province of Ontario, Canada
10:00 AM	Break	
10:15 AM	Putting the AVL Tool into the Winter Maintenance Toolbox	Wilf Nixon, PhD., P.E., Salt Institute, Utah
10:45 AM	Panel Discussion	
12:00 PM	Lunch	
1:00 PM	Use of Mobile Data Collection for Winter Maintenance Decision Support	Daris Ormeshir, South Dakota DOT
1:30 PM	Workshop Summary	Prof. Bahram Ravani, AHMCT-UC-Davis
2:00 PM	Open Forum and Networking	
3:00 PM	Workshop Commencement	

Copies of the presentations from the invited participants are provided in appendix A.

SUMMARY OF PRESENTATIONS GIVEN AT THE WORKSHOP

Short summaries of the presentations given by invitees are provided in this section. The slides used in the presentations are available in PDF format on the AVL workshop website (http://ahmct.ucdavis.edu/avl/). These presentation slides are provided by their corresponding presenters and they should be properly referenced with credit given to the individual presenters. The majority of the presentations were also video recorded, and the video streams can be accessed on the workshop website.

Caltrans (Presentation by Chris Smith)

This presentation provided a brief overview of Caltrans' winter maintenance capabilities. Caltrans has a $30 million snow/ice removal budget and clears snow and ice from 9,000 lane miles and employs 1,935 permanent employees in these maintenance efforts. The presentation highlighted some of California's current winter maintenance capabilities, which include staffed chain control areas; a highway advisory radio system; a network of Remote Weather Information Systems (RWIS); and avalanche control measures such as the Gazex and LoCAT systems, jet roofs, and snow fences.

Some of Caltrans' new winter maintenance projects include a pilot program to test the Epoke and Henderson spreaders; the development of a winter "Level of Service" metric based on snowfall, traffic delays, rainfall, flooding, mudslides, land-slides, and other factors; and Heads-Up display (HUD) systems to assist snow plow operators in adverse conditions. Additionally, Caltrans is testing the Snow Lion Ice Breaker system and is moving to use more brine as a new project as Caltrans now produces brine from grey water. The need to incorporate an MDSS (Maintenance Decision Support System) system into Caltrans Winter Maintenance Operations was also mentioned in the presentation.

Pennsylvania DOT (Presentation by Jon Fleming)

The Pennsylvania DOT manages 39,700 miles of roads and over 25,000 state-maintained bridges (3rd in the nation). In 2016, the Pennsylvania DOT invested more than $2.5 billion in construction projects and $1.5 billion in maintenance. A fleet of 2,250 trucks service 96,000 snow-lane miles at a cost of $170 million. In the winter of 2015-2016, the Pennsylvania DOT used 900,000 tons of salt and 7.5 million gallons of brine. During severe winters they may use up to 1.2 million tons of salt.

The Pennsylvania DOT considers AVL technology to have a broader application than just the equipment division, and therefore it must be able to interface with multiple departments. Pennsylvania's first implementation of AVL technology involved an internal solution utilizing the GPS capabilities of 800 MHz radio. The first pilot program was primarily targeted at getting GPS data. Disadvantages were that it could only poll every 5 minutes and had to compete with other technologies for limited Information Technology (IT) resources.

The second implementation of AVL technology by the Pennsylvania DOT was to use a wireless cellular system, starting with a pilot program of 100 trucks. The AVL system implemented would monitor truck GPS location, ground and air temperature, and receive spreader data. The system was later applied to monitor the GPS location of 700 trucks, ground and air temperature, and spreader data. The system interfaced with the 511pa.com website. No data was collected from the CAN bus system.

Pennsylvania's third stage of AVL technology integration has involved full implementation across 2,500 vehicles using three different types of AVL units. The first type of AVL units that were installed used Advanced Tracking System (ATS) from Certified Power, Inc. (http://certifiedpower.com). This system was considered the preferred equipment and only installed if it was compatible with the spreader control software on the snow trucks. These AVL units transmitted data over cellular signal using Verizon 1 G before porting to AT&T Fleet Manger. It provided location information to the 511pa.com vendor for general public release on the Department's website. The system had internal storage in the event of loss of cellular signal. The second type of AVL units installed were WT10X from Webtech Wireless (a division of BSM Technologies from Toronto, Canada) which were used when ATS was not compatible with the spreader controller software or when there was no spreader control present. These units provided data over cellular signals utilizing AT&T 3G signals. Although these units had the capability to be connected to the vehicle's Controller Area Network bus (CANbus) or On-Board Diagnostic (OBD) port, they were only used for their GPS function. They provide data on location information for general public release on the DOT's website. When seasonal rental vehicles were used for operations, a third type of AVL units were used. These consisted of WT2250 from WebTech Wireless which were used due to their plug-and-play nature of operation. They transmit data over a AT&T 3G signal.

When full AVL systems are utilized, they provide situational awareness of environmental conditions and operator actions. In a way, each truck is acting as a mobile mini-RWIS (Road Weather Information System) unit. This provides the ability to compare vehicle speed, road conditions, and treatment in real-time. The acquired data may be compared with grip data (roadway traction) from stationary RWIS sites. The system provides cost savings in route optimization, reduced paperwork, and labor to collect data. It also allows real-time operator oversight. In the future the system can be used to alert motorists to the slow moving traffic and work zones through the 511 traveler information and social media resulting in improved safety. Pennsylvania is also creating overall performance metric for winter operations based on the Winter Severity Index and route-based metrics.

Idaho DOT (Presentation by Steve Spoor)

The Idaho DOT's focus for AVL technology is not targeted to tracking the location of snowplows on a map, but for use in post-storm analysis.

In Idaho, AVL technology was first deployed for the purpose of GPS data collection in 2007. Full AVL implementation began with a pilot program of 5 trucks in 2010. The pilot program identified a potential for 40% cost savings, and the program was later expanded to 10 trucks. The extended pilot program highlighted challenges of interfacing AVL technology with snowplow controllers from many different manufacturers. In some cases, the data quality was poor due to loss of precision in unit conversion between equipment from different manufacturers.

In 2012, the Idaho DOT tried a Cirus Controls (from Minneapolis, Minnesota) controller, which has the ability to buffer data and communicate via Wi-Fi in the maintenance shed, thereby eliminating the need for a cellular modem capable of data buffering. Cirus Controls also provide software for collecting and inspecting data, which eliminates the need for a third-party data collection/data hosting vendor. Due to the features and benefits of the Cirus Controls controller, Idaho adopted the Cirus Controls controller, which is now owned by Certified Power, Inc. (http://certifiedpower.com), state-wide starting in 2012-2013.

Presently, the Idaho AVL program consists of 409 Single/Tandem Axle Plow/Spread trucks which have SpreadSmartRX Spreader Controller and DataSmart Reporting System provided by Certified Powered, Inc.

The Idaho implementation of AVL technology integrates AVL data with the RWIS system using Vaisala Navigator software, and it integrates with a Maintenance Management System (MMS) provided by Agile Assets for increased reporting accuracy and reduced labor. The AVL data provides for automated and granular snowplow operations assessment using the Winter Automated Reporting System (WARS). Idaho DOT is currently working on a storm summary report to monitor crew efficiency and consistency of application across routes as well as a mobility cost efficiency index based on AVL data.

In addition to collecting weather data (snow levels, ice, pavement temperatures, humidity, etc.), all of Idaho's RWIS sites also have non-invasive pavement sensors capable of providing a metric of tire grip. Idaho DOT overlaid AVL data onto RWIS data, allowing analysts to monitor grip level before and after a snowplow passed an RWIS site during a storm event. The analysis allowed operators to tailor the material mixture during the next storm event to reduce both the salt distributed on the roadway and the number of passes required, maintaining grip throughout the storm event. Idaho DOT encourages their operators to play an active role in understanding and analyzing their own data.

Iowa DOT (Presentation by Tina Greenfield)

The Iowa DOT manages 24,122 lane miles of roadway, has 102 maintenance facilities, and employs 1100 permanent staff and 400 seasonal staff. Additionally, the Iowa DOT has 892 snow plows and 12 tow plows in their fleet. The Iowa DOT uses an average of 123,000 tons of salt and 18.6 million gallons of brine each year.

The Iowa DOT began a pilot program implementing AVL technology in 2010. The purpose of the original AVL program was to understand and visualize real-time fleet movement and material usage. The aim was to provide tools for managers to direct the fleet, reduce paperwork for drivers, increase transparency to the public, and provide a better winter driving experience. Iowa's pilot program identified that the use of touch screens was troublesome and that systems with no driver interaction would be preferred.

Typical data collected were truck location, speed, heading, and whether the front wing plow is up or down. Some of this plow data was made available on a public-facing website in 2013. In addition, in the 2013-2014 time-frames, 420 plow cameras were installed on about half the truck fleet using mobile phones (iPhones). During truck operation, the cameras would take a picture every 10 minutes. This information resulted in fewer calls from public and law enforcement wondering if plows had been deployed at specific locations after a snow storm.

They found that having two cellular systems installed on the same truck was not ideal and also noted that better plow sensors were necessary. They also found that public engagement through the internet helped increase visibility and public support for their project.

In 2015, they issued a new Request for Proposals (RFP) to improve their system. This included a vendor hosted website, more external feeds, Wi-Fi on the trucks, more frequent spreader data, and better cell coverage. The contract value was $1.28 million.

Washington DOT (Presentation by Joe Schmit and James Morin)

The initial goals of the Washington DOT's AVL technology implementation were to collect GPS and spreader controller data to eliminate manual data entry and to provide a real-time webmap of snow plow locations.

As of October 2016, AVL technology systems have been installed in 360 vehicles (approximately 70% of their fleet), with 160 trucks remaining to be outfitted. Of the 360 vehicles with AVL technology systems, 90% are outfitted with Location Technologies' cellular modems, while the remaining 10% use a 700 MHz IP Radio System (IPMN). The modems interface primarily with Force America 5100 and 6100 spreader controllers, although some older systems use Parker, Raven and/or Dickey John spreader controllers. AVL data is collected on an internal Washington DOT database and accessible through an internal web application.

Their experience indicated the need to position AVL equipment within the truck so that it is readily accessible for maintenance. Additionally, equipment with bright LED status lights should be positioned behind the driver to minimize glare. They found that integration of the components into the vehicle is a challenge. Currently, the Washington DOT's vehicles have seven total antennas (including an 800 MHz IP, CB and dispatch radio antennas and a GPS antenna), which makes it difficult to trouble shoot communication issues.

The cost for AVL technology installation for one plow was $650 for the modem, wire harness and antenna and $12.30 a month for data service. Annually, the Washington DOT pays $54,000 for data service and $2,000 for server and software maintenance.

Although the Washington DOT has not completed a comprehensive cost-benefit analysis, it seems that the system has already paid for itself in snow and ice related handling of tort claims. Data obtained from AVL systems has allowed handling of tort claims in a more equitable fashion since data rather than speculations have been used in addressing such claims.

The Washington DOT collects AVL data in two minute intervals. Material usage is estimated using linear differencing between reporting intervals. The Washington DOT has found that specialized logic is sometimes necessary to filter outlier data and that estimated material usage sometimes varies up to 2% from actual usage. While this level of accuracy is sufficient for the Washington DOT's winter maintenance management program, workshop participants suggested that a more frequent polling interval could help increase the accuracy.

US DOT (Presentation by Paul Pisano)

Since well-maintained roads serve to reduce fatalities, increase mobility and minimize impact on the environment, it is therefore necessary, in planning for a winter storm event, to take into account not only the severity of the event but also the timing, current road and traffic conditions, and any pretreatments that may be applied to the roadways.

The US DOT has programs that are targeted to alleviate the impact of adverse weather by getting data to the right people at the right time to make better decisions, including a prototype of the first MDSS, the *Clarus* and Weather Data Environment tool, Weather and Connected/Automated vehicles, and a Weather-Responsive Traffic Management program. The US DOT is currently shifting the program focus from applied research to Knowledge and Technology Transfer as part of the "Every Day Counts" (EDC) and Weather-Savvy Roads program. The EDC program, which is currently in its fourth round of two year cycles, is a state-based model to identify and rapidly deploy underutilized innovations to shorten the project delivery process, enhance roadway safety, reduce congestion and improve environmental sustainability.

The Pathfinder project, part of the Weather-Savvy Roads program and a collaboration between the National Weather Service (NWS), Private Sector Weather Providers, State DOTs, and State Emergency Managers, has the goal to strengthen the working relationship between state DOTs and the NWS by disseminating road weather information that is clear, concise, impact-based, and consistent to allow drivers to make safe and efficient travel decisions. One of the outcomes of the Pathfinder project is a document that describes the basic steps and requirements to implement the Pathfinder program, including examples from individual state DOT programs.

The Integrating Mobile Observations (IMO) program is another part of the Weather-Savvy Roads program, and has the goal to deploy vehicle-based technology to collect, transmit and use weather, road condition and related vehicle data to improve transportation system management. The US DOT is currently working with the Minnesota DOT (~590 Vehicles), the Michigan DOT (~15 vehicles, ~310 Snow Plows) and the Nevada DOT (~60 vehicles) to collect information such as air temperature, relative humidity, surface temperature, wiper status, brake status, accelerometer data, snow plow spreader data, camera images and GPS location data. The data is used for a variety of purposes, including a predictive modeling system for pavement conditions and road weather forecasts, motorist advisories and warnings, and applications for operations including management reports and forecasts and recommendations for winter maintenance operations. The IMO has the potential to fill gaps in road weather observations, spur development of new applications, and improve efficiency and accountability. Additionally, the IMO program dramatically enhances existing systems by aiding in salt reduction strategies; optimizing the use of maintenance resources; generating actionable, automated alerts and messages; and providing the traveling public with timely and valuable information. Under Weather-Savvy Roads there will be extensive Knowledge and Technology Transfer resources made available to those state DOTs that sign up to implement either Pathfinder, IMO or both. Resources such as funding for site visits and peer exchange workshops and the development of an IMO implementation toolkit (including case studies, fact sheets, sample specifications, etc.) will be available over calendar years 2017-2018.

There is a standardization effort by SAE (Society of Automotive Engineers) to develop communication messaging protocol SAEJ2735. The US DOT is currently working with state DOT members to refine the standard.

Minnesota DOT (Presentation by Joseph Huneke)

The Minnesota DOT's AVL program began with a partnership with the Federal DOT. Minnesota's motivations for their AVL program include tracking and reduction of expenses, increased efficiency of winter maintenance activities, improved accountability for operators and reduction of environmental impact for operations.

Currently, AVL technology is installed in all 2004 and newer vehicles (600 plus units) with full-implementation expected in 3-4 years. The Minnesota DOT uses Force America 6100 controllers and a cellular 2-way communications platform. Trucks are equipped with a touch screen display and a suite of sensors for monitoring weather, vehicle, and snowplow operation data. Cameras are installed on a total of 240 trucks. Camera images are used as a decision-making tool to decide when to close roads. These images are made available on a public-facing 511 website.

In addition to collecting AVL data from maintenance vehicles, the Minnesota DOT collects atmospheric and road condition data from 99 RWIS and from an additional 99 aviation sites such as Automated Weather Observing System (AWOS) and Automated Surface Observing System (ASOS).

The Minnesota DOT manages their own IT infrastructure, which consists of eight virtual servers. They chose an internal solution in order to have full control of the data and increased flexibility in using and adapting the data to other applications. Minnesota's RWIS sites are integrated into their infrastructure, including a 511 system. They are currently working on incorporating vehicle camera data into a 511 system.

The Minnesota DOT was one of the first DOTs to incorporate AVL data (along with weather data from RWIS sites) into an MDSS. Minnesota's MDSS provides unique forecasts for all 810 plow routes with pavement condition prediction and treatment recommendations. Currently the MDSS is used as a recommendation for treatment application and is not intended to be authoritative. For example, the MDSS sometimes does not take into account turn lanes, off-ramps, etc. For such information they still rely on operator expertise. Minnesota’s DOT experience in connecting AVL to their MDSS program has been extremely positive and beneficial to their organization.

The Minnesota DOT is also using the AVL data to train their management staff and operators to minimize the environmental effects of chloride on the roadway as part of their Salt Solutions Program. In Minnesota’s experience, persistence and tailoring presentations on the benefits of AVL to each level/department within the DOT has helped push the application of the technology.

Colorado DOT (Presentation by Kyle Lester, Chris Volkert, and Al Martinez)

The Colorado DOT maintains 23,000 total lane miles of highway, 3,439 bridges and 21 tunnels with a fleet of 3,227 vehicles and spends a total of $270 million per year on highway maintenance activities. Recently Colorado has seen a dramatic increase in population, with 41.8 billion miles traveled on roadways each year and commute times increased two to three times. The Colorado DOT is expected to do more with less people and less funding by using technology.

Colorado began their AVL program starting in 2005/2006 using Iteris, Inc. as their provider. From the beginning, AVL data was incorporated into an MDSS for operational readiness. AVL/MDSS was initially a voluntary program for each district. Colorado investigated AVL systems from IWAPI, Network Fleet, Infusion, Zonar, Ameritrak and Delcan in an initial pilot program and ultimately chose Zonar as their AVL solution.

Zonar offers a ruggedized Android tablet for pre- and post-trip inspections, two-way communications, navigation, vehicle diagnostics and fuel management. Other applications are possible by writing custom Android software using Zonar's SDK. The system uses RFID (Radio Frequency Identification) technology to identify elements in the truck for maintenance and integrates with a timesheet SAP program. Lester estimated the cost of the Zonar system to be $800-900 per vehicle.

The Colorado DOT uses Force America controllers on their older snowplows and Cirus controllers for their newest applications. AVL reporting is fully incorporated into the newer Cirus controllers and partially integrated with older Force America controllers. Colorado DOT uses the

Verizon Network Fleet for Light Fleet Telematics (3/4 ton and below vehicles) and a key fob to identify operators.

Initially, the Colorado DOT's focus was to use AVL for the purpose of operational readiness, but starting in December 2014, the Colorado DOT found several examples of poor resource utilization in their AVL data (including three vehicles that idled for 24 hours). These incidents caused Colorado to shift their focus from operational readiness to operator oversight and equipment maintenance.

Operator oversight capabilities include monitoring hard braking, geofence violations, idle time, lost power, odd-hour operation, speed and other vehicle sensor data. Since implementing their operator oversight program, Colorado has seen reduced costs, idle times, fuel consumption, vehicle down time and response time. The reduction in idle time is estimated to have saved approximately $2 million dollars a year.

AVL data is also used for operational readiness in Colorado. All AVL data flow into a software called "Situator" and "Pike Alert." An automated alert system is currently in development to obliviate the need for human dispatchers.

City of West Des Moines (Presentation by Kevin Hensley)

The City of West Des Moines maintains 800 lane miles with 16 plow trucks that operate 50 miles per plow. The City of West Des Moines may bring in additional contractors during a heavy storm event.

The City of West Des Moines has been using AVL technology in their vehicles for approximately 13 years. The use of AVL technology has been for the purpose of inventory control, complaint resolution, real-time data (including road temperature and ambient temperature as measured from their plow trucks), customer support, and contractor oversight. The reporting capability includes material usage, stops reports (i.e. to monitor extended breaks and location of breaks), vehicle status, customer service, and GPS location data. West Des Moines also partners with Vaisala, who is responsible for the RWIS equipment that provides data for their weather forecaster.

The City of West Des Moines currently uses three different types of controllers, two types of AVL hardware and many different models/brands of temperature and pressure sensors/switches. Building an AVL system with components from different manufacturers has been challenging.

Currently, AVL equipment is mounted on the outside of the passenger seat in their vehicles so that it is easily accessible and serviceable. In using the equipment, regular calibration is essential for accurate data collection.

The first version of the AVL system had little buy-in from truck builders, who did not understand the goals of the system, and operators who did not want to be monitored. The City of West De Moines found the importance of actively engaging employees and proper training to streamline the adoption of AVL in their organization.

The City of West Des Moines' data, which is polled at 10 second intervals and transmitted via a cellular modem, is hosted by a vendor (Web Tech wireless). A 511 site is currently in development. The 511 site will show the number of snow-plow passes on each route coded by color. This visualization tool serves to protect operator privacy and provides a better metric of the level of service to the public, as opposed to showing the snow-plow's current geographic location.

A primary benefit of AVL technology for the City of West Des Moines is the reduction in material cost. The reduction of salt in first year alone is estimated to be enough to have paid for the system. All contractors are required to provide AVL data for the purpose of operator oversight.

Ontario Ministry of Transportation (Presentation by Max Perchanok)

The Province of Ontario, Canada has a population of 13.6 million people, 11,700 lane miles of roadway and 22-101 days of annual snowfall. Most spreaders in the Province are equipped for pre-wet; but the degree of implementation varies by contract area. The province also has 61 tow-plows. All vehicles are equipped with mobile infra-red thermometers for ambient air temperature and roadway temperature monitoring.

Ontario's Winter Maintenance program has been completely outsourced as of 2015-16. Each maintenance contract typically consists of 300-600 lane miles for a ten-year duration for both summer and winter maintenance activities. There are a total of 21 contract areas, which are currently split among five vendors. Contractors are required to monitor weather, provide equipment, operators, materials, and traffic protection for incident control. Contractors are also responsible for reporting AVL data at 10 second intervals and are required to have AVL on all systems. Contractors have full autonomy in selection of AVL vendors. Most use DM&T, Webtech or Lynxfield for AVL equipment/software and web services. The contractor handles all dispatches and reports on their own performance. The performance reports are subject to structured audits. All patrols are manned 24/7 through a winter period. Vendors are required to provide a monthly hard media archive and to provide web access to their data to the Ontario Ministry of Transportation. Ontario is currently working to establish a data retention policy.

The Province of Ontario contracts are performance-based, with key winter requirements for cycle times and time to achieve bare pavement. Performance is reported annually to the public along with a winter severity index.

Winter driving conditions are collected from each patrol vehicle 5-10 times a day and reported to a public facing 511 site. Additionally, weather data is collected from 144 RWIS sites. Each RWIS site consists of puck in pavement, overhead cameras. Additional sites on low-volume roads are instrumented with underground thermistors to monitor frost under roadway to establish weight restriction periods in during spring thaw. The RWIS network is also completely outsourced.

In use of AVL technology, the Ontario Ministry of Transportation found good correlation between AVL data and paper records (0.93 correlations). In their implementation of AVL technology they found that supervisor/manager buy-in can be challenging, and that it was sometimes necessary to prove the accuracy of the system, or provide a backup plan in the event of system failure. They feel that it is important to know your objectives and identify specific deliverables when specifying AVL technology. In their view, AVL technology is a fully-developed technology.

Salt Institute (Presentation by Wilf Nixon, Ph.D.)

While most of the presentations at the conference discussed technical implementation details of AVL technology within their organizations, this presentation discussed guiding principles for implementing AVL technology as a system within an organization. This presentation summarized many of the concerns that operators and managers may have for an AVL program including limitations on thinking and ideas to guide management in their application of AVL technology.

Some presenters mentioned resistance from operators who do not want to be tracked. Additionally, management may have concerns that an AVL program requires data management and storage infrastructure which either requires buy-in from their IT department or trusting data to a third party. Some organizations are sharing winter maintenance data with public-facing websites, while other organizations are only providing summary data or no data at all. Some questions to be considered are: what level of public involvement in internal actions of a DOT is suitable? Can we trust the public with the data? Ultimately there is not a one-size fits all solution to these questions, and these are dialogs that an organization should have internally before implementing an AVL program.

GPS/AVL data is simply another tool in the toolbox to analyze Winter Maintenance activities and just having this tool does not necessarily improve performance. AVL technology can address the issue that if you cannot measure data, you cannot manage it. In the implementation of AVL technology, it is important to develop a plan to use the new, collected data to ensure success. In general, adapting and integrating a new tool, such as AVL technology, into the workflow of a DOT is challenging. The presentation also included a discussion of the "swamp issue," i.e. how to deal with too much data. The challenge with the large amount of data that AVL technology provides is that it needs to be made actionable so that a small staff of managers will actually use it. Typical quality control procedures may consist of a few simple checks, where digging deeper happens if problems are found. Geofencing around an RWIS site is another way to make a large dataset more manageable. Automated systems to pluck out useful, actionable data would also be important.

AVL technology provides a powerful tool to monitor material usage, but to be used effectively it is essential to perform checks on the data. One way to verify AVL data quality is to weigh material/fuel/etc. before and after a shift. Furthermore, real-time measurement of weight in the hopper could provide a backup to material spreader data. Currently there is no consensus on how much variation in material reporting is acceptable. Some organizations accept a <5% error, whereas others prefer <1-2% error. The amount of acceptable error is an important criterion in specifying an AVL system. A tighter error tolerance requires a more frequent polling rate and calibration and potentially more expensive sensors, which can drive up the cost of an AVL system. Additionally, the errors in reporting accuracy need to be taken into account when using the data to check operator performance.

A DOT may consider investigating whether a quality control program to track maintenance operations (i.e. an ISO or equivalent system) would be beneficial. In general, the level of service goals should drive all decisions. The challenge is that there are many metrics for levels of service. Ultimately, an organization needs to select a level of service that is suitable to their operation and environment. The level of service should also be normalized by a winter severity metric. Once the goal is identified, the challenge is how to achieve the goal with an appropriate level of effort.

The use of grip factor during a storm event can be a performance metric (this was also discussed in the presentation by the Idaho DOT). Grip factor is, in fact, a pertinent and extremely useful tool to measure outcome of actions, but DOTs need to use judgment in conveying their level of service goals to the public to avoid creating the expectation of providing high grip throughout a storm event.

In conclusion, one should understand that AVL is not a magic wand, but a force multiplier. Significant issues remain and the end goals for an AVL technology program must remain central to the use of the technology.

South Dakota DOT (Presentation by Daris Ormeshir)

The South Dakota DOT began their AVL program in 2002 and it has been operational since 2004. They have equipped 110 out of 480 of their trucks with mobile data collectors. They have also made great strides in the use of AVL data for management purposes.

South Dakota is currently adopting a web-based MDSS to support rising demands from travelers and commercial carriers. This system has also enabled them to reduce labor, equipment and material costs as well as providing timely reporting of weather forecasts.

AVL and MDSS are complicated systems utilizing emerging technologies, and it may be difficult for any one individual to fully understand all of the details of its operation. Nevertheless, South Dakota has verified that the MDSS models and recommendations work in many experiments and they have become confident in their MDSS program.

South Dakota uses AVL and MDSS together to provide real-time material recommendations using two way communications to their operators. They have also used MDSS for blade wear studies. They have also used performance based metrics to compare different years and different storm events.

South Dakota's AVL system consists of a MDC-002 touch screen interface produced by Intelligent Devices in the cab, a Garmin GPS system, a Vaisala surface control system infrared temperature sensor, a mercury switch for plow blade position sensing, and an ambient air temperature sensor mounted on the mirror of the truck. Currently, the South Dakota DOT is moving to the MDC-004 touch screen interface, which includes a camera. They have primarily used modems from Sierra Wireless, such as the Raven XC, which have proven to be reliable in the last ten years. In some remote areas of South Dakota, different cell network providers provide better coverage, and therefore a carrier switching modem, such as the Raven RV50 has proven useful.

South Dakota partners with Parsons for mobile data collection. Data is polled at one minute intervals and is processed by Iteris. The plow operator supplies weather and road conditions manually by using the touch screen interface. South Dakota is currently working on using operator inputs to update their 511 system.

This presentation also emphasized the need for training snow plow operators and managers, preferably through a hands-on training, as well as providing an online refresher course for continuing education.

South Dakota has seen the value of AVL technology through decreased material usage, protecting the environment by using less salt, and decreased effort for bridge cleaning.

AASHTO (Presentation by Richard Nelson)

This presentation was not initially planned as part of the workshop, but was offered and was of interest to the participants. It did not deal with AVL technology, but about the color of snow plows used by different state DOTs and countries. A total of 23 states and 13 countries had been surveyed to find out what color each organization paints their snow plows.

The survey responses showed that 90% of all snow plows are painted white, school bus yellow, Omaha orange and a red/orange blend (from 1 state).

In terms of vehicle conspicuity, statistically data indicates that white cars are involved in fewer accidents. Furthermore, red cars are known to appear black at night, and fluorescent green is the most visible color. The same statistical data is inconclusive on whether yellow or orange is more visible. In short, there is inconclusive data to suggest an optimal color. In general, some conclusions are that brighter lighting is not always better and blue lights conflict with state legislation (often reserved for law reinforcement).

The research has indicated that the use of conspicuity tape may be more important that vehicle color. For example, the Nevada DOT has shown that the chevron pattern on the back of their street sweeper vehicles has been shown to reduce rear end collisions. Many organizations are beginning to equip their snow plows with lighting. Michigan and Ohio are beginning to use flashing green lights to increase conspicuity of their snow plows.

The American Association of State Highway and Transportation Officials (AASHTO) has a website (http://sicop.transportation.org/Pages/About-SICOP.aspx) for their Snow and Ice COPerative program (SICOP). In this website there is an Ontario report that describes the best practice for conspicuity lighting for snow and ice maintenance vehicles.

CONCLUSIONS

The workshop was successful in bringing together some key state DOTs and other organizations who have experience with the implementation of AVL technology in winter maintenance in order to participate and provide presentations. The gathering and presentations followed by question and answer sessions provided a forum for peer exchange among the participants, which led to the identification of best practices and the areas where the most benefits have been gained in use of AVL technology in winter maintenance. The peer exchange workshop provided data and information that addressed the following six research questions:

1. What are the experiences of other state DOTs and transit organizations in using AVL technology in winter maintenance?
2. What are some of the benefits and challenges in using this technology?
3. What are the common equipment or devices, material, and vendors that offer reliable AVL technologies?
4. What are some of the best practices in using AVL technology in winter maintenance operations?
5. What are some of the shortcomings of commercially available systems and services in this area?
6. What are some of the workflow and implementation issues?

This data is contained in the individual presentations, whose summaries are included in the previous section of this report.

What was not directly addressed at the workshop was the research question on the impact of AVL implementation on improving the sustainability of winter maintenance programs. What was addressed instead was an identification of what can be considered a set of ideal characteristics for a future implementation of AVL technology in winter maintenance.

Key conclusions of the workshop can be summarized as follows:

1. AVL technology is in a mature state for implementation for winter maintenance, with many state DOTs already having some form of implementation.

2. In AVL technology implementation a one-size-fits-all approach does not work, and the business and strategic needs of the organization should drive the process. A desired level of service should be established for each phase of the implementation based on business needs. Appropriate resources should be deployed to meet the desired level of service. Understanding the true business needs of the AVL technology can be critical in determining the steps required for any new implementation.

3. Successful implementation of AVL technology requires buy-in at all levels of the transportation organization. Planning and training for AVL technology implementation needs to be worked out from both the bottom up as well as the top down levels in the organization. In addition, the leadership for the field operation and the field personnel need to understand and support AVL implementation.

4. Starting with a pilot study is recommended before full implementation of AVL technology. This can reduce the risk, identify issues, and produce the best final results. Successful AVL technology implementation involves trial-and-error, and using a pilot study can facilitate the trail-and-error process.

5. AVL technology can be implemented at different levels in terms of the type of data collected, data analysis, storage requirements, and the sharing and communication of the information. A solution should be selected that best fits the needs of the organization. The limitations of the solution selected should be understood before its adoption.

6. Any implementation plans should consider continuous changes in new technology and supply chain or vendors and be able to update and adapt to such changes.

The workshop identified some of the specific characteristics of best practices in AVL technology implementations for the winter maintenance. These characteristics include:

1. Using a public facing website to share information on status of winter maintenance operations.

2. Using cameras and sharing photos (taken by snow plows in operation) of the winter conditions with the public through a public facing website.

3. Providing the ability to communicate information to the driver and allow the driver to have a forecast and material recommendation while dealing with changing weather patterns.

4. Utilizing the data collected through AVL technology to improve efficiency, reduce cost, or to integrate with an MDSS for further analysis.

5. Performing post-storm analysis to improve operations.

6. Developing sensor calibration processes and procedures to make sure that data collected and communicated is accurate and data flow is consistent without any unforeseen dropouts of the data.

An ideal future implementation of AVL technology for winter maintenance should have some of the following characteristics:

1. It will capture AVL data at regular intervals and transmit it to a server with only a short period of on-board storage, or preferably, in real time.

2. Integrates AVL data with relevant real time data from various sources including weather and traffic data by road segment for the winter maintenance vehicle.

3. Uses the integrated data (either offline or in real time) on a periodic basis for performance analysis in terms of safety and mobility as well as in terms of level of service and operational cost.

4. It geo-references and displays the winter operations on a map on a public facing website. Such displays are also used for monitoring the winter operations by the maintenance team.

5. Uses redundant systems for materials' usage estimation and checking, such as having on-board truck scales.

6. Uses a two-way communication between the operator and the dispatcher with information on weather, sensor, treatment information, equipment problems, and roadway grip or friction.

7. Provides a two-way situational awareness for the purpose of broadcasting the weather and the road conditions to the public during storms to improve safety and mobility.

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