SCAN TEAM REPORT

NCHRP Project 20-68A, Scan 07-03

Best Practices in Winter Maintenance

Supported by the

National Cooperative Highway Research Program

The information contained in this report was prepared as part of NCHRP Project 20-68A U.S. Domestic Scan, National Cooperative Highway Research Program.

SPECIAL NOTE: This report **IS NOT** an official publication of the National Cooperative Highway Research Program, Transportation Research Board, National Research Council, or The National Academies.

Acknowledgment

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The purpose of each scan and of Project 20-68A as a whole is to accelerate beneficial innovation by facilitating information sharing and technology exchange among the states and other transportation agencies, and identifying actionable items of common interest. Experience has shown that personal contact with new ideas and their application is a particularly valuable means for such sharing and exchange. A scan entails peer-to-peer discussions between practitioners who have implemented new practices and others who are able to disseminate knowledge of these new practices and their possible benefits to a broad audience of other users. Each scan addresses a single technical topic selected by AASHTO and the NCHRP 20-68A Project Panel. Further information on the NCHRP 20-68A U.S. Domestic Scan program is available at
http://144.171.11.40/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=1570.

This report was prepared by the scan team for Scan 07-03, Best Practices in Winter Maintenance, whose members are listed below. Scan planning and logistics are managed by Arora and Associates, P. C.; Harry Capers is the Principal Investigator. NCHRP Project 20-68A is guided by a technical project panel and managed by Andrew C. Lemer, Ph.D., NCHRP Senior Program Officer.

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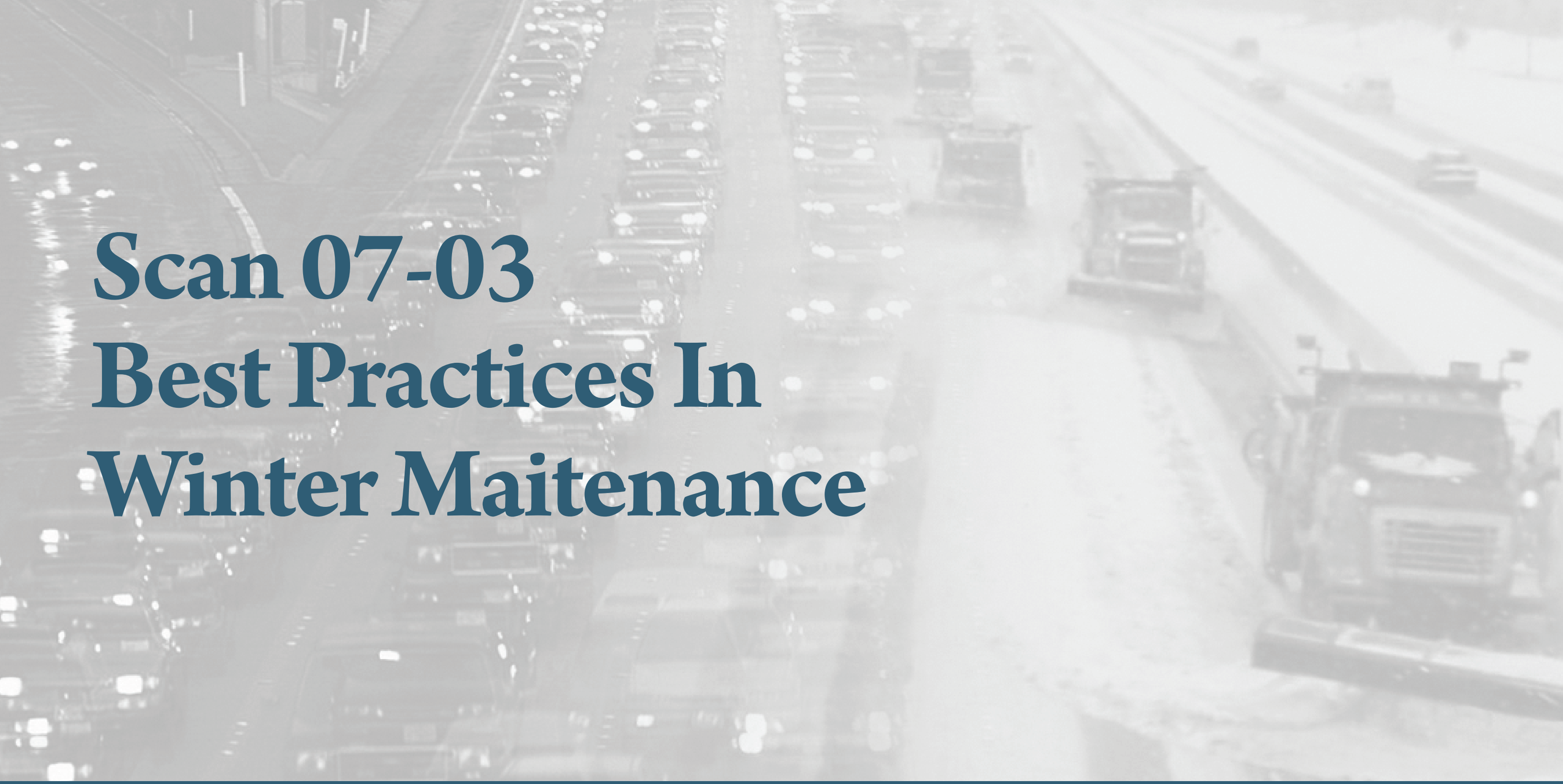
Disclaimer

The information in this document was taken directly from the submission of the authors. The opinions and conclusions expressed or implied are those of the scan team and are not necessarily those of the Transportation Research Board or its sponsoring agencies. This report has not been reviewed by and is not a report of the Transportation Research Board or the National Research Council.



Scan 07-03 Best Practices In Winter Maitenance

REQUESTED BY THE

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Table of Contents

List of Tables

List of Figures

Abbreviations and Acronyms

AASHTO	American Association of State Highway and Transportation Officials
APWA	American Public Works Association
ARMER	Allied Radio Matrix for Emergency Response
ASOS	Automated Surface Observing System
AVL	Automatic Vehicle Location
AWOS	Automated Weather Observing System
CBT	Computer-Based Training
CDL	Commercial Driver's License
CDOT	Colorado Department of Transportation
COTRIP	CDOT Web Site
CTMC	Colorado DOT Traffic Management Center
CTMS	Colorado Traffic Management System
DOT	Department of Transportation
E-470 PHA	E-470 Public Highway Authority (toll highway)
FAST	Fixed Automatic Spray Technology
FHWA	Federal Highway Administration
GIS	Geographic Information System
GPS	Global Positioning System
HAR	Highway Advisory Radio
HID	High-Intensity Discharge
INDOT	Indiana Department of Transportation
ITS	Intelligent Transportation Systems
LTAP	Local Technology Transfer Program
LOS	Level of Service
MDSS	Maintenance Decision Support Systems
Mn/DOT	Minnesota Department of Transportation
MORE	Maintenance Operations Research Engineering
NACE	National Association of County Engineers
NDOT	Nevada Department of Transportation
NCHRP	National Cooperative Highway Research Program
NWS	National Weather Service
ODOT	Ohio Department of Transportation

PHA	Public Highway Authority
PIARC	Permanent International Association of Road Congresses
PennDOT	Pennsylvania Department of Transportation
PNS	Pacific Northwest Snowfighters
ROI	Return on Investment
RWIS	Road Weather Information System
S&I	Salt and Ice
SICOP	Snow and Ice Cooperative Program
SHRP	Strategic Highway Research Program
SIRWEC	Standing International Road Weather Commission
SME	Subject Matter Expert
SOP	Standard Operating Procedures
TMC[1]	Traffic Management Center
TOC[2]	Traffic Operations Center
TRB	Transportation Research Board
UDOT	Utah Department of Transportation
USDOT	United States Department of Transportation
VDOT	Virginia Department of Transportation
WMTSP	Winter Maintenance Technical Service Program

[1] For the purposes of this report, the abbreviations TMC and TOC are use interchangeably. In practice, Mn/DOT and CDOT refer to their facilities as TMCs and UDOT and VDOT use TOC.

[2] See footnote 1

Executive Summary

Overview

The purpose of the Winter Maintenance Scanning Tour was to seek out and observe the progress that state and local highway agencies are making in advancing today's technology in the area of winter roadway maintenance. While this was the first tour in the United States, it was tailored after three previous scanning tours that had been conducted in European and Asian countries in 1994, 1998, and 2002. Much of what had been learned from these earlier international scans had become a new benchmark to several U.S. counterparts, inspiring them to pursue similar advances.

NCHRP 20-68A, U.S. Domestic Scan Program, was developed under the auspices of American Association of State Highway and Transportation Officials (AASHTO), Federal Highway Administration (FHWA), and NCHRP to assess the state of the practice of a variety of transportation subject areas in the U.S. and to evaluate the extent to which the international scanning tours had an impact on domestic operations. One of the tours included in this program is Scan 07-03, *Best Practices in Winter Maintenance.*

The Winter Maintenance Scan was conducted from March 25 to April 7, 2009, by a team that consisted of:

- William Hoffman, AASHTO Co-Chair, Nevada Department of Transportation (NDOT)
- Ben McKeever, FHWA Co-Chair, United States Department of Transportation (USDOT)
- Steven Lund, Minnesota Department of Transportation (Mn/DOT)
- Terry Nye, Pennsylvania Department of Transportation (PennDOT)
- David Ray, Ohio Department of Transportation (ODOT)
- Mike Schwartz, Virginia Department of Transportation (VDOT)
- Rodney A. Pletan, Subject Matter Expert (SME) Principal Author

Also traveling with the team was Armando Perez, American Trade Initiatives, who arranged for and coordinated all logistics relative to the tour.

Early in the process, the scanning team met and decided which locations to visit, primarily based on a desk scan prepared by the SME in October 2008. The following locations were selected and are listed in the order that they were visited:

- Minnesota Department of Transportation (Mn/DOT)
- Colorado Department of Transportation (CDOT)
    - City of Denver
    - City of Fort Collins
    - City of Grand Junction
    - E-470 Public Highway Authority (PHA) (toll highway)
    - Eisenhower/Johnson Memorial Tunnels
    - Hanging Lake Tunnel Operations Centers

- Utah Department of Transportation (UDOT)
- Indiana Department of Transportation (INDOT)
- Virginia Department of Transportation (VDOT)

To help the host locations prepare for the visits, the scanning team provided a list of topical areas it wanted to focus on, together with a listing of amplifying questions. The focus areas were:

- Maintenance Decision Support Systems (MDSSs)
- Automatic Vehicle Location (AVL) Systems
- Equipment Technologies
- Training and Development
- Management Issues
- Integration of Weather, Traffic, and Maintenance Operations

Summary of Initial Findings

While the objective of the scanning tour was to seek out and observe best practices, once the tour limited itself to a specific number of sites to visit, it is probably not completely correct to assume that "the best of what was seen" is the same as "the best there is." The desk scan did not identify every best practice that exists because the scan was only conducted from the desk and thus was limited to the phone calls and information gathered from the desk.

Nonetheless, this scanning tour did see a lot of the best, and it can report on the best of what was seen. So, for the purposes of this report, "findings" and "best practices" are often used synonymously to mean that the scan team found them to be the best that was seen compared to what was seen at the other places visited.

Initial findings of the Winter Maintenance Scanning Tour are listed below by topical areas.

Maintenance Decision Support Systems

- Data are being communicated successfully between the snowplow truck, the dispatch center, the MDSS provider (which generates treatment recommendations and the site-specific weather/pavement forecasts), and others.
- A multitude of data elements are being exchanged before, during, and after winter events including, for example, truck location and movement characteristics, current road conditions, and chemical application rates.
- New MDSS applications are being pursued during the summer (e.g., chip seals, paving, grass mowing, weed spraying, lane striping, and roadside assistance).
- Some agencies are beginning to identify cost benefits, with potential savings from, for example, saving chemicals, adjusting the number/length of shift deployments, and force accountability.
- Management is successfully using various marketing and implementation strategies to implement change.
- MDSS could be used to establish, supplement, or replace the winter severity index.
- MDSS is having a positive impact on management and employee culture.

Automatic Vehicle Location (AVL) Systems

- A variety of vendors is involved with AVL and AVL-related systems, like MDSS.
- It is being used for multiple purposes, from route reporting to resource consumption to incident response.
- Its potential value is dependent on how the resolutions are used. Low resolution (> 5 minute intervals) meets some real-time decision-making needs; however, high resolution (< 30 second intervals) is required if an agency wishes to automate data-collection systems that will generate time sheets and work-accomplishment reports.
- Its benefits to both management and operators are becoming more universally understood.

Equipment-Related Technologies and Facilities

- **Plows and wings:** Agencies are trying out wider plows on the front and dual wings on the sides; underbody plows are becoming more common. The scan team saw power brooms on the front of a tandem snowplow truck. Other tandems are pulling tow-plows, allowing a full two lanes per pass. Hydraulic-assist engineering is being used to reduce plow weight on the blade when conditions warrant, reducing cutting edge wear and extending life up to two winter seasons.
- **Plow cutting edges (plow blades):** Composite carbide and rubber blades are getting good reviews. Multiple-blade configurations, including triple blade setups (carbide, serrated, and rubber slush blade combinations) are being tried.
- **Saddle tanks** containing liquids for prewetting solids are being designed and integrated into dump boxes and beds on both tailgate and V-box spreader trucks, leading to better weight distribution and higher carrying capacity and allowing for longer route coverage during prewetting operations at the agency's optimized application rate. Prewetting application rates vary; for example, CDOT applies 4 to 12 gallons/ton.
- **Chemical and sand spreaders:** The zero-velocity solid-chemical spreader concept is continuing to be pursued. Slurry augers are being used so that chemicals in slurry form can be distributed. Large tankers (5,000 gallons) are being used as anti-icing spreaders preceding storms as well as to resupply liquid storage stations between storms. Off-season rental water tank trucks are used as anti-icing units.
- **Equipment accessories:** Several innovative accessories were noted during the tour., like:
    - Video cameras on plow trucks to provide front, side, and rear views from the cab
    - Wiper blade vibrators to reduce ice buildup
    - Air blowers to keep side mirrors clear of snow
    - High-intensity discharge (HID) headlights to provide three times the light and 10 times the life of other lights
    - Simple home-made "fog busters" to lift fog above the driver's line of sight
    - Laser beam guides to tell the operator how far out the wing or tow-plow is
    - Collision-avoidance systems to provide protection during white-out conditions
- **Fixed automatic spray technology (FAST):** These systems have developed and are proven to the point that they are no longer experimental.
- **Equipment funding mechanisms:** Equipment replacement purchases are funded by a variety of mechanisms, including annual appropriation from legislature or council, revolving accounts (where user units pay rent to owning units), and escrow accounts (where agencies put money every year for every unit so that they are fully funded when replacements are due).

- **Road Weather Information System (RWIS):** Advancements in RWIS include new low-cost portable units, solar- and wind-powered units, stations that include remote-controlled cameras providing streaming video, and noninvasive sensors to replace pucks embedded in the pavement.
- **Friction measurement systems:** These systems, which measure winter performance, continue to be developed both domestically and internationally.
- **Chemical storage:** Progressive and environmentally sensitive agencies store all solid chemicals under roof year-round with have space in the same building for loading trucks.
- **Brine making:** Brine manufacturing, commonly done in house and sometimes housed in the same building as solid salt, has become automated and controlled. Some agencies dispense brine using fuel-management systems to permit easy sales to other local agencies and to keep track of the amounts loaded onto individual trucks.
- **Truck washing:** Some washing facilities now use sediment traps and reuse their wash water. Contaminated water at equipment and chemical storage sites (e.g., water contaminated by truck washing and runoff from stockpile sites and loading areas) is now being collected both to protect the environment and to make brine.

Training and Development

- Government downsizing is leading agencies to set up flexible workforces, with a generic transportation worker classification replacing separate construction and maintenance classifications at the time of hire. Other agencies are cross-training nonmaintenance employees to operate snow and ice equipment during winter storms or to otherwise supplement/support the winter maintenance effort. In both scenarios, these changes are causing both challenges and opportunities for training and retraining workers for winter emergencies.
- Several agencies are setting up training programs using simulators, training academies, symposiums, and other methods (e.g., MP3-based training) to incorporate internally and externally developed training programs like the AASHTO computer-based training (CBT) program.

Management Issues

- Special funding for maintenance operations research and development is being promoted, more in some agencies than in others.
- Culture and management/employee relations are especially important during times of change.
- Outsourced and in-house work need to be managed the same, yet are often managed differently.
- Measuring winter maintenance performance is best done at the outcome level.
- Customers measure government by the consistency or inconsistency of levels of service (LOS) between winter plow routes, across internal organizational lines, and even across jurisdictional boundaries.
- Internal and external communications are important to the success of winter service providers.
- During winter events, one agency provides designated drop zones so that stalled and stranded vehicles can be moved off the highway.

Integration of Weather, Traffic, and Maintenance Operations

- Traffic Operations Centers (TOCs[3]) are being designed and organized to physically integrate representatives of several disciplines during winter and other emergency/incident-management type events. Example personnel already incorporated on-premises in one or more TOCs are:

  - Meteorologist
  - Maintenance Operations Dispatcher
  - 511 Coordinator
  - Highway Patrol Dispatcher
  - Courtesy Patrol Dispatcher
  - Snow and Ice Operations Coordinator
  - Traffic Signal Control Coordinator
  - FM Radio Announcer

- Some of the above integration is full-time, year-round, and other integration is only during incidents, including winter events.
- When an agency has a full-time meteorologist, that position manages a private (i.e., under contract) meteorology team that does the actual forecasting from space provided in the TOC. The staff meteorologist teams with the agency's Maintenance Operations to best utilize the forecasts.
- The key benefit of having up-to-date weather forecasting and road conditions in the TOC is that it allows for more timely updates to 511, Web sites, and other sources of information to which the public has access.
- Some agencies have converted to statewide 800 MHz for all emergency services, including Maintenance Operations. Mn/DOT's voice-over Allied Radio Matrix for Emergency Response (ARMER) system was extremely valuable during the Minneapolis 35W collapse.
- Traffic signal timing on key corridors is adjusted in response to winter events.

Recommendations and Conclusions

Based on the above-listed findings, the preliminary general recommendations of the scanning team are as follows:

Maintenance Decision Support Systems

- MDSS has proven that it adds effectiveness and efficiency to winter operations. Its return on investment (ROI) will greatly increase as it is applied to summer activities as well.
- To be successful and able to implement MDSS expediently, some marketing and implementation strategies have been tried and proven more effective than others, like those that involve top-down direction and support and those that achieve high employee buy-in.

Automatic Vehicle Location (AVL) Systems

- AVL systems have multiple uses, many of which are beneficial to employees and operations, and their use is expected to be universally expanded into maintenance operations. The higher the resolution (i.e., the frequency at which readings are recorded), the higher the cost; however, the lower the resolution, the lower its potential value.

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[3] For the purposes of this report, the abbreviations TMC and TOC are used interchangeably. In practice, Mn/DOT and CDOT refer to their facilities as TMCs and UDOT and VDOT use TOC.

Equipment Technologies

- Indications are that tow-plows have great potential in many areas. They can be operated with a single driver and crashes have not been a problem. Tow-plows do, however, require that trucks meeting certain minimum specifications pull them; these trucks are probably not available in existing winter maintenance fleets.
- Hydraulic assist has the potential to extend the life of some cutting edges (i.e., plow blades) up to two years.
- The carbide blade with a rubber insert is well liked and shows promise nationwide.
- Poly (plastic) plow blades should be considered for use in certain environments.
- Video cameras can expand a snowplow truck operator's range of view and should be considered for use as safety enhancers.
- Laser beams that extend to the front of the snowplow truck, showing the operator how far out the wing or tow-plow is, are economical and most probably cost effective.
- Though research was limited, vibrating wiper blades show promise.
- Fog busters, HID headlights, and other technologies that enhance operator visibility (i.e., both the ability to see and to be seen) should always be pursued and used once they are proven successful.
- Agencies should do whatever is necessary to:
    - Prevent the formation of salt brine at stockpile sites
    - Collect any brine formed from runoff or truck washing at storage sites (Sediment traps permit salt brine runoff to be reused or recycled.)

Training and Development

- Flexible workforces should be considered as demand for services continues to rise and government continues to downsize.
- Cross-training can be successful in supplementing snowplow operators.
- Generic and customized state-of-the-art training programs are available for use at training academies or symposiums. Real-life simulators, coupled with classroom lectures and computer-based training programs (e.g., AASHTO CBT), can be used for both initial and retraining purposes.

Management Issues

- Inter-jurisdictional relationships are important for promoting consistent LOS between otherwise invisible governmental boundaries.
- More work needs to be done to develop improved, outcome-based, customer-oriented performance measurements (e.g., regain time, friction measurement, speed monitoring, and road closure frequency/duration). These measurements should be implemented, applied, and reported to better manage both in-house and outsourced winter maintenance services.
- More winter maintenance agencies should copy models of dedicated and recurring funding for operational maintenance research funding. Successful models lead to grassroots ownership, thus creating a continuous improvement culture and improved relationships between employees and management.

Integration of Weather, Traffic, and Maintenance Operations

- ❖ Integrating traffic operations, weather forecasting, maintenance operations, highway patrol, media, and incident management into TOCs is proving to be a best practice.
- ❖ Better approaches are emerging for conveying real-time information (i.e., traffic and surface conditions and weather forecasting) to the traveling public using 511, Web sites, e-mail alerts, text messaging, and other methods.
- ❖ Implementing special signal timing plans during winter events has the potential to improve traffic flow for both the traveling public and the snowplow operators.

Overall conclusions from the scanning tour are as follows:

- ❖ MDSS has proven itself as an effective winter maintenance tool and was shown to improve operational efficiency through resource savings. Implementing MDSS is not easy, and it requires the agency to make deliberate financial and cultural commitments. Agencies that decide to implement MDSS should have their top staff openly declare their full support of the effort and develop specific implementation strategies that foster support and understanding at all maintenance staffing levels.
- ❖ Attitudes toward AVL systems have changed from resistance to "big brother is watching" to an appreciation that they provide an advantage to both management and workers. AVL increases the ability of operational managers and dispatchers to better adjust operations during a winter event, thus reducing the number of decisions that operators have to make on their own. AVL allows operators to focus instead on driving their vehicles safely in heavy traffic during the toughest conditions that exist. Tough economic times have pushed winter service agencies away from having all snowfighters be experienced professionals to situations where plow operators are generalists or shared workers who are often used only intermittently. In some cases, drivers and trucks are being provided by the private sector. AVL technology can help agencies bridge the gaps created by these new challenges. Using AVL to automate labor, material, material usage, and work-accomplishment recording is a further benefit to both workers and management.
- ❖ Considerable development and enhancement of existing technology have improved the performance, efficiency, and durability of ice- and snow-fighting equipment. Cost-effective means of increasing productivity and reducing equipment downtime, while at the same time extending equipment service life with innovative wash facilities, are common themes in the organizations the team visited. Advancements have been made in plow blade technology and configuration, winter chemical manufacturing and, chemical application systems. Almost all winter service organizations can relate to the successful, cost-effective innovations cited within the findings of this report to improve their own operations. The next step will be to provide funding to test and incorporate new technologies appropriately into current operations.
- ❖ As the pressure for governmental agencies to downsize continues, they need to seek out and study the models of flexible workforces and cross-training. The challenge of maintaining a trained workforce is magnified by the need to capitalize on new methods and new technology, all requiring enhanced training and retraining. The worst-case scenario for training is where winter maintenance is outsourced and, at least initially, core competencies differ even more, at least to the extent that their attitude toward public service may need to be nurtured. As a result, today's agencies need to emphasize training and development; benchmarking based on proven lesson plans and techniques is one way to minimize cost and, at the same time, expedite curriculum development.
- ❖ Customers continue to have high expectations, but their trust in and support of government-provided services is eroding. Their willingness to pay has deteriorated as government fails to measure itself from the

same point of view as the customer. Customers expect seamless LOS from route to route, from district to district, and even from city to city. In-house crews seek new ways to be efficient while political pressure suggests that the private sector can produce work more effectively, irrespective of cost. Managers need to develop performance levels that are measurable and correlate with customer expectations. Furthermore, government managers need to align their cost system so that it can correlate and be compared with the private sector system with enough accuracy to select which activities, if any, are most susceptible to being outsourced.

- TOCs can and should serve as the hub from which all existing and emerging road weather management advisory, control, and treatment strategies and technologies are dispatched.
  - Advisory – 511, Web sites, and e-mail alerts
  - Control – special signal timing and changeable message boards
  - Treatment – maintenance operation and incident management

This will improve the daily operations and decision-making capabilities of transportation agencies. Integrating maintenance operations, professional weather forecasting, incident response, and enforcement into the TOC during winter emergencies has great potential to prevent gridlock and reduce the number of crashes, enhancing the safe mobility of the traveling public.

Planned Implementation Actions

The winter maintenance community provides many conduits for disseminating the findings and recommendations of this scanning tour, including, but not limited to, the following:

Short Term

- Presentations at scheduled conferences (most scheduled at least annually)
  - Permanent International Association of Road Congresses (PIARC) World Road Association Winter Road Congress (2010, Quebec City)
  - Transportation Research Board (TRB) Annual Meeting
  - TRB Winter Maintenance Committee
  - TRB Committee on Surface Transportation Weather
  - TRB Snow and Ice Symposium (2012)
  - AASHTO Subcommittee on Maintenance
  - Pacific Northwest Snowfighters (PNS) Association
  - American Public Works Association (APWA) (Winter Maintenance Committee)
  - National Association of County Engineers (NACE)
  - AASHTO Eastern Snow Expo
  - APWA National Congress (September 2009, Columbus, OH)
- Presentations to pooled fund organizations
  - Snow and Ice Cooperative Program (SICOP) Winter Maintenance Technical Service Program (WMTSP)

  - Clear Roads
  - Aurora
  - Clarus Initiative
  - PNS
- Other meetings
  - National Winter Maintenance Peer Exchange
  - MDSS Showcase
- Webinar

Medium Term

- Identify potential projects with pooled fund organizations
- Coordinate activities with Lee Smithson, SICOP Coordinator
- Promote more MDSS-type showcases
- Establish a Winter Maintenance Best Practices Web site to post final report and presentations, plus add new best practices as they are identified

Longer Term

- Assist in developing Problem Statements for NCHRP
- Identify funding source for covering travel and other expenses for the above activities
  - NCHRP 20-68A
  - One or more already-in-place pooled funds
  - FHWA

CHAPTER 1

Introduction

Background

As recently as 50 years ago, some highway maintenance superintendents in snow-country U.S. still dispatched their most sophisticated operators in poorly heated trucks and motor graders with a simple V-plow on the front (see Figure 1-1). The operators often had only their own intuition to let them know that they were still on the roadway and not heading for a ditch. If they did get stuck, they often had to depend on faith alone that someone would eventually come out and find them. Back in the higher traffic urban areas, their colleagues were standing up in the box of a truck, hand-shoveling sand onto the slippery street below (see Figure 1-2).

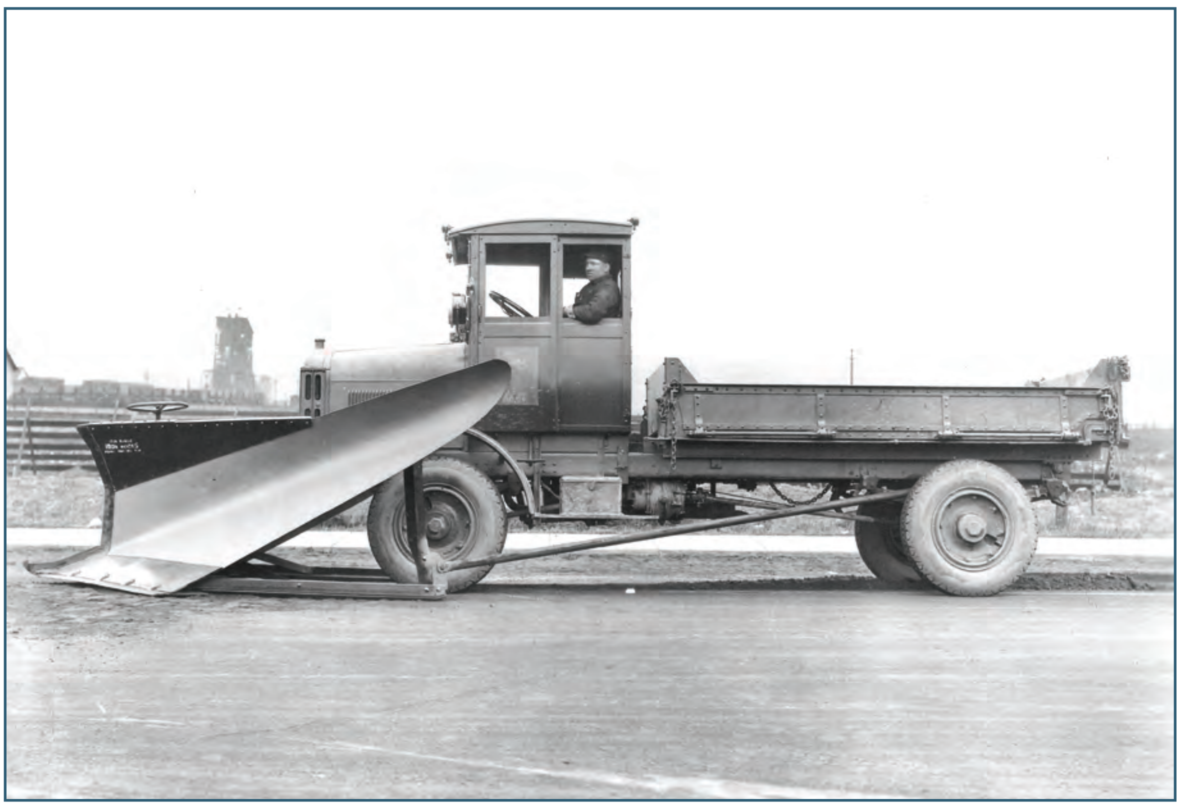

Figure 1.1 *Snowplow truck with V-plow, circa 1929 (Mn/DOT)*

Figure 1-2. *Here is an old photo of the original style of spreading sand or cinders on the Pennsylvania Turnpike in the early 1940s. (PennDOT)*

In April 2009, our scanning team completed a 14-day tour to five different states. In sharp contrast to the images shown here, the team members sat in the cabs of modern snow-control trucks that have so much electronic gear (i.e., gadgets, screens, cameras, and buttons) that there is only room for just a single operator (see Figure 1-3). The team visited dispatching centers with high walls covered with multiple screens showing roadway conditions received in real time from cameras relaying the same images that the snowfighters were seeing from their cabs.

The team talked to dispatchers who, at any given time, know exactly where every truck is on the road network. Likewise, individual drivers know where fellow operators in their own proximity are located on the plow route. The team met on-site meteorologists who were updating weather forecasts for the snowfighters based on real-time information received both from stationary devices out on the network and from the trucks' cabs. Chemical application rates were being adjusted according to conditions on the spot. The team observed plowing trucks, each operated by a single driver, clearing two traveling lanes at a time using a follow-behind tow-plow.

The team was shown a wide range of anti-icing and deicing chemicals that could be distributed in both liquid and solid form, separately or together. Solids were distributed at zero-ground speed to virtually eliminate bounce, and thus waste. The amount of chemical placed on the roadway, the roads covered, and even whether the plow is up or down were being automatically recorded instead of being written down by the driver or, worse yet, not being done at all.

In reviewing reports from the early European scanning tours, one striking difference is the variety of truck, plow, and sander designs available in other countries compared to the U.S. In the 1980s and earlier, it was quite common for U.S. DOTs to have a basic standardized snowplow truck, with almost all trucks having one of no more than two plow styles mounted on the chassis using a universal plow hitch with either a standard tailgate or a standard slide in V box spreader for sand or solid chemical. The biggest challenge that the user or buyer had was justifying a new truck with a tandem axle vs. a single axle.

Figure 1-3. *The modern snowplow truck is crammed with screens, keyboards, toggle switches, and other controls. (CDOT)*

Twenty years ago, U.S. agencies were probably inclined to blame the U.S. manufacturers for not offering options in their catalogs. The industry probably argued that the snowfighting agencies had never shown interest in buying anything new and different unless it cost less.

Nonetheless, this 2009 domestic scanning tour proves that U.S. agencies are much more progressive now than they were during the first international scanning tours and that suppliers and manufacturers servicing the U.S. markets are responding as well. Today, almost every truck is almost special ordered or is in some way different from those ordered the year before, either because of new options or new standards. New trucks even vary from district to district within a model year, depending on where each district is in respect to accepting new technologies. For example, plow vendors used to stop by the maintenance engineer with a single sheet of paper showing the few, if any, available options. Today, vendors have an entire catalog but still secretly hope that the engineer wants to order same thing as last year so that the vendor does not have to retool or custom build.

Objectives

The purpose of the Winter Maintenance Scanning Tour was to seek out and observe the progress that state and local highway agencies are making in advancing today's technology in the area of winter roadway maintenance. While this was the first tour in the United States, it was tailored after three previous scanning tours that had been conducted in European and Asian countries in 1994, 1998, and 2002. Much of what had been learned from these earlier international scans had become a new benchmark to several U.S. counterparts, inspiring them to pursue similar advances.

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Team Membership

Representation on the Winter Maintenance Scanning Team included one member selected by FHWA and five members selected by AASHTO. The FHWA member and one AASHTO member were co-chairs. The team (see Figure 1-4) during the actual tour consisted of:

Figure 1-4. *Scanning Team members*

Pictured, left to right:

- Steven Lund, Minnesota DOT
- Ben McKeever, USDOT, FHWA Co-Chair
- William Hoffman, Nevada DOT, AASHTO Co-Chair
- David Ray, Ohio DOT
- Mike Schwartz, Virginia DOT
- Terry Nye, Pennsylvania DOT
- Rodney A. Pletan, Subject Matter Expert (SME) Principal Author

During the project's pretravel phase, the team's composition changed from time to time because of the conflicting work schedules of some of the earlier AASHTO appointees. Other contributing team members included Rick Nelson (Nevada DOT), Dennis Burkheimer (Iowa DOT), Rob Grazioso (VDOT), and Steve Buston (VDOT).

Amanda Perez (American Trade Initiatives, Inc.) traveled with the team as the Scan Coordinator, who arranged for and coordinated all logistics relative to the tour.

John Almborg (American Trade Initiatives, Inc.), Harry Capers, and Melissa Jiang (both with Arora and Associates, P.C.) were not with the traveling team but provided pre- and post-travel oversight and direction.

Topical Areas

In August 2008, the scanning team developed a list of six topical areas that it wanted to focus on, beginning with the desk scan and continuing on through the tour itself and report writing:

- Maintenance Decision Support Systems (MDSS)
- Automatic Vehicle Location (AVL) Systems
- Equipment Technologies
- Training and Development
- Management Issues
- Integration of Weather, Traffic, and Maintenance Operations

Amplifying Questions

For each topical area, the team carefully developed a list of amplifying questions (see Table 1-1) that described in more detail the specific areas the team wanted included in the desk scan. These amplifying questions also served as a guide for the host agencies to prepare their presentations to the team during the actual scanning tour.

MDSS	❖ Does your agency use a maintenance decision support system (MDSS)? o If so, who is your provider? o If so, do you use the recommended treatments provided by the system or has the MDSS model been altered to follow the state's normal practices? ❖ Has your agency done any cost/benefit analyses on MDSS? If so, can you share them with us? ❖ What are you anticipating as left to do in the future to get to full deployment? ❖ Does your agency use MDSS during the nonwinter months? If so, what activities does MDSS support (e.g., pavement treatments, mowing, lane striping, vegetation control, etc.)? ❖ What are the ongoing obstacles or barriers to a successful MDSS deployment, if any? ❖ Which aspects of MDSS do you think need to be improved and why?
AVL/GPS	❖ Does your agency use AVL/GPS technology to support maintenance activities? If so, who is your provider? ❖ What data elements are being communicated between the vehicle and the center (e.g., pavement temperature, plow position, application rates, etc.)? ❖ How do you address multiple data formats and vendors, if applicable? ❖ What communication technologies does your AVL system use? ❖ How is this technology utilized at each of these levels: local, regional, and central? ❖ In implementing an AVL system, were there any labor or workforce issues to overcome? If so, how did you overcome them? ❖ Has your agency done any cost/benefit analyses on AVL/GPS? If so, can you share them with us?
Equipment Technology	❖ How have you integrated the use of liquids into your operations for both prewetting and anti-icing operations? ❖ What plow blade configurations are you using to optimize plowing efficiencies? ❖ What equipment and control systems are you using to optimize material application? ❖ Can you show examples of your anti-icing and prewetting systems? ❖ Are you using any components in the cab to improve human-factor conditions for the operator? ❖ What is your decision-making process for the selection of equipment configuration and individual component decisions? ❖ Has your agency done any cost/benefit analyses on equipment purchases referred to above? If so, can you share them with us?

Workforce Training and Development	❖ Describe any specialized training programs you have for winter operations. ❖ How does this training differ between full-time and temporary employees and different levels of responsibility and/or classifications? ❖ AASHTO recently developed and released a set of six winter computer-based training programs. How have you incorporated these modules into your training efforts? ❖ Does your organization utilize succession planning in preparation to fill rank-and-file, supervisory, and managerial positions?
Management Issues	❖ What do you measure and how do you measure the performance of your winter maintenance program (both statewide and at the local level)? ❖ How are employee and contractor performance measured? ❖ What experiences have you had in outsourcing (private or public) winter maintenance activities and have these been positive or negative? ❖ Do you use a Winter Weather Index to analyze your winter program? If yes, please provide details on the Index. ❖ How do you address the need for consistency in levels of service across jurisdictional or organizational boundaries? ❖ How have you modified operations to account for rising costs in fuel, salt, parts, and winter maintenance in general?
TMC/ Weather/511	❖ What functions does your Traffic Management Center (TMC[4]) provide as it relates to weather or winter maintenance? ❖ Does your TMC incorporate road weather information and winter maintenance into its operations? If so, how? ❖ How do TMC operators use road weather information to be proactive for their customers (e.g., retime signals, adjust ramp meters, disseminate information, etc.)? ❖ Is there a direct linkage between your road weather information and your TMC's traveler information tools (e.g., 511, Web sites, Highway Advisory Radio [HAR], dynamic message signs, media, etc.)? If so, is this linkage automated? ❖ Is the TMC staff trained to monitor weather forecasts and weather reporting stations such as RWIS or Automated Weather Observing System/Automated Surface Observing System (AWOS/ASOS)? If so, how? ❖ How do you coordinate weather-related information with other agencies (e.g., law enforcement, transit agencies, neighboring jurisdictions, etc.)?

Table 1-1. *Amplifying Questions*

[4] For the purposes of this report, the abbreviations TMC and TOC are used interchangeably. In practice, Mn/DOT and CDOT refer to their facilities as TMCs and UDOT and VDOT use TOC.

Desk Scan

During the pretravel process, the SME provided a desk scan that the team used to help determine the locations it would focus its time on during the tour itself. The desk scan is an office-based information-gathering report that supplements and further defines the selected topical areas. Defined objectives include:

- Further the efforts of the full scan team in acquiring information of value to the transportation community
- Increase the cost-effectiveness of the full scan by advising the team where best to commit its time during travel
- Help to refine the scope of the scan by identifying relevant sources of information around the agencies on the tour and narrowing the focus of the scan if it is determined to be too broad

The desk scan was produced as a written summary specifically designed and developed for internal use by the team itself and included following:

- Results of interviews with known U.S experts of the winter maintenance community to gather information as to what sites the scan should target
- A listing of literature and Web site sources for the latest reports of progressive advancements and accomplishments in winter maintenance management and operations
- A listing of individuals from government agencies and other organizations who were deemed most knowledgeable and advanced in this field
- Potential and recommended sites to visit

The SME's Desk Scan report was dated October 27, 2008.

Locations Visited and Scan Itinerary

Based on the desk scan report and other considerations, the scanning team met in October 2008 and identified the locations it would visit. Clearly, several good examples of state-of-the-art winter maintenance exist today in multiple locations. These sites are scattered among several state and local agencies throughout the snowbelt states. The team narrowed down the list to a workable number, choosing sites because they had several examples to observe at one time or because they were close to other good candidates. An effort was made to include examples of state, county, city, and toll-road operations. The following locations (see Figure 1-5) were selected and are listed in the order that they were visited:

- Minnesota DOT/Traffic Management Center (TMC)
- Colorado DOT/CTMC
    - City of Denver
    - City of Fort Collins
    - City of Grand Junction
    - E-470 Public Highway Authority (PHA) (toll highway)
    - Eisenhower/Johnson Memorial Tunnels
    - Hanging Lake Tunnel Centers
- Utah DOT/UTOC
- Indiana DOT
- Virginia DOT

Figure 1-5. *Locations the scanning team visited*

The Winter Maintenance Scan was conducted from March 25 to April 7, 2009. The tour itinerary is shown in Table 1-2.

Date	Location	Activities
Thursday, 26 March 2009	St. Paul, MN, Area	❖ Meeting in Mn/DOT Central Office, with presentations on organization, performance measures, best practices, training, research, etc. ❖ Meeting in Maplewood Truck Station with presentation/display on facility, equipment, chemical storage/blending, training simulator, etc.
Friday, 27 March 2009	St. Paul, MN, Area	❖ Meeting in Metro District Office and TMC with presentations on TMC/maintenance dispatching coordination, MDSS/AVL/RWIS, etc. ❖ Field trip to 35W bridge's fixed automatic spray technology (FAST). ❖ Meeting in Central Shop, with presentation/display on equipment management, purchasing, and fabrication. ❖ Meeting in Cedar Avenue Truck Station with presentation/display on salt and ice (S&I) equipment, automated washing facility, chemical storage, etc.

Date	Location	Activities
Monday, 30 March 2009	Denver and Fort Collins, CO, Areas	❖ Meeting in CDOT TOC with tour and explanation of how it leverages MDSS into traveler information programs. ❖ Meeting and presentation by E-470 PHA. ❖ Meeting at CDOT SH52/I25 Truck Station to see facility, chemical storage, and trucks equipped with MDSS electronics. ❖ Site visit along SH119 to observe bridge anti-icing system (FAST) ❖ Meeting in City of Fort Collins with presentations on use of winter technologies and tour of chemical-storage and liquid-dispensing systems.
Tuesday, 31 March 2009	Denver and tunnels westerly along I-70, CO	❖ Meeting at City and County of Denver facility with presentations on organization, use of MDSS, cost benefits, plus display of S&I equipment. ❖ Tour of CDOT Eisenhower/Johnson Memorial Tunnels facility on I-70 and presentation of its tunnel management control center. ❖ Tour of the CDOT Hanging Lake Tunnel facility on I-70 and presentation of its tunnel management control center plus use of MDSS and FAST systems in Glenwood Canyon.
Wednesday, 1 April 2009	Grand Junction, CO	❖ Meeting at City of Grand Junction for presentation on its S&I plan, organization, training, storm classification system, etc.
Thursday, 2 April 2009	Salt Lake City, UT	❖ Meeting at UDOT TOC with tour and presentations on coordination of weather, traffic, and operations, including its adverse weather timing plans, mobile fog buster, and tow-plow experiences.
Friday, 3 April 2009	Indianapolis, IN, Area	❖ Meeting at IDOT Indianapolis Sub-District facility with presentation of its use of MDSS technologies, including data analysis and cost benefit. Demonstration of tow-plow. ❖ Meeting at Greensburg facility to observe chemical storage, brine making, and automated truck-washing facilities.
Monday, 6 April 2009	Richmond, VA, Area	❖ Meeting at VDOT Central Office for presentations on its TOCs and 511, winter equipment technologies, AVL, MDSS, workforce training, and management issues. ❖ Tour of a chemical storage and brine-making site, including on-site storage of auxiliary equipment provided to contractor truck.

Table 1-2. *Scan Itinerary*

In addition, team meetings were held during the tour on March 25, March 29, April 5, and April 7.

CHAPTER 2

Findings by Topical Area

Background

The host agencies were all very well prepared to receive the scanning team, all focusing on the topical areas and amplifying questions that had been sent out in advance. The meetings took on a variety of forms, including presentations, classroom discussions, field demonstrations, tours, and general discussions. What was most special for the team was the opportunity to meet face to face with the champions of change who were actually developing, implementing, and/or using the new technologies being presented.

Note that the title of this section is Findings by Topical Area. The tour's name uses the term best practices, and the terms state of the art and state of the practice were also used in preliminary and background articles referring to this scanning tour. So do all these terms mean the same thing? Are the findings all best practices? If something is referred to as the state of the practice or state of the art, does that mean the same thing as best practice? Doesn't best practice mean the best there is any place and every place? If something is deemed best in one situation, does it have to be best in other situations to be called a best practice?

While the objective of the scanning tour was to seek out and observe best practices, once the tour limited itself to a specific number of sites to visit, it is probably not completely accurate to assume that the best of what was seen was the best there is. The desk scan did not identify every best practice that exists because it was only conducted from the desk and was limited to the phone calls and information gathered from the desk.

Nonetheless, this scanning tour did see a lot of the best and it can report on the best of what was seen. So for the purposes of this report, findings and best practices are often used synonymously, meaning that they are findings that were found to be the best that was seen compared to what was seen at the other places visited. That may mean that the findings are the best there is; however, the scanning tour did not look at everything, everywhere.

Findings

Maintenance Decision Support Systems

Introduction

Ever since RWIS became part of winter maintenance management, the next challenge has been to correlate forecasts before the event with recommended roadway treatments (i.e., starting time and application rates). Subsequently, efforts were expanded to update forecasts based on real-time field observations during the event, leading to adjustments in treatments and/or efficient curtailing of those treatments. These efforts were the beginning of what is now known as MDSS.

Finding 1a

Data is successfully being communicated back and forth between the snowplow truck, the dispatch center, the MDSS provider (which generates treatment recommendations and the site-specific weather/pavement forecasts), and others.

Literature research during the desk scan revealed that at least 20 state DOTs, as well as a smattering of cities, counties, and toll-road authorities, have made some commitment to deploying MDSS in their organizations. This is not to say that all users are defining MDSS the same; some use the term even though they are using it only to communicate weather, while others are expanding their definition to include systems that are more sophisticated. In a sense, the definition of MDSS is a moving target.

Today MDSS most typically incorporates forecasts of weather (both atmospheric and road conditions) and treatment recommendations. These can be adjusted based on real-time information accumulated during the event. Typically, MDSS is aligned with graphic mapping using Automatic Vehicle Location (AVL) systems.

Indiana DOT defines MDSS as:

> *… a decision logic system that integrates current weather, maintenance, and road condition information with forecasted weather and road-surface conditions to evaluate and recommend treatment options. MDSS transforms huge volumes of weather and maintenance information into better decision support tools. Its objective is to provide guidance to achieve more effective use of maintenance resources.*

Finding 1b

During winter events, data elements include:

- **Before event**
  - **Pavement forecast**
  - **Treatment recommendations**
  - **Start time**
  - **Route assignment**
- **During event**
  - **Vehicle identifier**
  - **Time**
  - **Truck location**
  - **Direction of travel**
  - **Lane identifier**
  - **Material form (i.e., liquid, solid, dry, wet, or blend)**
  - **Material usage, application rates (i.e., gallons or tons)**
  - **Vehicle activity (i.e., plow up/plow down and spreader on/off)**
  - **Travel speeds**
  - **Video views of pavement and eye-level condition from cab**
  - **Current pavement and atmospheric temperature**
  - **Precipitation**
  - **Revised forecast**
  - **Revised treatment recommendations**
- **After event**
  - **Routes covered**
  - **Material usages**

During the tour, the scanning team found that INDOT deployed MDSS statewide in the fall of 2008, equipping 172 plow routes (10% of all routes), with every maintenance unit having at least one route on MDSS. Somewhat in contrast, Mn/DOT initially began with only six units, focusing the deployment of MDSS mostly in one geographical district where there was a champion. Minnesota has recently expanded its program into every other district, with 22% of its routes (200 of 900) statewide on MDSS. Minnesota DOT is following an approved AVL/MDSS project business plan designed to fully deploy MDSS in the department over time. CDOT has been adding routes to its MDSS coverage since the 2004-2005 winter season and currently has routes covered in every region.

Figure 2-1 and Figure 2-2 show sample weather forecast information depicted on truck operator and dispatcher screens, respectively.

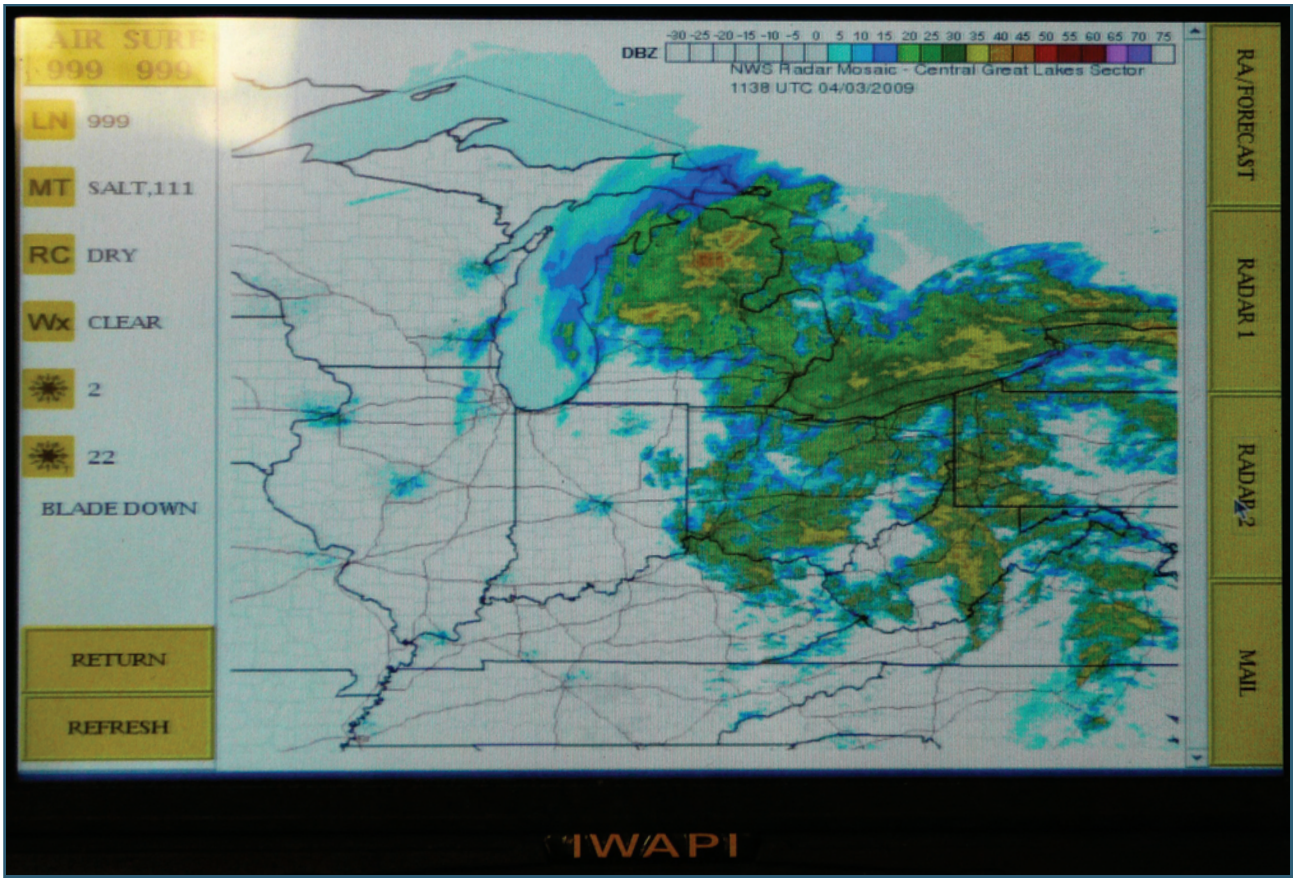

Figure 2-1. *The operator has access to screens providing weather and pavement forecasts. (INDOT)*

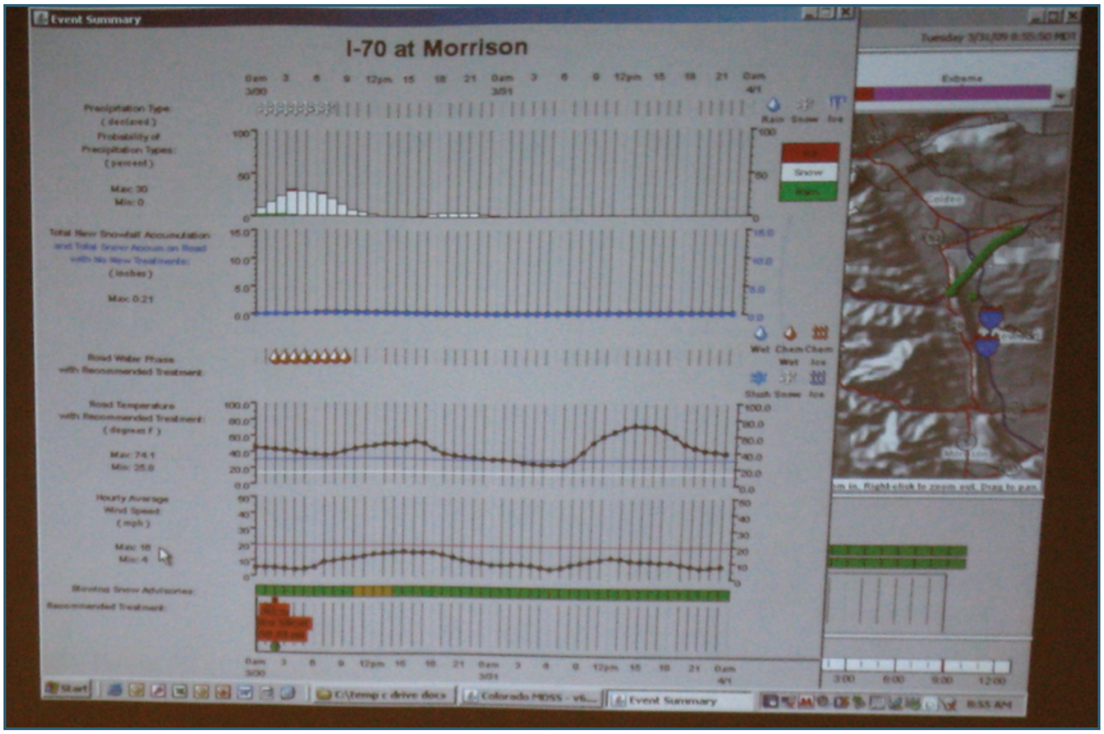

Figure 2-2. *The dispatcher's screen shows predicted snowfall, pavement temperature, air temperature, and more. (City/County Denver)*

Figure 2-3 and Figure 2-4 show how operators are able to send real-time information to the dispatcher.

Figure 2-3. *Operators can choose from a menu within reach while they are operating the vehicle. (INDOT)*

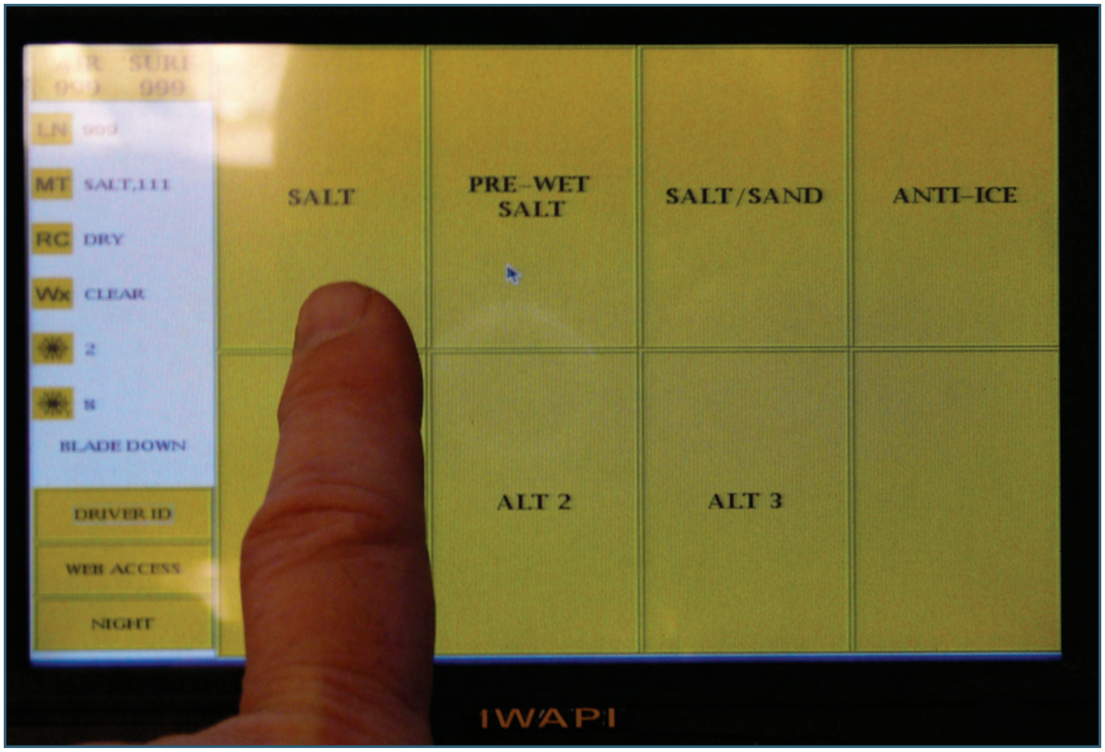

Figure 2-4. *If MATERIAL is chosen from the screen shown in Figure 2-3 the menu permits choice of material, from which the operator can input specific information relative to that material. (INDOT)*

Finding 1c

In summer, some new MDSS applications are being pursued (e.g., chip seals, paving, grass mowing, weed spraying, lane striping, and roadside assistance).

To date, most effort has been placed on using MDSS in winter operations, probably because winter is when weather incidents so directly and immediately affect customer mobility, not just operations. However, in his MDSS-related presentation at the 2007 Annual Conference of Transportation Association of Canada in Saskatoon, Saskatchewan, Lee Smithson (SICOP Coordinator) used both “winter and summer” in his presentation title. Some writings use Maintenance Operations Decision Support Systems (MODSS) rather than MDSS, leading to the inference that MDSS is destined to move beyond winter operations. Most certainly, the benefits of weather forecasting, AVL, and automatic data collection apply to most other nonwinter activities as well.

Finding 1d

Some agencies are beginning to identify cost benefits and savings potential from saving chemicals and the number and length of shift deployments, force accountability, etc.

Most users of MDSS cite its benefits, like more precision in setting start and end treatment times; savings in material, labor, and equipment; improved environmental protections; and improved and more consistent LOS. Some users, however, are actually calculating cost savings. For example:

- As chemical prices increase, even a 1% reduction in chemical usage leads to significant statewide or citywide savings.
- Savings in one hour of labor by more precise callout and ending times are significant and can be calculated

(depends on size of crew, time of day, and day of week).

- Indiana is paying for its MDSS implementation cost via salt savings. One load of salt costs $500 in material. If the state has 1,100 trucks, avoiding one extra trip per truck per event saves more than $500,000 in material statewide.
- The City/County of Denver calculates that if MDSS saves them from unnecessarily calling out two weekend shifts per season, the system's annual cost is paid for.
- Minnesota (see Figure 2-5) actually has a formula to estimate return on investment (ROI): ROI = MDSS / AVL2 x 3.14

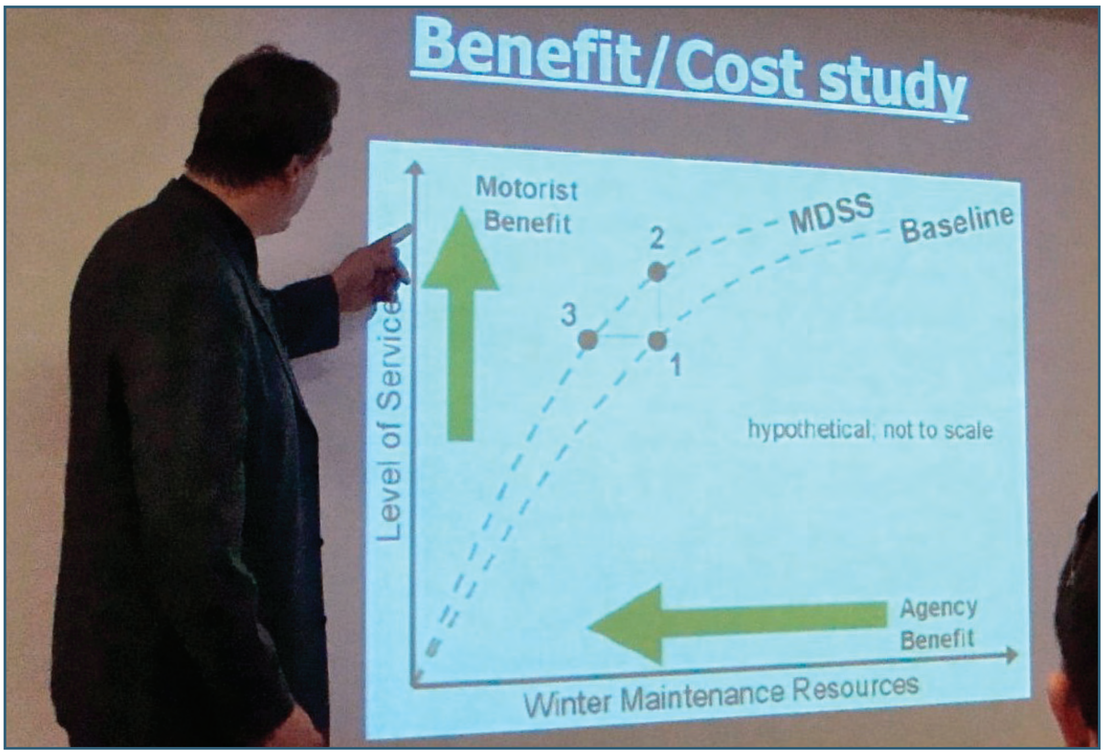

Figure 2-5. *Mn/DOT's benefit/cost analysis presentation to the scanning team*

Finding 1e

Management is successfully using various marketing and implementation strategies to develop and implement change, including:

- **Grassroots involvement and research**
- **Statewide versus by regions versus by crew versus scattered unit implementation**
- **Top-down direction**
- **Combinations of the previous strategies**

Mn/DOT's Maintenance Operations Research Engineering (MORE) fund was instrumental in launching MDSS in

Minnesota. (See Finding 5a for more information.) MORE provided seed money and the districts supplemented the costs from their own operating budgets. With MDSS, initial progress started in one district that had a champion. Expansion to other districts tended to be optional until today, when every district has at least one route on MDSS.

Other states typically develop an implementation plan, determining where to start and, depending on their organizational structure, expanding out from there, eventually getting to a point where every district is covered at least a little to start with.

INDOT is unique in that its commissioner was impressed with the potential of MDSS, appointed an implementation coordinator, and ordered that MDSS be implemented statewide (at least somewhat in each district), all at the same time. He was convinced that savings in salt would pay for the system's cost as it was being implemented.

Finding 1f

The hope is that MDSS can be used to establish, supplement, or replace the winter severity index.

The scanning team was not provided documents showing completion of an index that was already successfully developed. However, it was mentioned in Minnesota that, as experience with MDSS accumulates, the state hopes to develop a winter severity index that can compare the magnitude of one winter to another for analysis and cost-prediction purposes. INDOT uses hours of snow as its severity index.

Finding 1g

MDSS is having positive impact on management and employee culture.

As winter maintenance has moved from simply deicing to anti-icing, both the opportunities and the complexities of managing and carrying out a snow and ice plan have increased exponentially. The operator decisions of plow-up/plow-down and sand spreader on/off are still there, but now there are new chemicals (including liquids), application rates that vary from situation to situation, and additional levers and buttons to operate underbody blades, wings, tow-plows, etc. There are RWIS-based weather forecasts that change and can be communicated to the driver instantly. Dispatchers have access to TV monitors that show traffic flow and can report incidents.

It used to be that, once an event started, managers used to just get out of the way and let the plan play itself out until the Monday-morning-quarterback meetings. Now those same managers have access to a multitude of real-time information, allowing them to participate managerially during the entire event. Likewise, as conditions and forecasts change during an event, the new and updated tactics for retaining or recovering safe driving conditions on the roadway surface are conveyed to the operator. As new information is communicated to the cab, the operator may need to convey real-time information and results back, and the cycle repeats.

While MDSS has made it easier to do a better job, the addition of monitor screens, levers, buttons, dials, speakers, and cameras means that the cabs of snowplow trucks are beginning to look more like the cockpits of airplanes. But there is also a downside. Increased complexity is challenged by the incorporation of cross-training and flexible workforces, meaning that fewer operators have the familiarity of being behind the wheel day after day; some even are working at a drafting table or operating a CADD system in between storms.

During the scanning tour, the team had several opportunities to talk to today's more-progressive operators. A common thread seemed to be that the more complicated our job gets, the more we need access to sophisticated equipment like touch screens, voice-actuated or automated controls, monitors so that we can see to the sides and rear of the truck, and so forth.

As opportunities and expectations change at the management and the operator level, so does the culture.

Automatic Vehicle Location (AVL) Systems

Introduction

AVL mapping programs use a global positioning system (GPS) and geographic information system (GIS) to track agency vehicles, transmitting this information to a point where locations can be plotted and displayed in various tabular or graphical formats (see Figure 2-6, Figure 2-7, and Figure 2-8).

Figure 2-6. *The dispatcher is able to monitor the location, speed, and direction of the plow trucks. (E-470 PHA)*

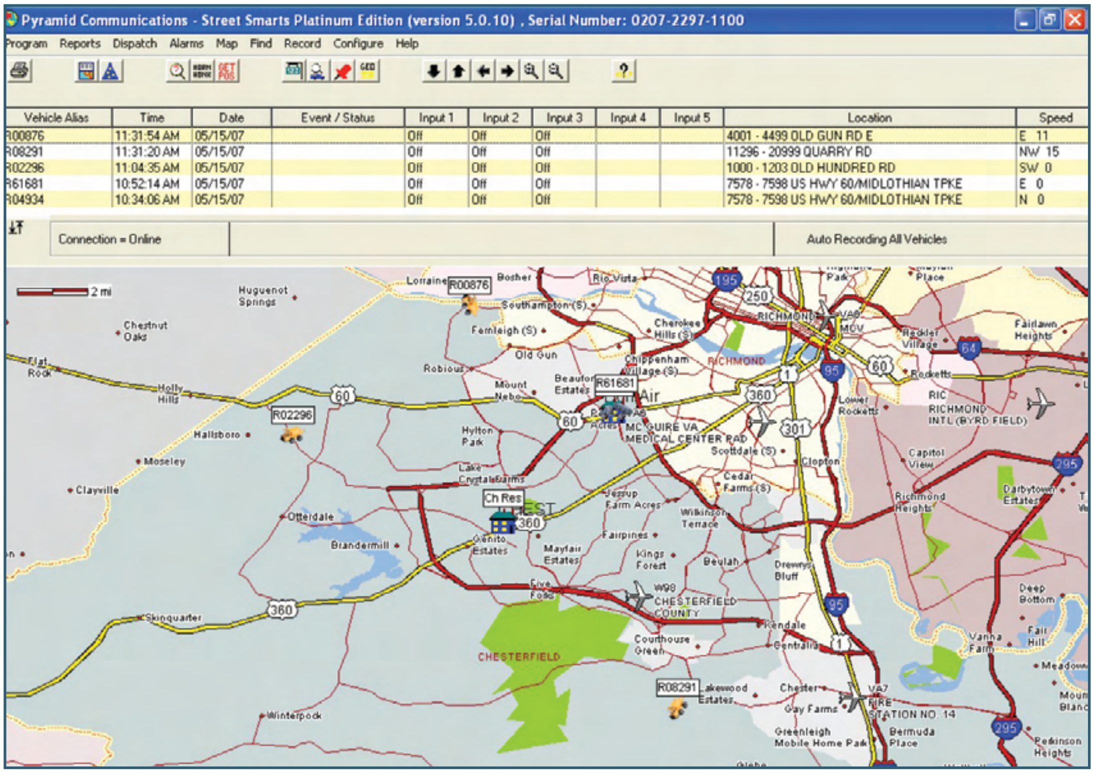

Figure 2-7. *A graphical representation of vehicle location and direction appears on the dispatcher's screen. (VDOT)*

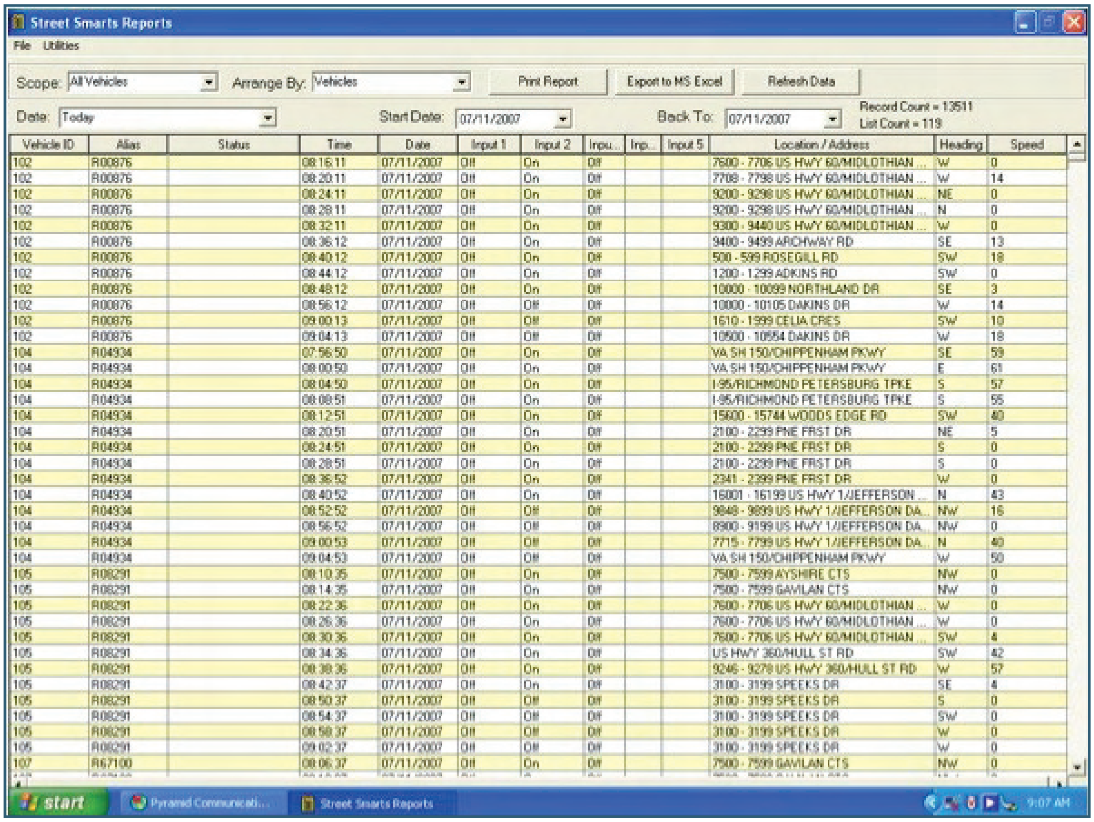

Figure 2-8. *A tabular representation of vehicle location, speed, and direction appears on the dispatcher's screen. (VDOT)*

When AVL first became available, there was a great deal of resistance among maintenance employees, who feared that it would lead to a “big brother” working environment, with management using it only to watch employees and keep track of where they are and how long they are there. During the scan, the employees with whom the team talked did not express those concerns; instead, it was more common to hear them volunteer how nice it was to know where their fellow snowplow truck drivers were in respect to themselves and not to have to repeatedly report their own location to their dispatch center. This permitted them more time to operate their truck, watch for others on the roadway, and adjust their plowing and sanding equipment.

For MDSS to be of full value, AVL is essential. The jury is still out on what percentage of vehicles will need to be equipped with AVL. Some agencies are installing AVL as new trucks are being purchased; some are accelerating the process by both installing it in new trucks and retrofitting old trucks. Literature reveals that some organizations are aiming at having 100% of their equipment equipped with AVL, including loaders and motor graders; others have yet to make that commitment. Periodic surveys by groups like SICOP keep track of how many AVL units are in place by agency:

- Minnesota – 100 of 800 trucks
- E-470 PHA – all 25 units
- Utah – soon to pilot-test 10 units
- Indiana – 172 units

Finding 2a

A variety of vendors are involved with AVL and systems related to AVL like MDSS.

AVL technology has been deployed in highway maintenance long enough to be quite mature; however, that is not to say that there weren’t growing pains that some find hard to forget. Agencies that have already implemented AVL are likely to have committed to a specific brand of product, probably because it was the first brand they used. Several good brands are available and are being used successfully, particularly in enforcement and incident-management vehicles. Partnering with others using AVL may make sense from both a cost and an integration/compatibility point of view. The pros and cons of specific brands of equipment can be easily checked out by contacting current users.

Finding 2b

AVL is being used for multiple purposes, ranging from route reporting to resource consumption to incident response.

While the focus was on AVL as applied to winter maintenance, discussions during the tour revealed that AVL has or is expected to have potential in other maintenance-related activities. As MDSS systems mature and data are correlated with maintenance-management, work-accomplishment, and time-reporting systems, AVL not only has the potential to replace handwritten or manually input data, it also has the potential to do it much more efficiently and accurately. For example, maps can be automatically generated to show roadsides mowed, pavement strips repainted, etc. Being able to see on a screen where a snowplow truck is working and the direction it is traveling will also allow someone on the telephone to be informed when the truck is expected to pass his or her home.

The City of Fort Collins, CO, uses AVL to track labor, material, and equipment usage. E-470 PHA uses AVL mostly to track all truck locations, while eight of the 25 trucks are equipped to collect and transmit data into the MDSS as well. The City of Grand Junction, CO, which has 11 trucks, has no AVL or MDSS system in place but is contemplating AVL maybe next year.

Other uses are security (alert on entry to/exit from the yards), identifying the closest unit to respond to an incident, evidence for use in resolving complaints or litigation against the agency or its employees, and locating stolen government vehicles.

Finding 2c

Low resolution (> 5 minute intervals) meets some decision-making needs, but high resolution (< 30 second intervals) is required for an agency to automate data collection-systems and generate time sheets and work-accomplishment reports.

Low-resolution monitoring equipment is a less costly investment; however, if a location is only monitored or recorded once every five minutes, the location of the truck on the screen could be off by up to three to five miles before it is updated. Relative to winter maintenance, if there is value to a driver knowing how close behind him his partner is, a low-resolution system would be of no help (see Figure 2-9). For more accurate information, especially if the information will be used for work-accomplishment data (e.g., parks mowed, roads patched, or miles striped), agencies need to invest in a much higher resolution system (see Figure 2-10).

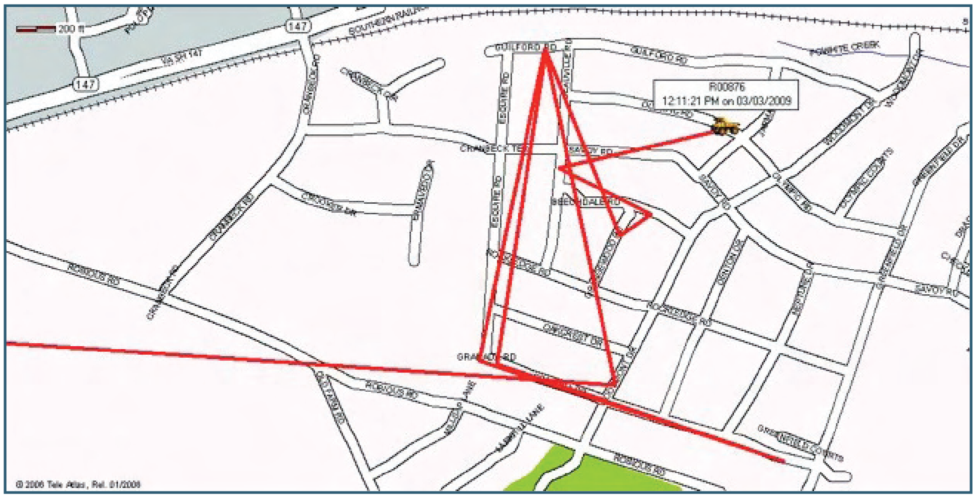

Figure 2-9. *Low resolution (frequency of readings) provides periodic location, but not the ability to identify the complete route.*

Figure 2-10. *The higher frequency of AVL readings can produce accomplishment graphics showing routes completed.*

Finding 2d

The benefits to both management and operators are becoming more universally understood.

While it has always been easy to understand the value of AVL when managing outsourced private contractors that are performing winter maintenance work, both management and in-house operators are now more aware of the competitive advantage an in-house operation has if it uses these same tools themselves, both in terms of effectiveness and efficiency.

As the percentage of vehicles equipped with AVL increases in an organization, assuming investments are made in high-resolution systems, the more an agency will be able to automatically generate time sheets for the operators, keep track of important work-accomplishment information, and monitor resource consumption. It is when AVL produces these kinds of services that operator support will be more fully achieved (see Figure 2-10 and Figure 2-11).

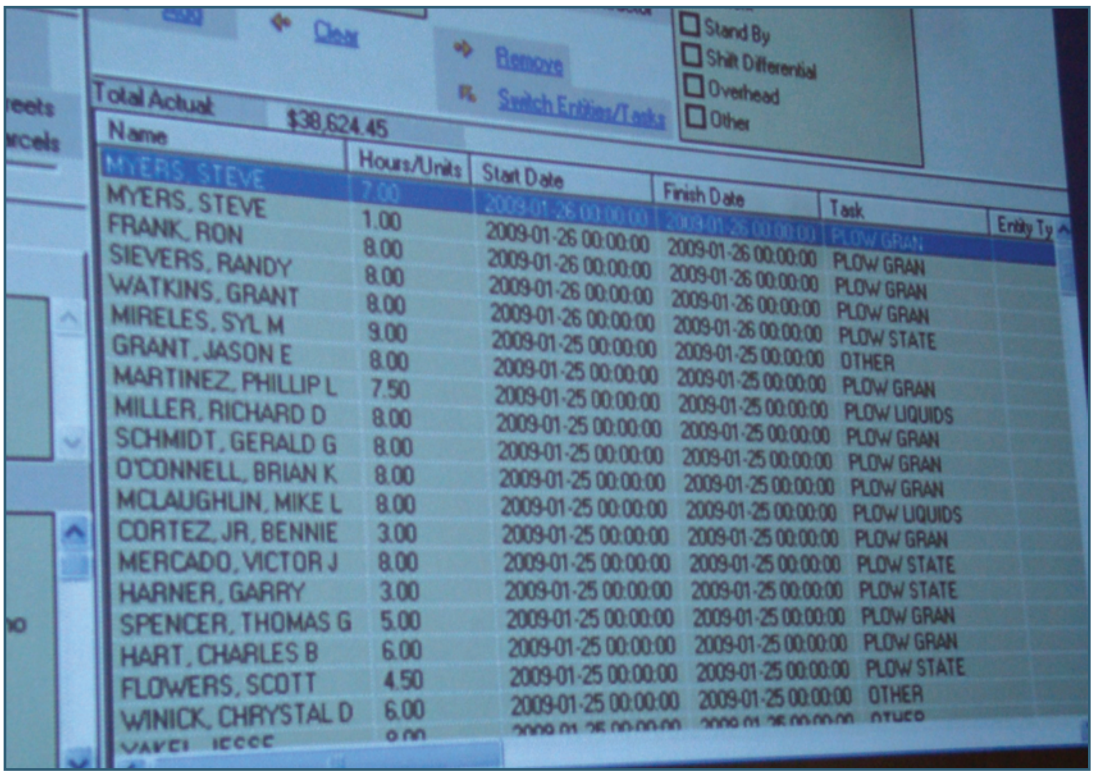

Figure 2-11. *Data is collected automatically, reducing the amount that operators have to manually input into labor, equipment, and material accounting systems. (City of Fort Collins, CO)*

Equipment-Related Technologies and Facilities

Introduction

It does not matter if you are a manager, a supervisor, or an operator—winter maintenance personnel always love to “display their iron.” They go out and find their newest and best, especially if it is something they modified themselves to make it work better. They get it all shined up and they make sure visitors get to see it. Because the team could not visit every location where special equipment is housed, the host agencies transported some pieces to the sites the team visited. This made the team happy, because managers love looking at state-of-the-art winter maintenance equipment and having the chance to talk with real operators.

Same goes for facilities. The sites selected by host agencies were typically their newest sites that had their newest building innovations built in. Featured on this tour were undoubtedly some of the more sophisticated, state-of-the-art chemical storage facilities, brine-making machines, and truck-washing bays in the US.

The following is a capsulated summary of the equipment and facility items that the team found most exciting to report:

Finding 3a

Plows and Wings

- **Wider front plows and dual wings are being experimented with.**
- **Underbody plows are becoming more and more common in several agencies.**
- **Tow-plows allowing full two lanes per pass are being successfully used.**
- **Hydraulic-assist engineering is being used to reduce plow weight on the blade when conditions warrant, thus reducing cutting edge wear and extending life up to two winter seasons.**

Front plows will always remain popular, but different shapes and widths are available. The team saw underbody plows at every site visited, with some expanding their numbers more aggressively than others. The City of Denver showed the team its poly (plastic) moldboard plow with rubber cutting edges, hoping that its lighter weight will be an advantage (see Figure 2-12). A reversible front plow with wings mounted on both sides of the truck is used in Utah (see Figure 2-13).

Figure 2-12. *Lighter weight poly (plastic) plow (City/County of Denver, CO)*

Figure 2-13. *Snowplow truck with reversible plow and both right- and left-hand wings (UDOT)*

Minnesota, Utah, and Indiana all talked up their tow-plows, coupled with a physical demo or videos or both (see Figure 2-14). The trucks towing these plows are one-man operated and are equipped with a plow and sander. The tow truck plows and spreads chemicals in its lane while the tow-plow essentially plows a second lane during the same pass (e.g., two lanes in one direction or a single lane with shoulders or turn lanes). The tow-plow can also distribute solid or liquid chemicals in its lane. Minnesota's tow-plow had the capability of spreading liquids, Indiana's spread granular chemicals, while Utah's spread both solids and liquids.

Trucks towing plows have to have adequate hitch and torque capacity, plus a hydraulic system capable of handling the steering, up/down blade mechanism, and spreader controls. Indiana's tow-plow featured on-board power for hydraulics so that it can be towed by a truck that is not as specially equipped. The tow-plow has not had any safety issues or unfavorable crash history to date.

An experimental hydraulic-assist plow was displayed in Indiana (Figure 2-15). Cutting edges normally ride at full pressure on the pavement surface, carrying the plow's full weight. Indiana has added hydraulics to reduce the rate of cutting edge wear by providing operator control to relieve this pressure (i.e., hydraulically lifting some of the weight off the plow blade during times when full cutting power is not needed). Doing so can extend the life of the plow blade, hopefully doubling it to two seasons.

An alternative way to remove snow with plows is to use power brooms. UDOT, which claims to have relatively lightweight snow, is experimenting with large brooms mounted on full-size, tandem-axle snowplows (see Figure 2-16).

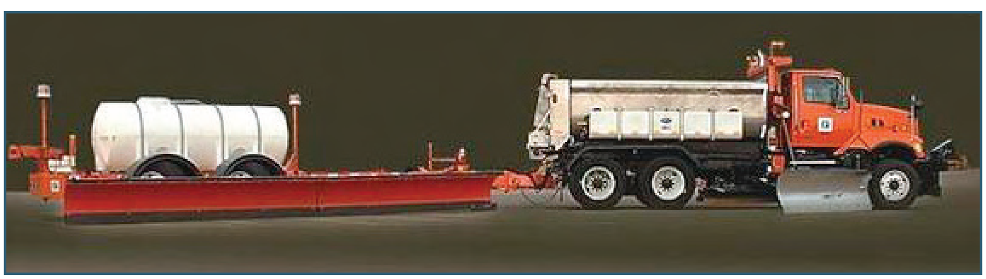

Figure 2-14. *Tow-plow equipped with liquid spreader (Mn/DOT)*

Finding 3b

Plow cutting edges (plow blades)

- ❖ **Composite carbide and rubber blades are getting good reviews.**
- ❖ **Triple-blade (carbide, serrated, and rubber slush blade) units are being tried.**

The type of plow cutting edges varies from state to state, mostly based on temperature, weather conditions, and whether you are dealing with solid ice, snow, or slush. There are blades made out of regular rolled steel, hardened steel, serrated steel, carbide steel inserted in steel, rubber blades (see Figure 2-17), and carbide steel inserted in rubber (see Figure 2-18). The most popular configuration is the standard single blade per plow configuration; however, experimentation is being done with double- and triple-blade configurations (see Figure 2-15 and Figure 2-19).

Figure 2-15. *Hydrolic - assist plow with triple blade (INDOT)*

Figure 2-16. *Rotary-power front-mounted brooms for removing lightweight snow (Note that this unit also uses a tri-axle pup trailer to spread liquid chemicals.) (UDOT).*

Figure 2-17. *Rubber blade reinforced with front steel blade and steel curb protection (CDOT)*

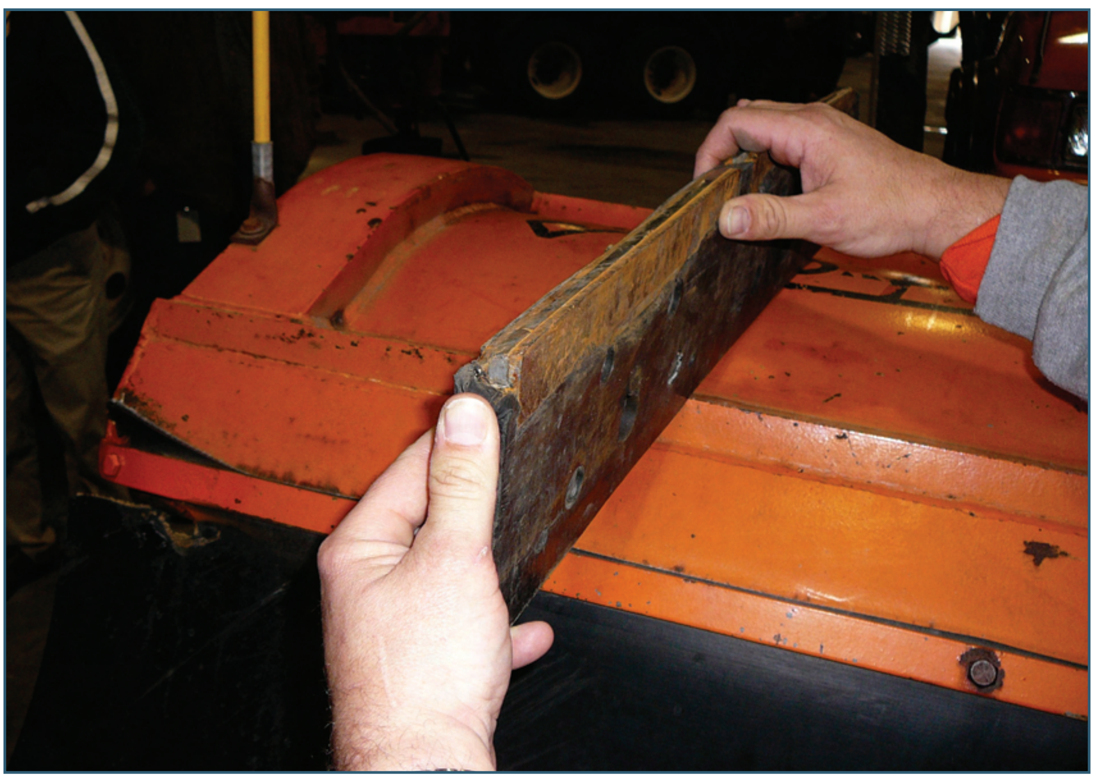

Figure 2-18. *Composite rubber blade with carbide steel insert. Note that the short section of the blade is photographed upside down with some rubber worn off to show the carbide insert. (Mn/DOT)*

Figure 2-19. *Triple-blade experimental plow with steel carbide (cutting), serrated (scarifying), and rubber (squeegee) blade (INDOT)*

While snow- and ice-removal agencies are interested in the experiences of others, they tend to do their own in-house experimenting and base purchasing selections on their own research. Much depends on their organization's own unique culture and their own weather and traffic conditions. Driving forces include:

- Extending life (thus reducing frequency of replacement)
- Reducing vibration
- Minimizing damage due to obstructions on the surface
- Reducing noise
- Balancing pressure to reduce chemical usage vs. willingness to achieve goals using more chemicals

Perhaps equally important is the operator's degree of interest and willingness to try or use something new. Today's industry is quite responsive to user agencies in providing options to cover varying needs and conditions.

Finding 3c

Saddle tanks for prewetting solids are being designed and integrated into dump boxes and beds on both tailgate and V-box spreader trucks, leading to better weight distribution and higher carrying capacity, allowing for longer route coverage during prewetting operations at an optimized application rate of 20 to 30 gallons/ton.

The team noted a variety of examples of how liquid tanks are molded to fit in otherwise unused spaces on the sides of dump boxes or the sides of V-spreaders. Mn/DOT uses rounded dump boxes and molded tanks that wrap under the outside of the box (see Figure 2-20). CDOT and Denver both slide V-box spreaders into dump boxes and use the triangular space between the box sides and the V-spreader to store specially molded liquid tanks (see Figure 2-21). INDOT displayed a unit that had a tank specially designed to fit between the back of the cab and the front of the dump box (see Figure 2-22).

Figure 2-20. *Saddle tanks on the side of the dump box carry liquid chemicals for prewetting solids and are used in conjunction with tailgate sanders for solid chemicals. (Mn/DOT)*

Figure 2-21. *Saddle tanks tucked between the dump box and the V-box spreader carry liquid chemicals for prewetting solids. (City/County of Denver, CO)*

Figure 2-22. *Liquid chemical storage between the cab and box (INDOT)*

Finding 3d

Spreaders

- **The zero-velocity concept is continuing to be pursued.**
- **Slurry augers are being used so that chemicals in slurry form can be distributed.**
- **Agencies using slide-in spreaders justify them for their overhead clearance. Tailgate sander users justify theirs because of their reduced dead load, lower initial investment, and minimal maintenance costs.**
- **5,000-gallon tankers are used during anti-icing and as resupply stations between storms.**
- **Off-season water tank trucks are rented as anti-icing units.**

Zero-velocity chemical spreaders are designed to push or blow solid chemicals at the same speed as the road surface (thus zero velocity) to avoid the bounce and scatter typically associated with standard chemical spreaders, which simply drop material onto to roadway (a 20 to 40 mph velocity differential). In the 1990s, several states experimented and in some cases purchased several *air-driven* units developed by a firm working in cooperation with Mn/DOT; however, these units are no longer available. UDOT currently runs 15 trucks with zero-velocity spreaders. Mn/DOT was the only agency on the tour that displayed the unit that it is experimenting with. The unit it showed is hydraulically driven and pushes prewetted material out into a pattern that is 97% where it is intended (see Figure 2-23).

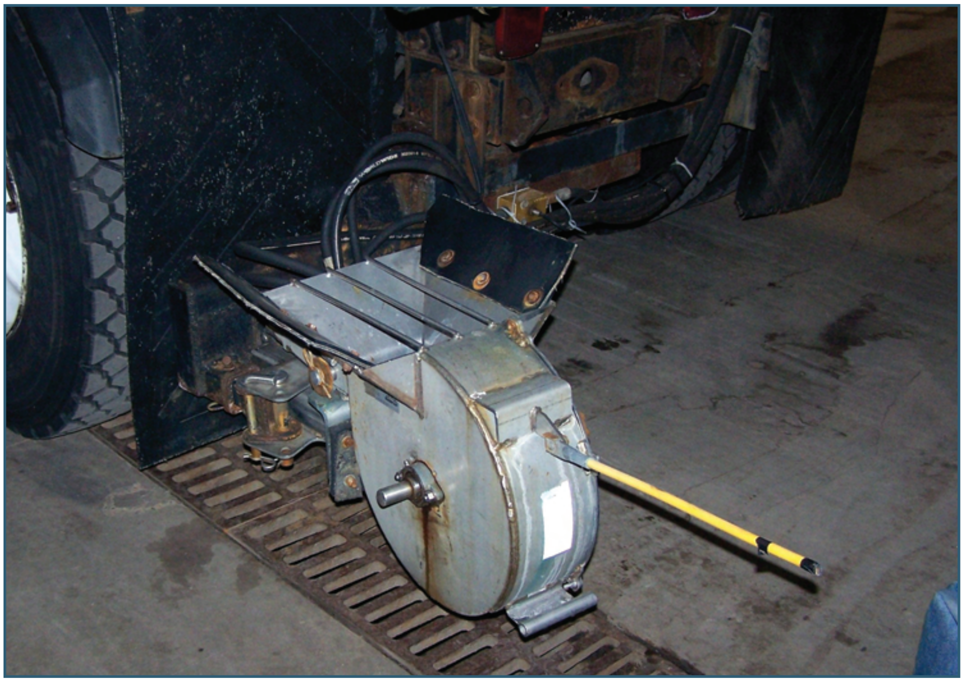

Figure 2-23. *The latest zero-velocity chemical spreader being tested by Mn/DOT is designed to discharge chemicals straight back at zero velocity with respect to the ground. (Mn/DOT)*

INDOT is testing a swing-out spinner assembly as a spreader on its concept truck (see Figure 2-24). Mn/DOT is trying several spinner modifications or chutes to lay down a windrow (or narrow row) of chemicals along the centerline or higher side of the roadway as opposed to spreading the chemical with a spinner across a wide area of the lane(s).

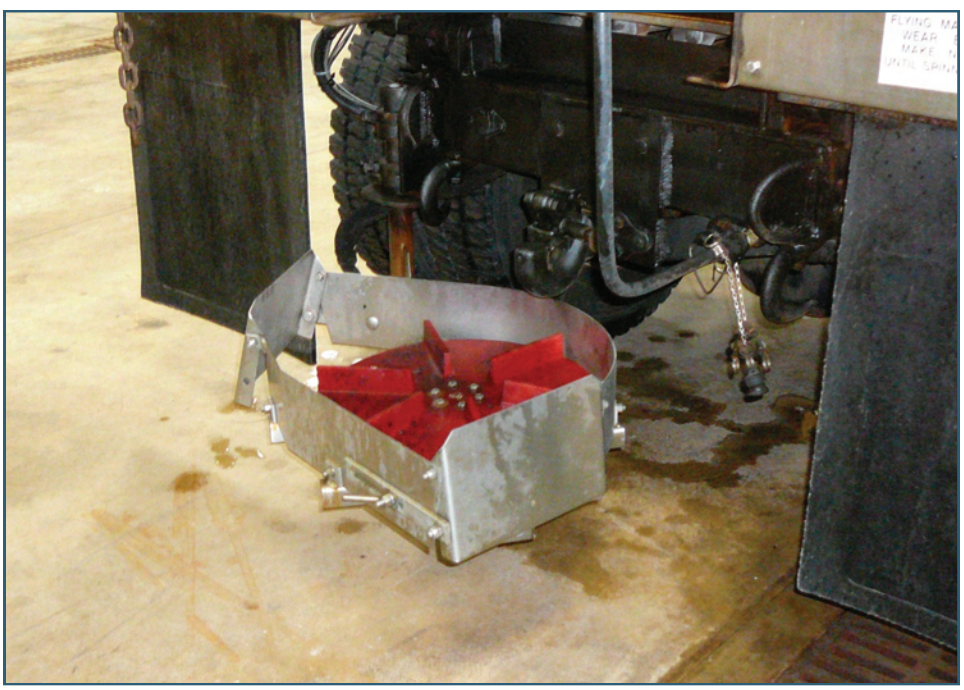

Figure 2-24. *Swing-out spinner for V-box conveyor salt spreader (INDOT)*

Mn/DOT is trying to capitalize on the benefits of using chemicals in slurry form and is modifying the augers in its tailgate sanders (see Figure 2-25).

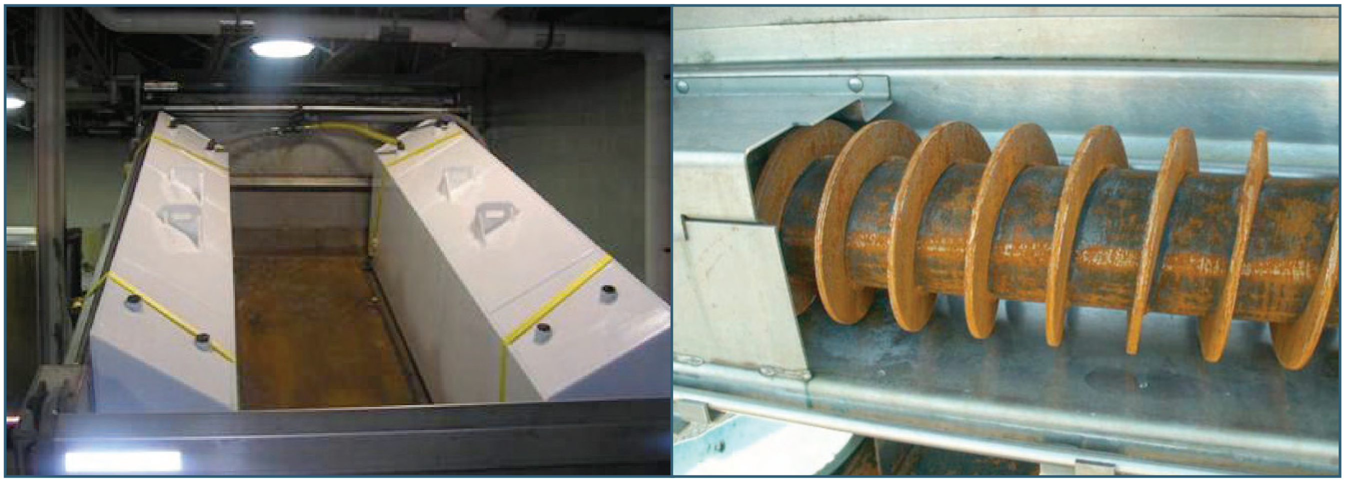

Figure 2-25. *Special tanks and tailgate sander modification to facilitate distribution of salt slurry (Mn/DOT)*

Agencies that have tailgate spreaders probably started out with tailgate sanders, as did those using V-box spreaders. Tailgate supporters argue that their spreaders involve less dead load, meaning greater load-carrying capacity for live load (i.e., chemical). Tailgate sanders also have a lower original cost and lower maintenance costs. V-box users don't have to worry about a raised box hitting a bridge. On the tour, all agencies used the V-box except for Minnesota, which primarily uses tailgate sanders.

It is very common for DOTs to have one or more 5,000-gallon trailer tankers equipped with a spray bar to distribute liquid de-icing chemicals over longer routes (see Figure 2-26). Likewise, smaller tanks that slide into the truck's dump box are common. VDOT places a 3,000-gallon unit on a flatbed trailer during winter and showed the team a tank being carried by a tandem-axle pup trailer. Utah's pup trailer example had tri-axles to better carry the weight (see Figure 2-27). VDOT has also found that at least one local equipment rental company is willing to rent out its fleet of water tankers in the off-winter season at quite a reasonable price, especially if the company name and logo are left on the trailer as advertizing (see Figure 2-28).

Figure 2-26. *Typical 5,000-gallon trailer-tanker for spreading liquid anti-icing chemical and resupplying storage tanks at local garages (Mn/DOT)*

Figure 2-27. *Flatbed-mounted 3,000-gallon liquid chemical spreader (VDOT)*

Figure 2-28. *Water truck available for off-season rental to spread liquid chemicals (VDOT)*

Finding 3e

New equipment accessories being tried include:

- **Video cameras on plow trucks to provide views of the:**
  - **Front view images of the driver's windshield perspective for the dispatcher**
  - **Side and rear view images of the truck for the operator**
- **Wiper blade vibrators to reduce ice buildup**
- **Air blowers to keep side mirrors clear of snow**
- **HID headlights to provide three times the light of other bulbs and 10 times their life**
- **UDOT's fog buster to lift fog above the driver's line of sight**
- **Laser beam guides to show the operator how far out the wing or tow-plow is**
- **Collision avoidance systems to help prevent accidents in white-out conditions**

A video camera that lets the dispatcher see what the truck operator sees was mounted right behind the passenger windshield in the cab of a CDOT truck. The images sent to the dispatcher or MDSS coordinator provide a much clearer understanding of the real-time conditions in the field than an operator could by either putting it into words or clicking a condition rating box on a monitor (see Figure 2-29).

Figure 2-29. *In-cab video camera mounted on the passenger side of the windshield is capable of sending to the dispatcher pictures of the road and weather conditions as they actually exist from the driver's view (CDOT)*

Both Indiana and Minnesota displayed trucks that had video cameras mounted so that the truck operator can glance at a monitor and see selected views around the truck, like the rear, sides, and front. Video cameras enhance safety (e.g., for backing up) and also provide the operator with key information, like how much material remains in the spreader, the pattern of the chemical being spread, and the position of the tow-plow or wing (see Figure 2-30).

Figure 2-30. *Video camera views are displayed in the cab so that the operator can know what is going on to the right, left, rear, and front of the truck, including in the spreader box (left). A tow-plow behind the truck (right). (INDOT, Mn/DOT)*

Over the years, many innovations have addressed the problem of snow/ice buildup on the wiper blades. Some Minnesota operators are impressed with the vibrating blades they are testing. The air blowers on the side mirrors to reduce snow and ice buildup appeared to be less promising.

The winter maintenance community is continually looking for truck lighting packages that help the operator both see and be seen. As technology continues to develop, experimentation and trial installation continues in several agencies. Minnesota currently is experimenting with HID lights, which can provide three times the light and have 10 times the life of other lights. Unlike halogen or incandescent bulbs, HID bulbs do not have a filament; they produce an arc between two electrodes, something like lightning.

UDOT uses a fog dispersal system to deal with continuous and very dense fog hanging in low mountain valleys, especially those in urban areas along some heavily traveled interstate highway systems. Liquid CO_2 is sprayed into the truck's slipstream through a very small nozzle mechanism mounted on snowplow or spreader trucks. The cold temperature of the gas causes fog to precipitate into ice crystals, a phenomenon that can increase visibility at eye level for up to four hours (see Figure 2-31). Utah is expanding the use of this fog dispersal system to 10 more areas in the near future.

Figure 2-31. *Nozzles on the fog dispersal system distribute CO2 to lift fog away from the travel lane. (UDOT)*

One of the relatively low-expense items becoming popular on trucks with wings and/or tow-plows is a laser beam that projects a colored marker forward from the cab onto the snow-covered roadside so that the operator can see where the edge of the wing or tow-plow will extend. This allows the operator to know how close to the guard rails, bridge railing, mail boxes, and traffic signs that the tip of the equipment extends (see Figure 2-32).

Figure 2-32. *A laser beam system projects green light onto roadside snow to show the operator how far out the wing or tow-plow extends. (Mn/DOT)*

Collision-avoidance systems continue to have application where snowplow operators are concerned about equipment visibility (e.g., not being seen by fast-approaching vehicles from the rear or not seeing stalled or slow-traveling vehicles in the front during white-out conditions). This technology was discussed during the tour but was not displayed as something that is being implemented. Likewise, heads-up displays and magnetic tape systems to ensure that vehicles are traveling the driving lane were not displayed for the team, presumably meaning that this operational research is on hold, at least temporarily.

Finding 3f

FAST systems have been developed and proven to the point that they are no longer experimental.

FAST technology is not very old. Mn/DOT first learned of it at a Standing International Road Weather Commission (SIRWEC) meeting in Birmingham, England, in 1996. Two years later, Mn/DOT was operating its first one near Duluth.

In the early days, FAST systems were plagued with reliability problems and users had to resort to manual operation. Today the technology has matured to the point that automated activation systems have a much higher level of confidence. While individual sites still need to be custom designed, basic hardware can now be procured from boilerplate specifications. The question now is not “Do they work?” but rather “How many can we justify and what sites get priority?” Several states currently have 20 or more FAST systems installed and in use.

During the tour, both Mn/DOT and CDOT displayed examples of one of their most recent FAST installations. Minnesota’s, which was on the new I-35W bridge over the Mississippi River, is an installation that delivers liquids from within the lanes (see Figure 2-33). Colorado’s example, on SH119, sprays from the shoulder so future overlays will not disrupt the nozzles.

Figure 2-33. *FAST system graphic (Mn/DOT)*

Finding 3g

Equipment replacement purchases are funded by a variety of mechanisms, including:

- **Annual appropriation from legislature or council**
- **Revolving accounts (where user units pay rent to owning units)**
- **Escrow accounts (where the agency puts aside money every year for every unit so that they are fully funded when replacements are due)**

Different funding mechanisms for procuring mobile and scientific equipment have always existed. What intrigued the team is the variation that existed even within the five states visited on the tour.

Minnesota explained its cooperative purchasing programs, where state and local governmental units purchase equipment (as well as supplies and materials) from the same open competitive contract, allowing smaller agencies to benefit from quantity-purchase discounts. This has been achieved by bid prices for as many options as multiple agencies' needs dictate (e.g., power steering, chemical spreaders, torque requirements, and plow configurations).

The City of Grand Junction, CO, maintains a special Equipment Replacement Fund. Starting when a unit is new, the city deposits enough money into the fund every year so that, at the time of projected replacement, the fund will be able to purchase its replacement. In other words, if a unit's expected life is 10 years, 10% of its projected replacement cost is deposited into the fund each year for 10 years. This way, equipment purchases in a given year do not compete with other funding categories.

In most cases, equipment is still being replaced with funds appropriated every year by the state legislature or local city/county elected bodies. Some agencies, however, are set up with revolving accounts where a central body owns the equipment and rents it to the agency departments on a per-mile, per-hour, per-month, or per-year basis, thus generating its own income for replacement purposes. Additions to the fleet and upgrades require that the requesting department provide extra funding for the first purchase.

Finding 3h

RWIS station advancements include:

- **Low-cost portable units**
- **Solar- or wind-powered units**
- **Stations that include remote-controlled cameras providing streaming video**
- **Noninvasive sensors to replace pucks embedded in the pavement**

RWIS stations have progressed from being expensively and permanently mounted along the roadside (even on an existing sign post or overhead mast) to being electrically powered and collecting data from a puck embedded in the road. UDOT made a special point to show the team examples of its newer RWIS stations, which are portable, lightweight, solar- or wind-powered, and video-camera equipped (see Figure 2-34). Furthermore, CDOT pointed out that new technology can now gather surface condition information noninvasively from the roadside and is able to provide a useful measurement of slipperiness (i.e., friction) (see Figure 2-35).

Figure 2-34. *These low-cost, portable RWIS data-gathering stations are solar-powered and camera-equipped. (UDOT, VDOT)*

Finding 3i

Friction measurement systems for measuring winter performance continue to be developed domestically and internationally.

Over the last 10 years, domestic activity in this area was pretty slow. At the 2008 TRB Snow and Ice Symposium in Indianapolis, IN, however, the team learned of some renewed activity. Several states, including North Dakota, Ohio, Indiana, Utah, Virginia, and Wyoming, are reported to be using friction measurement devices. Friction measurement continues to be the state-of-the-practice in some other parts of the world, including Japan and Norway.

Both Indiana and Utah (Figure 2-36) are working on friction measurement systems, but it was not featured, nor did the team pursue discussion on friction measurement during any part of the tour.

Figure 2-35. *Noninvasive surface sensor identifies the presence of water, ice, slush, snow, and frost and provides an indication of slipperiness. Unlike pucks, which are embedded in the pavement, these sensors are mounted alongside or above the road.*

Figure 2-36. *Friction measurement device being experimented with in Utah. (UDOT)*

Finding 3j

Progressive and environmentally sensitive agencies store all solid chemical under roof year-round, with space available to load trucks inside the same building.

Every year the Salt Institute recognizes several state-of-the-art chemical storage buildings, and the team observed at least two of the best. IDOT's Greensburg building has its brine-making unit and liquid storage tanks within its new granular chemical building. The City of Fort Collins has a 10,000-ton granular storage building with a self-loading prewetting conveyor system coupled with a 170,000-gallon liquid dicer storage capacity on the same site. It stores 150% of a typical annual need and services four different agencies in the region. Granular material is delivered to the site by rail. Truck loading during a winter event is done from inside the storage building to make sure that no spillage is exposed to the weather (see Figure 2-37).

Figure 2-37. *Solid chemical storage building designed for stockpiling via conveyor and inside loading of trucks during winter events; liquid storage is alongside. (City of Fort Collins, CO)*

The City of Ft. Collins uses an automated inventory system to keep track of who draws how much of what kind (i.e., solid or liquid) of material. Granular material is automatically weighed and liquid is dispensed using an automated fuel-management-like system from a quick-attach truck-loading island (see Figure 2-38).

Figure 2-38. *Trucks are loaded with liquids using a system similar to a fuel-dispensing station with the ability to keep track of which agency draws material for which truck. Solid chemicals that are loaded are automatically weighed. Both liquids and solids are dispensed to multiple agencies. (City of Ft. Collins, CO)*

INDOT's storage facility in the Seymore District also has inside, drive-through loading, and its computerized salt brine-making system, liquid storage, and brine-loading station are housed in the same building as well (see Figure 2-39).

Figure 2-39. *This soft-top building stores both solid and liquid chemicals and has its own brine-making facility. Trucks drive through so all loading is done inside. (INDOT)*

Agencies that load salt while trucks are outside the building have the problem of cleaning up spillage before it is subjected to moisture (rain or snow), plus having to slope the loading area in a manner so that all of the runoff is collected and properly disposed of. Virginia collects contaminated runoff in a pond that is the source of water for manufacturing salt brine on the same site (see Figure 2-40).

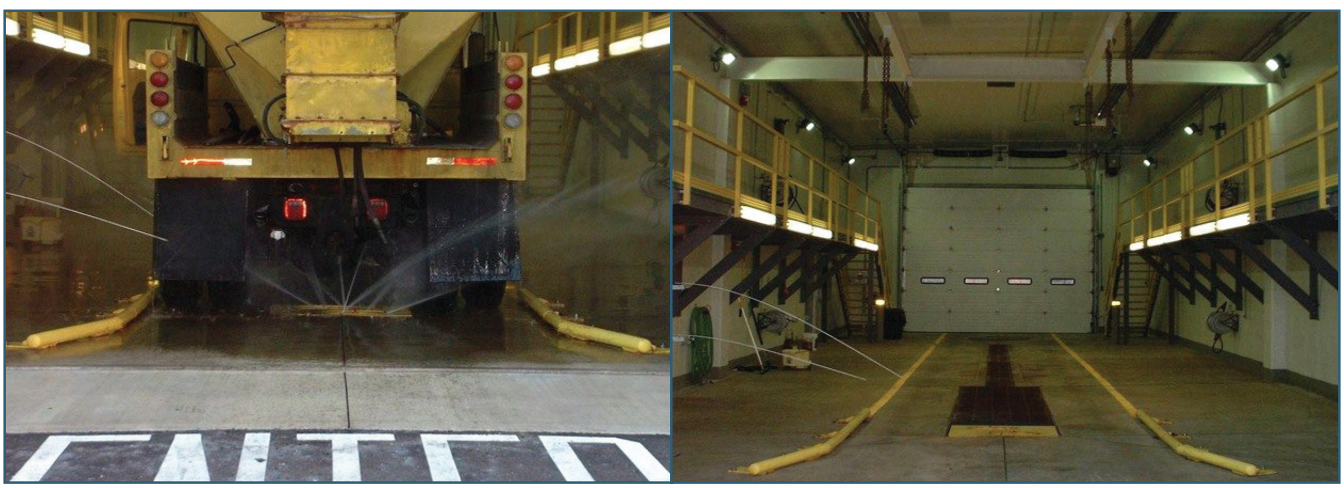

Figure 2-40. *State-of-the-art truck-washing facilities have undercarriage sprayers and spreader box lifters. (INDOT)*

Finding 3k

Brine-making and brine-storage systems have become automated and controlled.

- **Some are housed inside in same building as solid salt.**
- **Some are dispensed using fuel-management systems to permit easy sales to other local agencies and to internally keep track of the amounts loaded onto individual trucks.**

In addition to the Fort Collins, CO, and INDOT examples (see Figure 2-37 and Figure 2-39, respectively), other host agencies showed the team similar state-of-the-art brine-making systems. All were appropriately housed, if not in the granular storage building like in Indiana, then in or near a dedicated building to house the controls. Dispensing systems were at various levels of sophistication, with the Fort Collins system being the best that was seen.

Finding 3l

Sophisticated truck-washing facilities employ sediment traps and reuse wash water.

Both INDOT and Mn/DOT made a point of showing the team their best truck-washing facilities. INDOT's facility features an undercarriage wash and a snowbed removal rack so that the bed can be lifted off the truck for washing out salt from a catwalk (see Figure 2-40). Both bays are automatic drive-throughs, and both use collection, filtering, oil/water separating, recycling, and proper disposal processes to properly manage the wash water that becomes contaminated while washing chemical-spreading equipment. The City/County of Denver's washing and wash-water collection systems were outside, next to the building.

Finding 3m

Contaminated truck-washing water and runoff from stockpile sites and loading areas are being collected and used to make brine to prevent them from contaminating the environment at equipment and chemical storage sites.

Salt brine runoff is generated whenever chemicals are subject to moisture, like rain or during truck-washing exercises. This is particularly true if trucks are loaded outside a covered building during operations. Chlorides do not settle out but remain suspended once brine is formed. Special systems are being used to collect salt-brine wash water and runoff from stockpile sites (see Figure 2-41 and Figure 2-42).

Figure 2-41. *To be environmentally friendly, chemical storage and loading areas need to be designed to prevent runoff from leaving the property. Collection drains and collection ponds are a means to do that. (VDOT)*

Figure 2-42. *Wash water from washing chemical-spreading trucks is contaminated with dissolved salt and needs to be collected and reused, treated or properly disposed of. (INDOT)*

Whether inside or outside a building, every salt-brine-making device and liquid storage tank needs to have walls in place to retain liquids in case of leaks or fractured tanks (see Figure 2-43).

Figure 2-43. *Brine storage and brine makers must have protection from spills or leaks. Note the wood wall around base of this salt brine maker. (VDOT)*

Environmentally savvy agencies use practices that minimize the amount of salt brine formed by avoiding spillage during loading; designing equipment without ledges for salt to collect on; or using dry, high-pressure air to remove solids before entering the wash bay. Sites with an inground treatment system (i.e., drain fields) must collect and haul brine off site for proper disposal. Because of the cost to build an environmentally safe wash bay, consideration needs to be given to partnering and sharing such facilities with other agencies.[5]

Training and Development

Introduction

Training in an organization is an attitude. Training depends on the culture. An organization can send people to training classes and not have much learning going on. Sometimes hands-on training is the best path to learning. Developing personalized training programs is expensive and can take months, if not years, to develop. So programs developed by others need to be considered, even though they might appear to be canned. Organizations with a culture of continuous improvement or places with active employee participation programs achieve learning differently than those that do not. In-house training may be considered best; however, thinking outside the box is best achieved when students mingle with students from other agencies. Smaller organizations have different challenges than large agencies. So because of variations in attitude and culture, what works well in one agency may not necessarily work as well in another.

While training and development was a focus area, some agencies visited expounded on their program and some did not, or at least not as much. As expected, however, every agency that is providing winter services is learning new things every day.

Finding 4a

Government downsizing is leading more agencies to set up flexible workforces where generic transportation worker classifications are replacing separate construction and maintenance classifications at the time of hire. Where this is not happening, nonmaintenance employees are being cross-trained to operate snow and ice equipment during winter storms or otherwise supplement/support the winter maintenance effort. In either case, such changes are causing both challenges and opportunities for training and retraining workers for winter emergencies.

Because of the economic conditions during which this scanning tour was conducted, every agency visited was dealing with budget cuts, if for no other reason than revenue derived from taxes tends to diminish during times when unemployment is high, property values are down, personal spending is being more tightly controlled, and fuel consumption is reduced. Even though it is during these times that dependence on government services often goes up, constituents expect politicians to make government smaller rather than bigger. Unlike public institutions like the police, firefighters, and teachers, federal stimulus programs for public works are aimed at creating private jobs, not retaining public jobs.

For several years now, Mn/DOT has required that new hires have a commercial driver's license (CDL) whether they are applying for work in construction contract administration or in highway maintenance. Civil service classification titles no longer carry words like maintenance or construction technician. This way, during a winter emergency, maintenance can draw from other parts of the organization to obtain legally licensed snowplow operators

In the other cases, employees from other disciplines within the DOT are solicited or often required to serve as

[5] Ref: Mn/DOT Maintenance Manual, Clear Roads Chapter

supplement or backup snowplow truck drivers. In either case, preparing employees to perform new and different work requires a lot of training. Furthermore, since they may not practice the skill set year-round, retraining becomes essential.

By law, Virginia is downsizing its DOT from 9,500 to about 7,500 employees. At the same time, VDOT is in the process of contracting out all Interstate maintenance; because of downsizing, several districts are outsourcing non-Interstate work, including winter maintenance.

The agencies visited on this tour are the ones that are most aggressively implanting new technologies into their operations. This requires that both existing full-time and supplemental, on-call-as-needed personnel be trained.

Finding 4b

Several agencies are setting up training programs using simulators, training academies, symposiums, and other methods (e.g., MP3-based training) to incorporate internally and externally developed training programs like the AASHTO CBT program.

Mn/DOT has the following training:

- Snowplow Operator Training (SPOT) program: a five-year-old program; a two-week retreat at a military training camp for new drivers (see Figure 2-44); focused on learning how to drive a single-axle snowplow truck, plus learning federal motor carrier laws and regulations, pre-trip inspections, etc.

Figure 2-44. *Snowplow Operators Training (SPOT) program is a two-week retreat at a Minnesota National Guard training facility. (Mn/DOT)*

- ❖ Annual Refresher Course: for both single-axle and tandem-axle trucks; review of SPOT subjects plus chemical usage and application rates, bare-lane performance measure reporting, right-to-know, loader operations, plow route characterization, and SOP review.
- ❖ Snow and Ice Material Workshop: for supervisors and superintendents; covers environmental impacts, prewetting, anti-icing, application rates, choosing the right material, sand usage, and sander calibration.
- ❖ Training Simulator: for full-time priority drivers (357 drivers trained to date); two units housed in enclosed tractor-trailer combination; four-hour simulator session coupled with CBT and classroom instruction (see Figure 2-45).

Figure 2-45. *Training simulators are becoming popular for training snowplow operators, especially when the workforce has high turnover or is drawn from flexible or cross-trained staff. (Mn/DOT)*

UDOT has an off-site boot camp and, like Mn/DOT, a simulator. UDOT also likes the AASHTO CBT program.

CDOT has the following training:

- ❖ 40-hour mandatory training for all new operators
- ❖ Maintenance Training Academy: two-week course for new hires
- ❖ Maintenance Training Academy: one-week refresher for all full-time maintenance personnel
- ❖ Annual Retraining: eight-hour course for all employees
- ❖ Salt Solutions: works with both CDOT and local agencies; covers calibration, application rates, promotion of new ideas, problem solving, and brine production

INDOT's program is focused on making MDSS implementation a success. It covers drivers and mechanics and includes an introduction to quality assurance/quality control accountability. Its data gathering/transmitting unit, mounted on a plywood board, is placed in a van and plow operators are trained using this system while being driven around in the van.

Fort Collins, CO, sends its people outside the agency for training.

The City of Grand Junction, CO, has developed its own Audio Route Technology Training Program. The program involves making a voice recording for every route, giving the operator step-by-step instructions on where to turn

Figure 2-46. *The City of Grand Junction's Audio Route Technology Training Program gives time-synced, turn-by-turn, step-by-step instructions for each plow route. Operators, especially first-time or infrequent drivers, can key in a route number, listen while they drive, and be alerted when to turn, where the obstructions are, etc. (The playback device shown is for illustration purposes only.) (City of Grand Junction, CO)*

and what to watch out for, from start to finish, throughout the entire assigned route. This concept could be especially attractive to crews that have infrequent call-outs or in areas where backup drivers are called in sporadically, are assigned to different routes all the time, or otherwise do not know the route well (see Figure 2-46).

VDOT has a Maintenance Training Academy (Figure 2-47) that offers three courses:

- Snow Operations for Supervisors: half-day course; focus on calibrations, strategies, safe/unsafe practices, and best practices
- Snow Removal Training for Operators: three-day course; hands-on truck driving school, covers operation, preventive maintenance, and other topics
- Anti-Icing and Pretreatment: one-day course tailored to varying audiences (e.g., district maintenance personnel, residence administrators, maintenance managers, superintendents, and operators); uses aids from AASHTO and the Salt Institute

Figure 2-47. *VDOT Maintenance Training Academy (VDOT)*

Management Issues

Introduction

Under the umbrella of management issues, the team has carried forward a variety of issues that are important but did not fit into one of the other major topical areas nor justified topics of their own. Included are findings that relate to promoting research, developing managerial/employee relations, outsourcing work, measuring performance, and communicating with customers.

Finding 5a

Funding for maintenance operations research and development is important.

The scanning team was quite impressed with Mn/DOT's MORE fund. For almost 20 years, Minnesota has maintained MORE at the $750,000-per-year level (although it was recently reduced due to the economic downturn). It started simply as a special new initiative with a legislative appropriation for testing noncorrosive salt additives. The $750,000 initiative subsequently remained in the base budget, and the district maintenance staff retained it as a special MORE fund, with administration and staffing provided at the central office level. Candidate projects are owned at the operating level because nominations originate from the field. Every project must have a designated champion to lead the project to completion. A statewide review committee makes project selections. The MORE fund frequently provides seed money and the districts supplement the costs from their own operating budgets (see Figure 2-48).

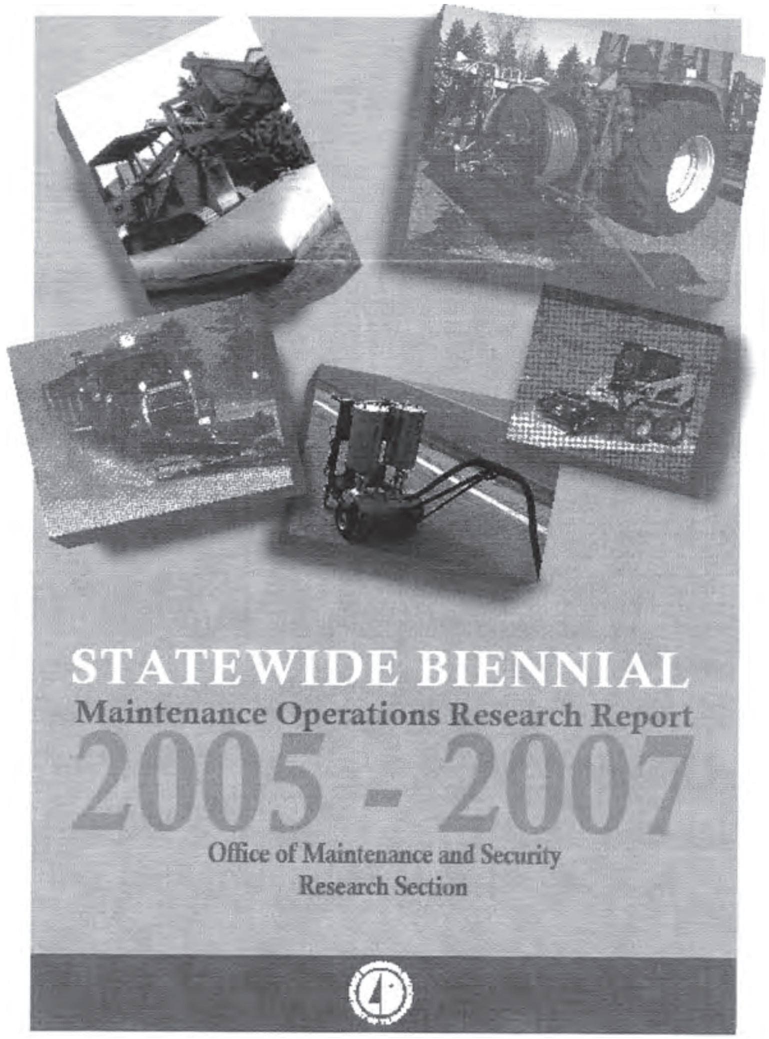

Figure 2-48. *Mn/DOT's MORE program has been funded at $750,000 per year since the early 1990s, providing seed money for district champions to try out new products or new ideas. (Mn/DOT)*

UDOT has a $250,000 fund dedicated to maintenance research.

Dedicated and recurring funding for operational research with maintenance promotes an innovative spirit from the grassroots level on up. Creating an environment where ownership of new ideas begins at the grassroots level leads to greater buy-in; however, this buy-in may take time to achieve, thus extending implementation time compared to top-down directed policy.

During a discussion period with some of the grassroots people in a truck station in Minnesota, a front-line employee volunteered to the team that where he works, he was convinced that management listens. He went on to say that the workers agreed that their success was due to management's willingness to allow new ideas to be put into place from their suggestions. In other words, the attitude of continuous improvement can coexist at all levels in an organization.

Finding 5b

Culture and management/employee relations are especially important during times of change.

In Indiana, the team was convinced that top-down support and direction are essential to more rapid implementation. In this case, identifying projected savings and committing them to research and implementation of new directions can lead to enhanced upper management support. INDOT had already saved 30% in salt with only 10% of the trucks on MDSS; however, the sales approach was based on how much the snowfighters would benefit, not how much money was saved.

Minnesota, for example, finds it very beneficial to arrange short-term (six to 12 months) mobility assignments of field maintenance personnel to the central office to work on research development and implementation. Maintenance workers are respected by their peers, and evidence that the central office has direct field experience among its ranks adds much to the credibility levels between the central office and the field.

Success in achieving new directions is dependent on the extent to which key players have ownership and believe they are receiving value from it. For example, during the stress of plowing snow, operators have to be convinced that the value of MDSS exceeds the extra work and distraction it causes while they are driving.

An ideal example of management caring for operators came up in Fort Collins, CO. Management ordered the installation of a gas-station-like hot dog maker in the crew room. Free hot dogs are provided to drivers during winter emergency events. Breaks do not disrupt the flow of work during emergencies if it is not necessary to leave the premises to obtain food and drink.

Finding 5c

Outsourced vs. in-house work needs to be managed the same, yet they are often managed differently.

Sometimes people are quick to think that outsourcing work means turning over the entire project to a private contractor. During the tour, the team was reminded that outsourcing work is commonly being done at many different levels or to many different degrees; for example:

- Equipment rental only, but operated by the agency
- Equipment with operator, but supervised by the agency
- Equipment with operator, supervised by the contractor, but managed by the agency
- Full turnkey contracts where all road maintenance is managed completely by a private contractor and the agency only inspects for deficiencies

When an agency first finds it necessary to outsource a particular category of work, it often finds that defined expectations used in house are not always adequate for outsourced work. Expectations can be defined as:

- Input based (i.e., quantitative) – number of trucks on the road during the event, the size of the trucks, etc.
- Output based (i.e., methodology) – show-up time, speed of travel, defined application rate, hours of coverage, etc.
- Outcome based (i.e., qualitative) – regain time, achievement of bare lanes or bare pavement, etc.

Mn/DOT uses regain time to measure and monitor in-house winter maintenance performance (see Figure 2-49). This points out that some agencies measure in-house work at the outcome performance level more extensively than other agencies measure performance of outsourced work. On the other hand, some agencies have higher expectations for outsourced work than it appears they expect or deem acceptable in-house.

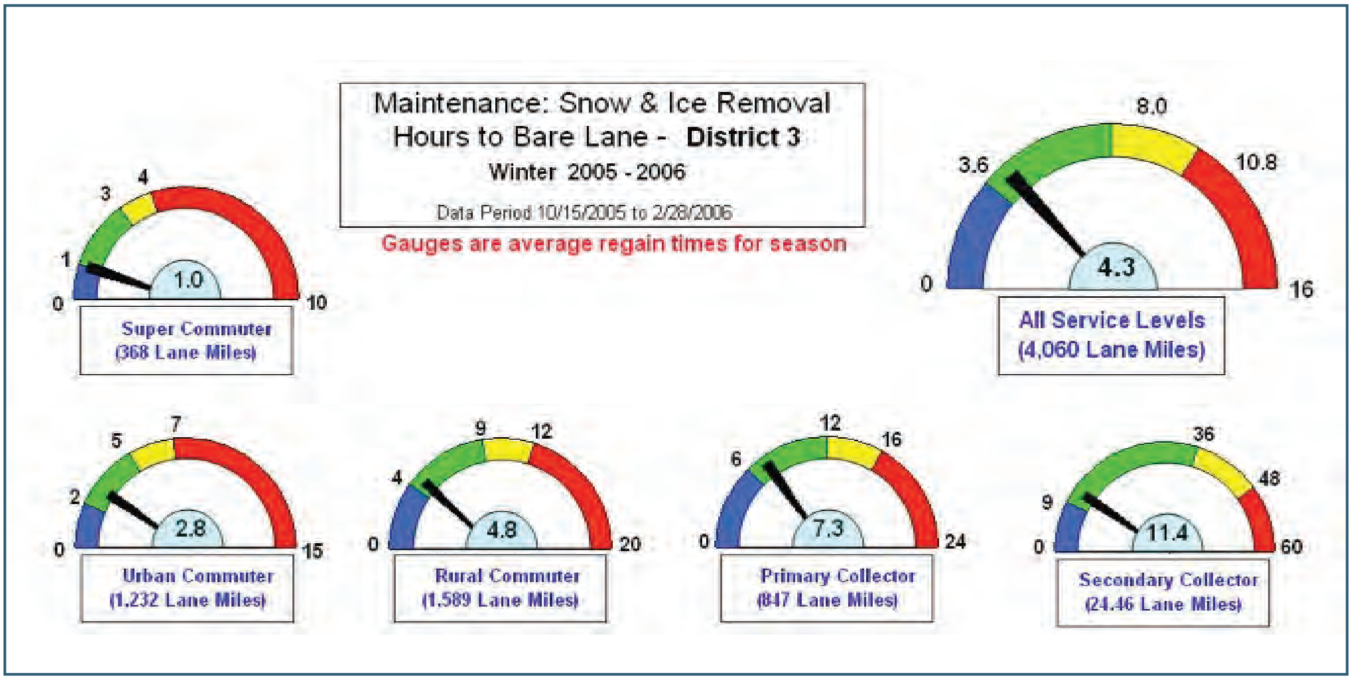

Figure 2-49. *Regain time: The time from the end of an event (e.g., snowfall) until bare lane is obtained. Target regain time is dependent on the road's classification (i.e., traffic volume). Bare lane is defined as driving lanes being free of snow and ice between the outer edges of the wheel tracks; some snow may still remain along centerline and outer edges of pavement. On the chart above, green is satisfactory, yellow and red mean targets were not met, and blue means targets were exceeded (generally at the expense of not meeting targets elsewhere). (Mn/DOT)*

VDOT has, by law, outsourced basically all routine maintenance work on its entire Interstate highway system. Furthermore, budget cuts and forced staff reductions have pressured VDOT into perhaps more outsourcing of non-Interstate maintenance than other states. With the general lack of good performance-based measurements and criteria for maintenance services, VDOT, like others, still basically defines quantity of inputs and methodology to manage its outsourced winter work. Photographs depicting expected results are used to argue payment reductions for unsatisfactory results (see Figure 2-50 and Figure 2-51).

Also discussed during the tour was that pay items for outsourced work vary from agency to agency:

- Pay units of input (e.g., labor hours, equipment hours, etc.)
- Extra pay for show-up or standby time
- Guaranteed hours
- Extra pay for equipping private equipment vs. agency-mounting accessory equipment on private vehicle
- Disincentives for failure to meet expectations

It is acknowledged that management of outsourced work becomes complex if pay items do not directly relate to defined and measured performance expectations

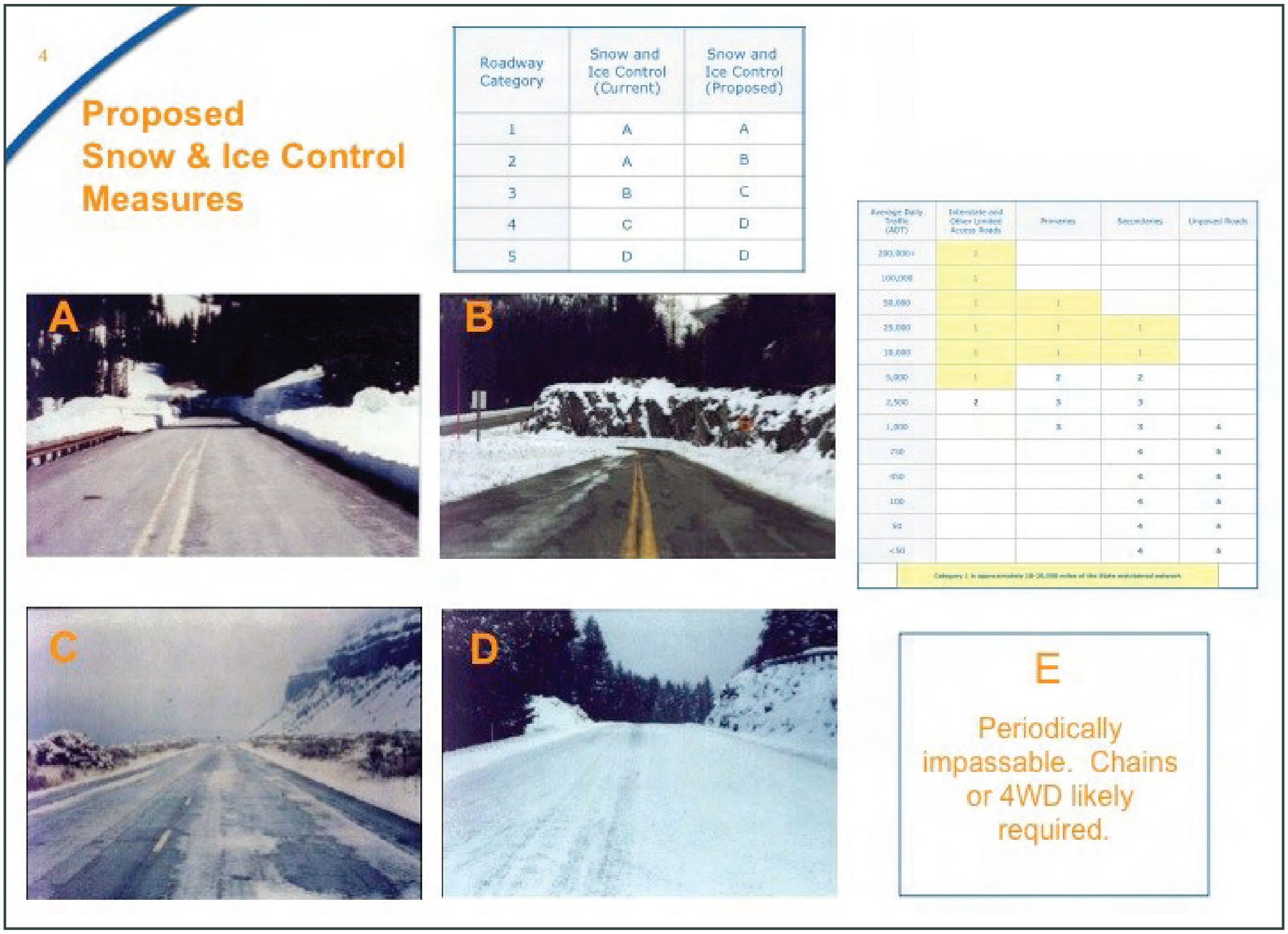

Figure 2-50. *Service levels pictured are used to define expectations. (VDOT)*

Finding 5d

Winter maintenance performance measurement is best done at the outcome level.

Because of the importance of winter maintenance, anything not measured is just practiced. Outcome-based measurements best correlate with how customers achieve satisfaction, thus the development of measures like friction and regain time.

Mn/DOT tracks bare lane indicators, costs, and salt/brine usage for each district. Maps show the time to regain a bare lane in the wheel tracks and less than 1 inch of snow for the rest of the pavement. The driver records the end of the event, together with the time it takes to achieve bare-lane conditions. The belief at Mn/DOT is measure what you want to manage. This is an outcome-based measurement.

Market research conveys what satisfies the public, and such studies indicate that, rather than working toward achievement of full bare pavement, achieving bare lane meets needs. In Mn/DOT, the measurement criteria are based on market research done in the mid-1990s and in 1999 with 1,100 participants. In this research, the public was asked if it was satisfied with various LOS depicted in video clips or photographs. Participants were asked if they would be satisfied with the LOS shown. Customers did not need to see a centerline itself if the wheel tracks were clear; one could assume that the centerline was covered with snow. Once the employees understood and accepted that the measurement reflects what the customer is measuring, negativism on the part of the employees diminished.

UDOT thinks that traffic-speed monitoring also has potential. Others suggest monitoring and recording the frequency and duration of highway closures, because efficiency and system availability have an economic impact on society. Also important, but perhaps more difficult, would be determining an accurate correlation between LOS and vehicular crashes.

Photos of various LOS can be used:

- During focus group meetings to better understand what satisfies the public (market research)
- Prior to a winter season to define and train public or private operators what the expectations are
- During an event to define current conditions

Reporting methods can vary. Dashboard gauges, which are used by both Mn/DOT (see Figure 2-49) and ODOT, show when performance does or does not meet standards as well as when standards are exceeded (exceeding standards indicates over-performance, thus opportunities for savings). Mapping completed routes during an event is an alternative, additional form of reporting. Lastly, graphs and charts showing comparisons between crews, districts, or regions do not necessarily set firm targets. They do, however, motivate operational units to progress to at least the 85th percentile (best practices reporting systems).

3

Scan 07-03 Best Practices in Winter Maintenance

Management Issues

Levels of Service for Snow & Ice Control

Table A

Accumulation (inches)	Priority 1 Routes Treated/Plowed/Cleared	Priority 2 Routes Chemical Treatment & Plowing During the Storm	Priority 3 Residential Streets Sanded/Plowed	Priority 4 Roads Sanding as needed; Plowing when feasible
0-2	100% Bare Pavement within 12 hours after end of storm	Completion within12 hours after end of storm	Sanding as needed; Plowing when feasible	
2-4	100% Bare Pavement within 12 hours after end of storm	Completion within 18 hours after end of storm	Sanding as needed; Plowing when feasible; Roadways passable	
4-8	100% Bare Pavement within 24 hours after end of storm	Completion within 36 hours after end of storm	Sanding as needed; Plowing when feasible; Roadways passable	
8-12	100% Bare Pavement within 24 hours after end of storm	Completion within 48 hours after end of storm	Sanding as needed; Plowing when feasible; Roadways passable	All other roads not in Priorities 1-3
12-18	100% Bare Pavement within 36 hours after end of storm	Completion within 48 hours after end of storm	Sanding as needed; Plowing when feasible; Roadways passable	
18+	100% Bare Pavement within 48 hours after end of storm	Completion within 72 hours after end of storm	Sanding as needed; Plowing when feasible; Roadways passable	
Ice or Freezing Rain	100% Bare Pavement within 12 hours after end of storm	Completion within 12 hours after end of storm	Sanding as needed; Roadways passable	

Figure 2-51. *Levels of service for route priorities (1-4). Bare pavement to be achieved within a specified number of hours after end of storm, depending on snow accumulations. (VDOT)*

Data-gathering mechanisms include automatic data collection (e.g., plow-up, plow-down, and application rates) using MDSS/AVL technology, streaming video from the operator's cab to the dispatcher or from the RWIS site to the TOC, and real-time condition reporting by operators on the touch screens in their cabs.

Finding 5e

Customers measure government by consistency (or lack thereof) of LOS between winter plow routes or across internal organizational lines and even jurisdictional boundaries.

More than once during the tour, agencies mentioned that they work closely with abutting agencies (even adjacent states) to help provide uniform LOS across boundaries. This need is consistent with the market research done in Minnesota, which found that consistency in LOS is of high importance to the public. So the tendency for one crew to outdo another actually makes the agency look bad. And if doing so leads to one crew exceeding LOS objectives, then resources have been wasted.

Using AVL to help two crews turn around where they will meet rather then at some route pre-defined terminus would lead to consistency of LOS. Adjoining agencies or crews getting together before, during, and/or after a winter season to compare snow and ice plans can at least get a conversation going to achieve relative consistency of LOS across jurisdictional boundaries.

Finding 5f

Internal and external communications are important to the success of winter service providers.

Snow and ice plans are prepared in advance, and these plans need to be followed so that everyone is working off the same plan. Equipment mechanics need be involved in planning and meetings because they are part of the emergency team during an event.

Meetings can occur at many different levels and frequencies (e.g., annual pre-season meetings, pre-storm meetings, and post-storm meetings). Some meetings need to involve locals and others need to be statewide, some involve other jurisdictions, some involve adjacent states (to discuss consistency of service across boundaries), and some involve user groups and media.

Agencies are learning how to capitalize on public access to Web sites, including social networking sites (e.g., Twitter). One agency has set up automatic e-mail alerts to subscribers, including schools and trucking companies.

Finding 5g

One agency provides designated drop zones so that stalled and stranded vehicles can be moved off the highway during winter events.

CDOT outsources the removal of stalled, stranded, or stuck vehicles to local towing companies to get around laws that prevent state vehicles from towing or pushing vehicles. In the Denver area, CDOT provides designated off-highway drop zones where such vehicles are taken. Related to incident management, the E-470 PHA has an arrangement with an auto insurance company to financially support or sponsor its incident management operation in return for free advertizing rights on the side doors of the incident response vehicles. This arrangement could also work with other types of companies.

Integration of Weather, Traffic, and Maintenance Operations

Introduction

TOCs and TMCs are designed to be and are becoming very well equipped to monitor, detect, respond to, and disseminate information relative to emergencies and incidents along the roadway. They have the ability to observe activities in real time via cameras, activate traffic warning systems, and override traffic control systems. Their communication system with emergency and law enforcement units is often the most up-to-date system available within their agency.

Incorporating road weather information and forecasts into the TOC is becoming essential. Every winter storm that adversely affects the motorist is increasingly being recognized as an incident or emergency and thus treated more like other traffic incidents. This is leading to increased involvement of the TOC with RWIS and maintenance operations. This is one of the corrective actions VDOT implemented following the Springfield Interchange closure due to an ice storm on February 12, 2009. Other notable examples are Mn/DOT's maintenance dispatcher residing in its TMC and UDOT having a full-time meteorologist assigned to its TOC.

Finding 6a

TMCs are being designed and organized to physically integrate representatives of several disciplines during winter and other emergency/incident-management type events.

Examples already incorporated into one or more TMCs are:

- Since 2003, Utah DOT has a full-time salaried meteorologist in its TOC. He manages five contractor meteorologists whose full-time offices are on the site, even though they have other clients.
- Mn/DOT has a full-time Maintenance Operations dispatcher in its TMC.
- 511 coordinators are commonly associated with the TMC.
- Mn/DOT's TMC has a Highway Patrol dispatcher in the TMC year-round. CDOT does not, but it maintains direct communication with the Highway Patrol.
- Colorado and Minnesota dispatch Courtesy Patrol and Motorist Assistance from the TMC.
- Utah, Minnesota, and Colorado have a Traffic Signal Control coordinator in their TOCs.
- CDOT has a retired maintenance supervisor on call as a TOC operator during events.
- Mn/DOT has a publicly funded FM radio announcer on site every day. At a moment's notice, the announcer diverts to continuous traffic reporting, including winter weather, during winter and other emergency incidents. The announcer reverts to broadcasting jazz music at other times.
- CDOT has a former radio announcer on staff as a TOC operator and therefore maintains a good relationship with the media.
- UDOT provides special space and provisions for housing media representatives during events.

As noted, some of the above integration is full time, year-round, and others are only during incidents, including during winter events.

CDOT is launching a new version of its Web site (COTRIP). The new Colorado Traffic Management System (CTMS) brings in a number of data sources for the operator. The operator still has to enter information from CTMS into COTRIP and 511, but all data sources are in one place, including RWIS, MDSS/AVL, road temperatures, National Weather Service (NWS), Highway Patrol reports, and more.

UDOT's full-time meteorologist manages a contracted private meteorology team that does the actual forecasting from space provided in the TOC. The staff meteorologist teams with maintenance operations in the agency to best utilize the forecasts.

As is done in VDOT, the key benefit to having up-to-date weather forecasting and road conditions in the TOC is that it allows for more timely updates to 511, the phone system, Web sites, and other sources of information to which the public has access.

Some agencies, like CDOT and Mn/DOT, have converted to statewide 800 MHz for all emergency services, including maintenance operations. (Mn/DOT's voice-over ARMER system was extremely valuable during the 35W collapse.)

Traffic signal timing is adjusted on key corridors in response to winter events.

CHAPTER 3

Recommendations and Conclusions by Topical Area

Based on the findings in the previous section, the general recommendations of the scanning team are as follows:

Recommendations

Maintenance Decision Support Systems

- MDSS has proven itself to add effectiveness and efficiency to winter operations; its ROI will greatly increase as its application extends to summer activities.
- To be successful and able to implement MDSS expediently, some marketing and implementation strategies have proven to be more effective than others. Strong support and commitment from upper management is one key element; having a strong change agent in charge of the project who convincingly conveys value to the grassroots employee is another.

Automatic Vehicle Location (AVL) Systems

- AVL systems have multiple uses, many of which are beneficial to employees and operations, and their use is expected to be universally expanded into maintenance operations.
- The higher the resolution (frequency of readings recorded), the greater the cost; however, the lower the resolution, the lower the potential value received.

Equipment Technologies

- Indications are that the tow-plow has great potential in many areas. Tow-plows can be operated by a single driver and crashes have not been a problem. Tow-plows do, however, require that the trucks that pull them meet certain minimum specifications in terms of hydraulics and torque; these trucks are probably not available in existing winter maintenance fleets.
- The concept of hydraulic assist should have the potential to extend the life of some cutting edges (i.e., plow blades) to up to two years.
- The composite of a rubber blade with a carbide insert is well liked and shows promise nationwide.
- Poly (plastic) plow blades should be considered, at least in certain environments.
- Because video cameras expand the snowplow truck operator's range of view and thus enhance safety, their use should be considered.

- Laser beams that project a colored marker forward from the cab onto the snow-covered roadside so that the operator can see where the edge of the wing or tow-plow will extend are economical and most probably cost-effective.
- Though evidence of research was limited, vibrating wiper blades show promise.
- Visibility enhancers like UDOT's fog buster, Mn/DOTs use of HID headlights, and other technologies that enhance the ability for operators to see and be seen should always be pursued and used once they have proven successful.
- It is important that agencies do whatever is necessary to both:
  - Prevent the formation of salt brine at stockpile sites
  - Collect any brine formed from runoff or truck washing at a storage site. Sediment traps permit salt brine runoff to be reused or recycled.

Training and Development

- Flexible workforces need to be considered as demand for services continues to rise and the government downsizing trend continues.
- Cross-training can be successful in supplementing snowplow operators. But serving as a professional snowfighter requires multiple skills and a high degree of commitment. Care must be taken, therefore, in selecting who should be cross-trained. Selections need to be based on capabilities, interest, and attitude. At the end of the training, testing and evaluations are required to determine who is actually skilled enough and qualified to safely be assigned behind the wheel of a snowplow truck, especially part-time and intermittent personnel.
- Several generic and custom-made training programs are available as state-of-the-art examples for use at training academies or symposiums. Real-life simulators coupled with classroom lectures and computer-based programs (e.g., AASHTO CBT) can be used for both initial and retraining purposes.

Management Issues

- Interjurisdictional relationships are important to promote consistent LOS between otherwise invisible governmental boundaries.
- More work needs to be done to develop improved outcome-based and customer-oriented performance measurements (e.g., regain time, friction measurement, speed monitoring, and road closure frequency/duration). These measurements need to be implemented, applied, and reported to better manage both in-house and outsourced winter maintenance services.
- More winter maintenance agencies need to copy models of dedicated and recurring funding for operational maintenance research funding. Successful models lead to grassroots ownership, thus the creation of a continuous improvement culture and improved relationships between employees and management.

Integration of Weather, Traffic, and Maintenance Operations

- Integrating traffic operations, weather forecasting, maintenance operations, highway patrol, media, and incident management into TOCs is proving to be a best practice.
- Better approaches for conveying real-time traveler information to the public using 511, Web sites, e-mail alerts, and text messaging are emerging. Information related to traffic conditions, surface conditions, and weather forecasting is being disseminated.

- ❖ Implementation of special signal timing plans during winter events has the potential of improving traffic flow for the traveling public, as well as for the snowplow operators.

Conclusions

Overall conclusions from the scanning tour are as follows:

- ❖ **MDSS** has proven itself an effective winter maintenance tool. It was shown to improve operational efficiency through resource savings. It was also found that implementation of MDSS is not an easy effort. Agencies must make a deliberate financial and cultural commitment. If an agency decides to implement MDSS, it is recommended that top staff openly declare its full support of the effort and that specific implementation strategies be developed that foster support and understanding at all maintenance staffing levels.
- ❖ **AVL systems**, which used to be resisted because of the perception that they were big brother watching, are now perceived as providing an advantage to both management and workers. AVL increases the ability of operational managers and dispatchers to better adjust operations during a winter event, thus reducing the amount of decision-making operators have to make on their own. AVL allows operators to focus instead on driving safely in heavy traffic during the toughest conditions that exist. Tough economic times have pushed winter service agencies from having all snowfighters be experienced professionals to situations where plow operators are generalists or shared workers, often used only intermittently. In some cases, drivers and trucks are being provided by the private sector. AVL technology can help agencies bridge the gap as these new challenges are faced. Using AVL to automate labor, material, and material usage and automatically record work accomplishment is a further benefit to both worker and manager.
- ❖ Considerable **development and enhancement of existing technology** have occurred to improve the performance, efficiency, and durability of ice- and snow-fighting equipment. Cost-effective means of increasing productivity and reducing equipment downtime, while at the same time extending equipment service life with innovative wash facilities, are common themes in the organizations the team visited. There have been advancements in plow blade technology and configuration, winter chemical manufacturing, and chemical application systems. Almost all winter service organizations can relate to ways in which the successful, cost-effective innovations cited within the findings of this report can improve their own operations. Providing funding to test and incorporate new technologies appropriately into their own operations will be the next step.
- ❖ As the pressure for governmental agencies to downsize continues, they need to seek out and study the models of **flexible workforces and cross-training** that are in practice at other agencies. The challenge of maintaining a trained workforce is magnified by the need to capitalize on new methods and new technology, all requiring more enhanced training and retraining. The worst-case scenario for training is where winter maintenance is outsourced and, at least initially, core competencies differ even more, at least to the extent that their attitude toward public service may need to be nurtured. As a result, today's agencies need to place a lot of emphasis on training and development. Benchmarking of proven lesson plans and techniques is one way to minimize cost and, at the same time, expedite curriculum development.
- ❖ Customers today continue to have high expectations, but their trust and support of the government providing services for them is eroding. Their willingness to pay has deteriorated as government fails to measure itself from the same point of view that the customer does. Customers expect seamless levels of service from route to route, from district to district, and even from city to city. In-house crews seek new ways to be efficient while political pressure suggests that the private sector can produce work more effectively, irrespective of cost. Either way, managers need to develop **performance levels that are measurable and correlate with customer expectations**. Furthermore, government managers need to align their cost system

so that it can correlate and be compared with the private sector systems enough to select which activities, if any, are most susceptible to being outsourced.

- **TOCs can and should serve as the hub** from which all existing and emerging road weather management advisory, control, and treatment strategies and technologies are dispatched to improve daily operations and decision-making capabilities for transportation agencies.
  - Advisory strategies include 511, Web site, and e-mail alerts.
  - Control strategies include special signal timing, changeable message boards, and other tactics.
  - Treatment strategies include maintenance operation and incident management.

Integrating maintenance operations, weather forecasting professionals, incident response, and enforcement into the TOC during winter emergencies has great potential to avoid gridlock and reduce crashes, therefore enhancing the safe mobility of the traveling public.

CHAPTER 4

Implementation Strategy

Introduction

The winter maintenance community in the U.S. is fortunate to have several conduits to disseminate the findings and recommendations of this scanning tour. Several are small group committees that meet regularly and/or organize and sponsor conferences for larger audiences. Others are pooled fund programs that actually sponsor winter-related research for the winter maintenance community and share the results.

Potential inter-maintenance audiences represent separately or together all levels of U.S. public agencies from city to county to state to national; others are international in scope. In most cases, participants include both the public and private sectors.

Information can be shared one-on-one, in small group discussions, or as formal presentations in front of a conference audience. In addition, documents can be easily disseminated both in hard copy and in digital form. There is potential of sponsoring or sharing Web sites as well as using options such as podcasts, webinars, and blogs. In this electronic age, the possibilities are many and can be taken advantage of as opportunities present themselves.

Implementation Activities

More specifically, there are several regularly scheduled venues where this project's findings can be disseminated as oral presentations. As of this report's submission date, scanning team members have been, or are already, scheduled and committed to many conferences. In addition, there are potentially several other, more local venues where findings will be shared.

Also emerging are new and exciting ways to provide findings electronically on the Web, including both written documents and video presentations. Special winter maintenance Web sites and blogs can be developed. Photos can be shared and discussion initiated via social networking sites (e.g., Facebook, MySpace, and Twitter). Live discussions can be scheduled and conducted for individualized audiences via webinars.

The list of potential opportunities is long; in time, the list will become longer. Whenever two or more winter maintenance community members meet, another new idea is likely to emerge.

Implementation activities include, but are not limited to, the following:

Short Term

- Presentations at scheduled conferences (most scheduled at least annually)
    - PIARC World Road Association Winter Road Congress (2010, Quebec City)
    - TRB Annual Meeting
    - TRB Winter Maintenance Committee
    - TRB Committee on Surface Transportation Weather
    - TRB Snow & Ice Symposium (2012)

  - AASHTO Subcommittee of Maintenance
  - Pacific Northwest Snowfighters
  - APWA American Public Works (Winter Maintenance Committee)
  - NACE National Association of County Engineers
  - AASHTO Eastern Snow Expo
  - APWA National Congress (September 2009, Columbus, OH)
- Presentations to pooled fund organizations
  - SICOP WMTSP
  - Clear Roads
  - Aurora
  - Clarus Initiative
  - PNS
- Other meetings
  - National Winter Maintenance Peer Exchange
  - MDSS Showcase
- Webinars

Medium Term

- Identify potential projects with pooled fund organizations
- Coordinate activities with Lee Smithson, SICOP coordinator
- Promote more MDSS-type showcases
- Establish a Winter Maintenance Best Practices Web site to post the final report and presentations, plus allow new best practices to be added as they are identified

Longer Term

- Assist in developing Problem Statements for NCHRP
- Identify funding sources for covering travel and other expenses for the above activities, including, possibly:
  - NCHRP 20-68A
  - One or more already-in-place pooled fund
  - FHWA

In summary, the team members, together with their peers, are committed to capturing every opportunity that comes along to better implement the things learned from this scanning tour.

APPENDIX A

Scan Team Biographical Information

Benjamin (Ben) B. McKeever (DOT/FHWA Co-Chair) is a program manager in the Research and Innovative Technology Administration (RITA), ITS Joint Program Office (JPO), where he oversees the Real-time Traveler Information program and the Road Weather Management program. He currently develops new work areas, coordinates strategies and funding priorities, and monitors overall effectiveness for each of the programs. In addition, he serves as liaison to the I-95 Corridor Coalition. He ensures that Coalition projects are aligned with the ITS Program's strategic objectives and that the ITS Program can transfer the lessons learned from the I-95 Corridor to other areas of the country. Prior to joining USDOT, McKeever worked for three years as a project manger at the Metropolitan Transportation Commission (MTC) in Oakland, California. There he managed several traveler information projects for MTC's award-winning 511 program as well as the Vehicle Infrastructure Integration (VII) test bed project, a joint Caltrans and MTC initiative deploying and testing VII technology and applications in the Bay Area. Prior to joining MTC, McKeever worked for eight years as a consultant, where he served as project manager/engineer on numerous transportation-engineering projects with emphasis in ITS planning, design and evaluation. He holds a master's degree in Transportation Engineering from The University of Texas at Austin and a bachelor's degree in Applied Mathematics from the University of Virginia. He is a registered civil engineer in California and Missouri.

William (Bill) H. Hoffman (AASHTO Co-Chair) is the Chief Maintenance and Operations Engineer for the Nevada Department of Transportation (DOT) in Carson City, Nevada. Hoffman currently is responsible for administering the Statewide Maintenance and Operations Programs for the Nevada DOT. He also has a responsible role in the research and implementation of innovative technology in the area of snow and ice control. His current research emphasis includes Maintenance Decision Support Systems, Mobile Data Collection, and Winter Maintenance Concept Vehicles. Hoffman has served with the Nevada DOT for more than 15 years. He is a graduate of the University of Nevada-Reno and holds a Bachelor of Science degree in Civil Engineering. He is a licensed professional engineer in the State of Nevada and serves on several committees. Hoffman chairs the AASHTO SCOM Snow and Ice Task Force, is the Vice Chair of the Aurora Winter Maintenance Pooled Fund and sits on the Winter Maintenance Technical Services Program Committee (SICOP).

Steven M. Lund is the State Maintenance Engineer for the Minnesota Department of Transportation. He is the Director of the Office of Maintenance, which provides statewide support to the department in the areas of fleet management, emergency management, maintenance training, and contract support, along with various other statewide maintenance management support services. Lund has been with the Minnesota Department of Transportation for approximately 25 years and has held a variety of Central Office and District positions. He graduated from the University of Minnesota with a bachelor's degree in Civil Engineering. He is a professional engineer registered in the State of Minnesota. He serves on the AASHTO Subcommittee of Maintenance and is the Vice Chair of the Performance Management Focus Group.

Terry J. Nye is a 27-year veteran of the Pennsylvania Department of Transportation. The past 17 years, he worked as the Assistant District Executive in Engineering District 1-0. Nye has been in charge of Maintenance Operations for the last three years, which includes winter services over the six-county region based in the northwest corner (the snowbelt region) of the state. This region can receive in excess of 300 inches of snow due to the proximity of Lake Erie, creating the most challenging winter service operations in the state. Included in maintenance responsibility are over 3,700 miles of roadways and 2,084 bridges, with a support workforce of approximately 650 people, spread throughout six counties. Nye is a 1981 graduate of Penn State University with a Bachelor of Science degree in Civil Engineering and holds a professional engineering license. He also is a member of the Association of State Highway Officials.

David (Dave) J. Ray is the State Maintenance Engineer for the Ohio Department of Transportation. Ohio's state maintenance efforts are carried out by 2,500 dedicated employees operating more than 1,500 trucks with plows to cover 43,000 lane miles working out of more than 200 maintenance facilities. Ray is a licensed engineer and professional land surveyor. The state maintenance office develops policies that include snow and ice control and winter material usage and provides maintenance support to Ohio's transportation districts. He utilizes education along with more than 22 years of transportation experience to help keep traveling customers safe during the winter and maintains Ohio's transportation system during all seasons. Ray holds a bachelor's degree in Civil Engineering from Youngstown State University and a master's degree in Business Administration from Cleveland State University. His field experience includes various management positions in three of Ohio's transportation districts. Ray has taught engineering classes at three colleges or universities. He is a member of the American Public Works Association and is a planning committee member of the annual North East Ohio's Snow and Ice Technologies Workshop.

Michael D. Schwartz is a Program Analyst with the Virginia Department of Transportation Central Office Maintenance Section in Richmond, Virginia. He is one of the team members that compiles, reviews, and evaluates the Turnkey Asset Maintenance Service contracts and contractor performance throughout Virginia. These contracts are for routine and ordinary maintenance that include contracted snow operations on the interstate system. Schwartz has more than 27 years' experience with VDOT and is involved in numerous snow-related duties that began with driving a snowplow and included supervising snow operations, developing snow-removal plans, and teaching snow-response classes for maintenance crew members.

Rodney (Rod) A. Pletan (Subject Matter Expert) is a retired State Maintenance Engineer from the Minnesota Department of Transportation (Mn/DOT). He currently works as a maintenance management consultant and teaches the maintenance operations and management course as part of a public work curriculum at the college level. During his 40-year association with Mn/DOT, he promoted advanced winter maintenance technologies both internally and externally. He served two years as loaned staff to the American Association of State Highway and Transportation Officials (AASHTO), coordinating its Snow and Ice Pooled Fund Cooperative Program (SICOP). Pletan was active in several research committees and expert panels for ASSHTO, the Strategic Highway Research Program (SHRP), the Federal Highway Administration (FHWA), the National Cooperative Highway Research Program (NCHRP), the World Road Association Committees of Road Management (C6), the Winter Road Congress (G1), and the Transportation Research Board (TRB). He chaired the Winter Maintenance Committee for TRB. Post-retirement, Pletan co-authored a report entitled Best Practices of Outsourcing Winter Maintenance Service and directed the rewrite and update of the Maintenance Manual for Mn/DOT. He graduated with a bachelor's degree in Civil Engineering from the University of Minnesota. He retains his license as a registered professional engineer in Minnesota.

APPENDIX B

Scan Team Contact Information

Team Composition

1-FHWA (Co-Chair)
5-AASHTO (to include Co-Chair)
1-Subject Matter Expert (SME)
7-Total

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APPENDIX C

Presentations and Handouts by Host Agencies

Minnesota DOT

Maintenance Overview, PowerPoint presentation by Steve Lund and Sue Loudal, 14 slides

Winter Maintenance Performance Measures, PowerPoint presentation by Steve Lund, 22 slides

Annual Snow and Ice Plan, PowerPoint presentation by Steve Lund, 4 slides

District Engineer's Monthly Report – 2008-09 Snow & Ice Season, PowerPoint presentation, Steve Lund, 28 slides

Program and Project Management System (PPMS) & Work Management System (WMS), PowerPoint presentation by Rocky Haider, 10 slides

Winter Maintenance Operations, PowerPoint presentation by Gabe Guevara, 29 slides

Clear Roads, Maintenance Manual Chapter 2, digitized handout, 51 pages

Research & Training Overview, PowerPoint presentation by Linda Taylor, 18 slides

Snowplow Operator Training (SPOT), PowerPoint presentation by Rick Shomion, 18 slides

Mn/DOT Plow Trucks, PowerPoint presentation by Ryan Otto, 15 slides

Salt Solutions Program, PowerPoint presentation by Joe Huneke, 18 slides

Snowplow Simulator Training, PowerPoint presentation by Andy Kubista, 26 slides

Metro District Snow & Ice Operations 2008-09, PowerPoint presentation by Beverly Farraher and Mark Fischbach, 17 slides

Maintenance Business Management Team (MBMT) Mission Statement & Meeting Minutes, digitized handout by Steve Lund, 2 pages

AVL/MDSS Project Business Plan, digitized handout by Steve Lund, 14 pages

Draft: Mn/DOT Deployment Plan for AVL/MDSS, 3/24/2009, digitized handout by Steve Lund, 8 pages

RWIS, AVL & MDSS in Mn/DOT, PowerPoint presentation by Curt Pape, 19 slides

Mn/DOT Snow & Ice Equipment, PowerPoint presentation by Randy Cameron and Bob Ellingsworth, 23 slides

FY 2009 Plow Truck Standard, handout by Bob Ellingsworth, 1 page

Cedar Ave Truck Station, handout by Gary Bergeson, 2 pages

A Snowplow — COOL!, public service DVD warning children to not build snow forts near streets

FAST User Training Session — 35W Bridge, PowerPoint presentation and digitized training manual on CD, provided by Boschung America, 81 slides

Colorado DOT

Snow Removal in Colorado – Where We've Been, Where We Are and Where We Are Going, PowerPoint presentation by Phillip Anderle, presented by David Wieder, 60 pages

E-470 Public Highway Authority - Toll Highway

Surface System Inc (SSI) Weather Data Tabulations and Charts, handouts, presentation by Matt Alexander

City of Fort Collins

Welcome, Street Operations, We Know Snow Campaign, and Stormfighting Technology Tools, PowerPoint presentation by Larry Schneider, Neal Jaspers, Holli Keyser, Scott Bowman, and Stan Welsch, 41 slides

City and County of Denver

MDSS Demonstration 3, PowerPoint presentation by Pat Kennedy, 21 slides

City of Grand Junction, CO

Snow & Ice Program Presentation, PowerPoint Presentation by Dave Van Wagoner, 22 slides

Snow & Ice Control Plan, 1/5/06, handout by Doug Cline and Dave Van Wagoner, 26+ pages

SnowPlan, brochure for public use, 2 pages

Sample Reports – Templates, Charts and Tables, digitized handouts by Dave Van Wagoner, 15 pages

Utah DOT

Guideline and Procedure Update – Utah DOT Traffic Operations Center, digitized handout, 8 pages

Mobile Fog Dispersal, handout, 1 page

Tow-Plow, demonstration movie on CD

Indiana DOT

INDOT Presentation, Indy Sub & Greensburg Unit, PowerPoint presentation by Tom McClellen, 23 slides

MDSS Forecasted Data, Sample Charts and Graphs, PowerPoint presentation, 7 slides

MDSS Observed Data, Sample Charts and Graphs, PowerPoint presentation, 14 sides

Change of Seasons – Seasons of Change, PowerPoint presentation by Tony McClellen, 45 slides

Virginia DOT

Traffic Operations Centers and 511Virginia, PowerPoint presentation by Michael Washburn, 19 slides

Winter Maintenance Equipment Technology, PowerPoint presentation by Branco Vlacich, 21 slides

Automatic Vehicle Location Test Program, PowerPoint presentation by William Brown, 25 slides

MDSS = Maintenance Decision Support System, PowerPoint presentation by Allen Williams, 5 slides

Snow Removal Workforce Training and Development, PowerPoint presentation by Dan Roosevelt, 27 slides

Management Issues, PowerPoint Presentation by Robbie Prezioso, 10 slides

APPENDIX D

Key Contacts in Host Agencies

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APPENDIX E

Internet Web Sites

(Used Primarily for Desk Scan)

AASHTO Innovative Highway Technologies – Anti-icing/RWIS

http://leadstates.transportation.org/rwis/

APWA Sub-Committee on Winter Maintenance

http://www.apwa.net/About/TechSvcs/Transportation/Winter-Maint/

FHWA Road Weather Management

http://www.ops.fhwa.dot.gov/weather

Pacific Northwest Snowfighters (PNS)

http://www.wsdot.wa.gov/partners/pns/default.htm

AASHTO Snow and Ice Pooled Fund Cooperative Program

http://www.sicop.net/?siteid=88

AASHTO Center for Environmental Excellence

http://environment.transportation.org/environmental_issues/construct_maint_prac/compendium/manual/

FHWA Listing of State Transportation Department Web Sites

http://www.fhwa.dot.gov/webstate.htm

Clarus Initiative

http://www.clarusinitiative.org/

Aurora

http://www.aurora-program.org/

Clear Roads Pooled Fund Project

http://www.clearroads.org/

Research and Innovative Technology Administration (RITA) Intelligent Transportation Systems

http://www.its.dot.gov/library.htm

Intelligent Transportation Society Rocky Mountain Chapter

http://www.itsrm.org/

Intelligent Transportation Systems Course FHWA-NHI-137030, Principles and Tools for Road Weather Management

http://www.nhi.fhwa.dot.gov/training/course_detail.aspx?num=FHWA-NHI-137030&cat=&key=road+weather&num=&loc=&tit=&sta=%25&typ=%25&lev=%25&ava=1&str=&end=&drl

City and County of Denver, CO

http://www.denvergov.org

COTRIP Traveler Information

www.cotrip.org

APPENDIX F

Other Reports, Presentations, and References

(Used Primarily for Desk Scan)

MDSS

Transportation Pooled Fund Study TPF-5(054) Fact Sheet, *Maintenance Decision Support System*, June 2007, Dave Huft, South Dakota Department of Transportation.

Huft, David L, Leon F. Osborne, *MDSS Development & Deployment,* Transportation Pooled Fund Study TPE-5(054), presented at the MDSS Stakeholders Meeting #10, Reno, NV, August 6, 2008

Smithson, Leland D, *MDSS—The U. S. Success Story,* presented at Management Systems to Support Winter and Summer Road Maintenance Decision-Making, 2007 Annual Conference of Transportation Association of Canada Saskatoon, Saskatchewan

American Association of State Highway and Transportation Officials (AASHTO), *MDSS-Maintenance Decision Support System—Guiding Your Customers Through the Storm*, January 2008

Petty, Kevin R., William P. Mahoney III, James R. Cowie, and Arnaud P. Dumont, National Center for Atmospheric Research, "Providing Winter Road Maintenance Guidance, An Update of the Federal Highway Administration Maintenance Decision Support System," Transportation Research Circular E-C126, Transportation Research Board of the National Academies, Washington, D.C., 2008, pp 199–214.

Hart, Robert D., John J. Mewes, Benjamin W. Hershey, Leon F. Osborne, Jr., and David L. Huft, "An Overview of Implementation and Deployment of the Pooled Fund Study Maintenance Decision Support System," Transportation Research Circular E-C126, Transportation Research Board of the National Academies, Washington, D.C., 2008, pp 229–239.

Kennedy, William (Pat), "Maintenance Decision Support System Is Not Just for State Departments of Transportation," Transportation Research Circular E-C126, Transportation Research Board of the National Academies, Washington, D.C., 2008, pp 240–249.

Strong, Christopher K., and David L Huft, "Benefits and Costs Associated with Maintenance Decision Support Systems," Transportation Research Circular E-C126, Transportation Research Board of the National Academies, Washington, D.C., 2008, p. 641.

U.S. DOT ITS Joint Program Office, U.S. Department of Transportation, *A Case Study of the Maintenance Decision Support System (MDSS) in Maine*, 2007I, by Cris Cluett and Jeffrey Jenq, Battelle Seattle Research Center, Source: http://ntlsearch.bts.gov/tris/ntlc/itsjpo/record30234.shtm

Kernan, Dean, *Illinois DOT – MDSS … A Smart Investment*, Web Conference presentation, Sept. 30, 2008

Goodwin, Lynette C., *Best Practices for Road Weather Management*, Mitretek Systems, Inc, for Paul Pisano, FHWA, May 2003

Murphy, Ray, *MSDD Update*, presentation by FHWA at Webinar, September 30, 2008

McKeever, Ben, *Road Weather Management Program – An Overview*, presentation by FHWA at Webinar, September 30, 2008

Kennedy, Pat, *VII & Road Weather,* presentation by FHWA at Webinar, September 30, 2008

McKeever, Ben, *The* Clarus *Initiative,* presentation by FHWA at Webinar, September 30, 2008

Roemer, Alfelor, *Performance Measures for Road Weather Management*, presentation by FHWA at Webinar, September 30, 2008

Kennedy, Pat, "Transportation Technology Aids in Urban Snow Response," *ITS Rocky Mountain Chapter Newsletter,* 10/21/07

McClellan, Tony, "Alphabet Soup," article in Roads and Bridges, October 2008, pp 28-31.

AVL/GPS/VII

Shi, Xianming Ph.D., Christopher Strong, Robb E. Larson, David W. Kack, Eli V. Cuelho, Nabil El Ferradi, Aswinkumar Seshadri, Katgie O'Keef, and Aaura E. Fay, NCHRP Project No. 20-7(200), *Vehicle-Based Technologies for Winter Maintenance: the State of the Practice,* Western Transportation Institute, Montana State University, AVL pp 7–25.

Meyer, Eric, *Cost-Benefit Assessment of Implementing AVL in KDOT Maintenance Vehicles,* June 2002

Strong, Christopher, Nabil El Feradi, and Xinming Shi, *State of the Practice of Automatic Vehicle Location for Winter Maintenance Operations,* Transportation Research Annual Meeting 2007 CD paper number 07-3003, Transportation Research Board of the National Academies, Washington, D.C by Western Transportation Institute, Montana State University.

Petty, Kevin R., and William P. Mahoney, *Weather Applications and Products Enabled Through Vehicle Infrastructure Integration (VII): Feasibility and Concept Development Study,* National Center for Atmospheric Research, January 2007

Petty, Kevin R., and William P. Mahoney, *Enhancing Road Weather Information Through Vehicle Infrastructure Integration (VII),* National Center for Atmospheric Research, paper presented at TRB Annual Meeting, January 2007

Stern, Andrew D., Paul A. Pasano, Patrict J. Kennedy, Kevin R. Petty, and William P. Mahoney, *A Next Generation of Observations Based on Passenger Vehicles,* Noblis, Inc., FHWA and National Center for Atmospheric Research, 2008

Pisano, Paul, Lynette C. Goodwin, and Blake P. Christie, *ITS Standards Impacting the Maintenance Community,* FHWA & Noblis, ITS Division, July 2007

Equipment Technology

Tilley, Jeffrey S., Scott S. Kroeber, Jennifer Green, Diana Clonch, and Don Halliday, “Measurements of Pavement Condition and Road Weather Environment Within North Dakota Using a Tow-Hitch Mount Road Grip Tester,” Transportation Research Circular E-C126, Transportation Research Board of the National Academies, Washington, D.C., 2008, pp 364–378

WisDOT Synthesis Report, *Using Friction Measurements to Gauge Winter Maintenance Performance,* for Clear Roads Pooled Fund Study, by CTC & Associates LLC, WisDOT Research & Library Unit, 03/25/08

Bell, G. T., W. A, Nixon, R. D. Stowe, *A Synthesis to Improve the Design and Construction of Colorado’s Bridge Anti-Icing Systems,* Colorado DOT Report #CDOT-2005-19, January 2006

Shi, Xianming Ph.D., Christopher Strong, Robb E. Larson, David W. Kack, Eli V. Cuelho, Nabil El Ferradi, Aswinkumar Seshadri, Katgie O’Keef, and Aaura E. Fay, NCHRP Project No. 20-7(200), *Vehicle-Based Technologies for Winter Maintenance: The State of the Practice*, Western Transportation Institute, Montana State University, FAST, pp 67–78

Bridge, Paul, “Noninvasive Road Weather Sensors,” Transportation Research Circular E-C126, Transportation Research Board of the National Academies, Washington, D.C., 2008, pp 407–415 (2008).

Training

WisDOT Synthesis Report, *Virtual Snowplow Training: State of the Practice and Recent Research,* CTC & Associates LLC, WisDOT Research & Library Unit, 03/25/08

Strayer, David L, Frank A. Drews, and Stan Burns, *The Development and Evaluation of a High-Fidelity Simulator Training Program for Snowplow Operators,* University of Utah, Department of Psychology, for Utah DOT, November 2004

Commercial Motor Vehicle Operator Snowplow Operator Training (SPOT), Minnesota Department of Transportation, 08/16/05

Kihl, Mary, and Pete Wolf, *Using Driving Simulators to Train Snowplow Operators: Lessons Learned from Some Preliminary Evaluations,* Arizona State University, presented at TRB, January 2007

Roemer, Alfelor, *Road Weather Management Training and Outreach,* presentation by FHWA at Webinar, September 30, 2008

Management Issues

Loh, Wei-Yin, Siao (Shaw) Wujin (Chin), and Mike Sproul, *Development of New Performance Measure for Winter Maintenance Using Vehicle Speed Data,* University of Wisconsin-Madison and WIDOT, presented at TRB, January 2008

Caldwell, Jeff, *Evacuating Tradition*, regarding VDOT’s Emergency Response Program, article in *Transportation Management & Engineering (TME)* magazine, October 2008, pp 12–15.

Stidger, Ruth W., *Managing City Streets This Winter*, article in Better Roads magazine, October 2008, pp 38–39.

Stapp, Richard, and Rodney Pletan, *Best Practices of Outsourcing Winter Maintenance Services,* funded by VMS, Inc, June 1, 2001, 29 pages plus appendices.

TMC/Weather/511

Strong, Christopher, and Xianming Shi, "Integrating Weather into Transportation Operations – A Utah Department of Transportation Case Study," Transportation Research Circular E-C126, Transportation Research Board of the National Academies, Washington, D.C., 2008, pp 318–333.

Integration of Emergency and Weather Elements to Transportation Management Centers – Baseline Conditions Report, by Battelle, for FHWA, May 20, 2005

Roemer, Alfelor, *Weather Responsive Traffic Management (WRTM),* a presentation made at Webinar, September 30, 2008