Optimized and Sustainable Winter Operations in Canada and the United States

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Paper prepared for presentation
at the

Innovations and Opportunities in Maintenance Methods and Practices

Session
of the 2012 Conference of the
Transportation Association of Canada
Fredericton, New Brunswick

ABSTRACT

Climate change is becoming a reality in Canada and United States bringing record setting winter storms with some of the lowest temperatures and heaviest snowfalls and ice storms experienced in modern times. These massive storms caused major impacts to the economy, resulting in billions of dollars lost. However, it could have been much worse without the right snow removal equipment, advanced RWIS and chemical application technologies and a trained workforce.

This paper documents how research findings, from the comprehensive U.S. Strategic Highway Research Program (SHRP), combined with discoveries, from the International Winter Maintenance Technology Scanning tours produced better methods to accomplish winter maintenance, improve transportation safety and reliability and enhance winter hazard mitigation. Successful courses of action used to take SHRP winter maintenance research in road weather and forecasting, anti-icing, snow and ice control equipment, and new chemistry from theory to operational state-of-the-practice are presented.

Although these proactive snow and ice control operations in Canada and the US are reported to be more efficient and effective, their negative impact to the receiving natural environment remains a concern. This paper examines how those negative impacts are being minimized by using improved and more comprehensive road/weather forecasts, optimized treatment recommendations and better snow and ice control equipment. The paper will then illustrate how these optimized operations will evolve into more sustainable solutions that will integrate into the PIARC B-5, Winter Services Committee, “triple bottom line” (economic concerns, societal interests, and environmental protections) concept models being developed for world-wide use.

TEXT

Introduction

Snow and ice control operations world-wide have undergone major changes in the past twenty years. Winter operations traditionally relied on the hand-me-down knowledge and experience of older field supervisors and fellow workers to interpret an atmospheric forecast into a snow and ice control plan for each storm. The response was reactive process of watching upstream as the storm approached, letting the snow begin to accumulate and then activating the crew to apply brute force to scrape compacted snow and sand the curves and stop approaches as needed. The meteorological community concentrated on the upper atmosphere and did not consider the influence of the earth’s mass on the temperature at the roadway surface.

During the past two decades research, operations and meteorological communities around the world have collaborated to develop and implement improvements in winter maintenance. A new science of surface transportation weather has evolved and new pro-active technologies were developed and integrated into snow and ice control operations. These efforts have resulted in more efficient and effective snow and ice control operations that provide safer roadways, improved and more reliable mobility, and increased consideration for the receiving environment.

The Surface Weather Forecasting and Decision Support System Evolution

The first efforts to connect the maintenance snow and ice control and the meteorological communities began in the mid-1990s as they worked together to build on the road weather information systems (RWIS) and anti-icing research completed in early 1990s by SHRP [1-4]. Although the SHRP research results were sound, technology transfer was difficult and did not produce consistent field results. The Federal Highway Administration in an effort to improve the basic understanding supported additional field studies. The project, known as TE28, enabled the maintenance operations and the meteorological communities to concentrate their efforts to improve the basic understanding of the microclimate at the road surface and develop appropriate treatment responses. A manual of practice was developed which pulled together the results of field tests into a description of winter maintenance operations decision-making processes for eight winter storm scenarios [5].

In an effort to deepen the science and its field applications, the FHWA and the Office of the Federal Coordinator for Meteorology of the U.S. Department of Commerce extended the TE28 work by involving a wide range of stakeholders from the winter maintenance community in two collaborative efforts: the Surface Transportation Weather Decision Support Requirements (STWDSR) activity which began in 1999 and the Weather Information for Surface Transportation (WIST) project which started in 2000 to identify and fully define needs in the field of surface transportation weather [6].

Annual stakeholder meetings were held where problems were analyzed and solutions proposed and successful outcomes were discussed. The major outcome from the stakeholder meetings was a consensus to develop a maintenance decision support system (MDSS) to integrate computerized winter maintenance practices developed from the TE28 manual or practice treatment recommendations and user requirements identified in the STWDSR and WIST efforts with state of the art weather forecasting models [7]. FHWA funded the development of a Federal Prototype MDSS with the National Science Foundation’s National Center for Atmospheric Research providing the technical lead. Others joining the team included The U.S. Army Cold Regions Research and Engineering Laboratory, the Massachusetts Institute of Technology-Lincoln Laboratory, and the NOAA National Severe Storms Laboratory and Forecast Systems Laboratory.

Three Iowa DOT maintenance garages field-tested and evaluated the Federal MDSS Prototype during two winters, starting in 2002. Start-up problems during the first winter were traced to the road weather forecasting models, which were being field-tested for the first time. In the second winter, implementation went well with several of the recommended treatments applied without modification and other recommendations requiring only minor modifications. The third year of field demonstrations took place in the winter of 2004-2005 in central Colorado.

This location provided new challenges for the MDSS prototype to address the more complex terrain around the Denver area instead of the relatively flat terrain of central Iowa. The Colorado demonstration showed that weather forecasting was much more difficult on the leeward side of the Rocky Mountains which subsequently lead to significant improvements to the forecasting components of the Federal MDSS prototype and corresponding improvements in the treatment recommendations. The Colorado DOT reported the start and stop times for precipitation were very close resulting in increased efficiency in their operations.

Another outcome from the stakeholder meetings was a need to have a better understanding of the RWIS station data. Little was known about the characteristics of the locations of the RWIS stations. Metadata such as location (on a hill or in a valley or flat open terrain, orientation to the sun, etc.) was needed. FHWA in response to this data issue began a project in 2003 to establish guidelines for siting RWIS environmental sensor stations (ESSs). The project was finished in 2005 and a report presenting criteria for siting tower locations and mounting various sensors and the camera was published [8].

Another issue that surfaced at the stakeholder meetings was the accuracy of the RWIS generated data was uncertain and not in a common format. The U.S. DOT, Federal Highway Administration's (FHWA) Road Weather Management Program (RWMP), the Intelligent Transportation Systems (ITS) Joint Program Office and the National Oceanic and Atmospheric Administration (NOAA) in 2004 joined forces in a project called Clarus to collect weather observations, analyze the data for accuracy and then package the data into a common format that would meet the expectations of public and private end users. The result is a complete and accurate weather snapshot anywhere in the United States that is available to any user at any time. The Clarus system can be accessed at http://www.clarus-system.com . As of August 2011 a total of 37 States, 5 Local governments and 4 Canadian Provinces were connected to the Clarus system with access to 2,253 Senor Stations (ESS) with 52,471 individual sensors.

The early successes in the Federal MDSS Prototype provided the catalyst needed to develop two pooled fund studies with private enterprise. The first pooled fund study with FHWA assistance and support involved five state DOTs, South Dakota as lead, North Dakota, Minnesota, Indiana, and Iowa. The study contracted with Meridian Environmental Technology of Grand Forks, North Dakota, to develop, integrate and deploy a winter MDSS. Indiana DOT's leadership was so impressed with the results they were able to move to statewide implementation in the 2008-2009 winter season. The second pooled fund with DTN-Meteorlogix (now part of Schneider Industries) leveraged the capabilities of the Federal MDSS Prototype to create a web-based MDSS tool complementing the company's WeatherSentry® forecast product. Ten states (Idaho, Iowa, Maine, Michigan, Missouri, Nebraska, Nevada, New York, Ohio, and Wisconsin and the New York State Thruway Authority evaluated the new service in the 2005-2006 winter season. In the second season, 2006-2007, 11 state DOTs and 75 local agencies used the WeatherSentry® MDSS. The following winter over 30 states used Televent-DTN weather services, 21 in conjunction with the WeatherSentry®MDSS and more than half applied the system statewide. That number has now increased to more than 1,000 city and county subscribers to their weather services, with approximately 25% subscribing to the MDSS.

The use of MDSS in Canada was an agenda item for discussion at the 2011 Transportation Association of Canada Conference, Summer and Winter Maintenance Subcommittee September 10th meeting which the author of this paper attended. At that time Alberta Transportation was the only Province using MDSS. They offered MDSS to their contractors on a trial basis. Four contractors accepted the offer and found MDSS to be useful saving them both overtime and chemical costs. Then on February 7, 2012, Alberta Transportation advertised request for proposal (RFP) to provide all services required to develop and implement a MDSS for winter road maintenance suitable for Alberta's road and climatic conditions. Outcomes from that RFP are currently being analyzed so are not available for inclusion in this paper. Those details likely will be available when this paper is presented and the author will include some discussion on how this MDSS effort is progressing at that time.

The author of this paper has had conversations with Max Perchanok, Research Coordinator, Ontario Ministry of Transportation (MTO), and learned MTO has developed a comprehensive four year plan to roll out MDSS for that Province sometime in 2012. The Province's RWIS service provider is also working on a limited scope demo of MDSS. More details of MDSS in the Province will likely be available when this paper is presented.

Studies have shown good paybacks on proactive snow and ice control using both anti-icing/RWIS and the MDSS. At the conclusion of the first SHRP in 1993 DOTs reported benefit-cost ratios of 2:1 to 13:1 on investments in RWIS and anti-icing technologies along with increased travel safety and level of service and improved environmental quality [9]. New Hampshire DOT was selected as a case study in the second season, 2006-2007, and a simulation was performed on a 9-mile segment of I-93 for seven consecutive winter seasons. The simulation inputs included weather data from nearby weather stations, rules of practice for winter maintenance operations, and daily records of salt usage. Costs associated with implementing the MDSS included software and operations costs, communication costs, in-vehicle computer hardware, training, addition weather forecast provider costs, and administrative costs. Measuring from the baseline condition, the DOTs standard rules of practice were applied without the MDSS had a projected annual cost of $2.9 million. Providing the same level of service with MDSS and at the same level of resources would cost $2.4 million, thus showing MDSS could reduce costs, reduce material usage, reduce delay, and improve safety [10]. Another study conducted during the 2008-2009 winter season with Indiana DOT using MDSS showed a savings of $12 million in salt use and $1.4 million in compensation for overtime. When those savings were normalized for varying winter conditions, Indiana realized a savings of $10 million in salt use and $1 million in overtime [11].

The Equipment Evolution

During the same time frame (mid 1990s to early 2000s) when efforts were underway to connect the maintenance snow and ice control and the meteorological communities, a consortium project was created to identify, design and assemble the ideal platform for mobile winter operations. The project was titled the Highway Maintenance Concept Vehicle (HMCV). Part of the inspiration and vision for the HMCV came from the need to develop a new snow and ice control vehicle to meet the equipment needs identified in the anti-icing operations from the SHRP research and the new technologies identified on an International Winter Maintenance Technology Scanning Tour to Japan and Europe in March 1994 [12]. The scanning tour participants discovered differences in snow removal equipment, material spreaders, anti-icing and deicing materials and methods, weather monitoring, winter hazard mitigation and road user information that had great potential for improving the efficiency and effectiveness of winter operations here in the U.S.

The consortium project was divided into three phases: prototype functions and feasibility; prototype evaluation; and field tests and evaluation. The research consortium was formed in the fall 1995 with support from FHWA, the Iowa, Michigan and Minnesota DOT. Two additional partners, Wisconsin and Pennsylvania DOTs, joined during the last phase of the project. The Center for Transportation Research and Education (CTRE) at Iowa State University provided technical assistance and support during all phases of the project. The consortium learned early on that defining the scope and breadth of the research beyond the first phase would be difficult because while innovative technologies and new equipment options were being explored and tested, new ideas would arise for consideration. A multiphase research plan therefore was adopted, with the earlier phases described in detail and the later phases broadly defined to provide flexibility for accommodating discoveries [13]. Since the process of identifying the capabilities of a concept vehicle was similar to that used in the manufacturing community for developing a new product the consortium approached Rockwell International for assistance in selecting and conducting focus groups for input. Rockwell recommended the quality function deployment process which encourages direct customer input, expressed in the customers' words, not in the terminology of a design engineer or marketing specialist [14]. The focus groups also followed the procedures of total quality transformation, which encourages participants to concentrate on the causes of the problem, not on symptoms. The consortium pursued the development of public-private partnerships for building the vehicle.

Phase I, 1995-1997, identified the HMCV functions, evaluated their feasibility, and enlisted private-sector partners to supply the functionalities, technologies, and equipment. The focus groups provided a list of ideal features the HMCV, including the ability to:

- Measure roadway friction and surface temperature
- Record vehicle activities, such as plow-up or plow-down, and spreading chemicals or not
- Improve fuel economy and provide adequate horsepower for plowing operations
- Carry and distribute several types of materials with removable salt and brine dispensing systems
- Provide sensors for obstacle detection when backing up

Phase II, 1997-1998, focused on assembling the HMCV in each consortium state. This consisted of installing selected technologies on the prototype vehicle and to conducting proof of concept in advance of field evaluations planned for Phase III [15]. Each truck was equipped with a

Global Positioning System receiver, with an antenna mounted above the cab. The truck's location was recorded every 5 seconds and recorded by the PlowMaster™ system developed for the concept vehicles. Data from the pavement surface and air temperature sensors, friction meter, material applicator, plow operations, and the truck's engine were integrated into the PlowMaster ready to display on monitors in the garage, or communicated to other intelligent transportation system programs. All three prototype vehicles were equipped to spread dry, prewetted, or liquid materials for anti-icing or deicing operations. Each prototype vehicle had a hydrous-ethanol injection system that automatically injected ethanol into the engine providing a 20% power boost when maximum power was needed. A ROAR friction measuring device, manufactured by Norsemeter was installed and tested but needed to be redesigned to withstand the rigors of the snow and ice control environment. Infrared sensors monitored air and pavement temperatures and conveyed the data to a digital display gauge in the truck cab and to a recorder in the PlowMaster. A Global Sensor System was installed which could detect obstacles behind the truck and automatically apply the brakes when the truck was in reverse.

Phase III, 1998-1999, concentrated on conducting field tests and evaluation on all functionalities to determine if they were ready to implement and product data flow and decision process maps to integrate the functionalities into management systems [16]. A major field effort was directed to evaluating the redesigned friction measuring device SALTAR which had been redesigned to withstand the rigorous snow and ice control operating environment. Field evaluations of the technologies, particularly the friction meter, were conducted at the National Aeronautics and Space Administration facilities at Wallops Island, Virginia for warm weather testing and North Bay, Ontario for winter weather testing. The SALTAR demonstrated that the principle of continuously measuring friction and transferring the data to the vehicle management system was sound. A failure analysis of the redesigned device showed that one gearbox had been damaged by corrosion and therefore needed further hardening before large scale deployment. Other equipment and technologies evaluated in Phase III were successful and field ready.

Phase IV, the final phase of the HMCV project, deployed the HMCV in two winters of operation, starting in 2000-2001. Data were collected on the bench testing and field testing of a new functionality, freeze-point detection sensors; friction measuring device; an AVL/GPS system; a new design radius dump body, which has rounded corners to improve flow of material to the spreader; dual, side-mounted, 120 gallon pre-wetting tanks; a 900 gallon stainless steel anti-icing tank; high intensity discharge (HID) plow lights; and the integration of these technologies and systems, along with communications links. Results of the Phase IV showed the HMCV to be a viable system for improving winter maintenance operations [17]. Additional field hardening and possible redesign was needed on the friction measuring device and the freeze-point detection sensors. The HMCV research results quickly made their way into new equipment purchases. The author in 2004 visited with an engineer at Monroe Snow and Ice Control, a Midwest equipment assembler and was told that most state DOTs were ordering trucks equipped with all the functionalities listed in the HMCV Phase IV project with the exception of the friction measuring and mobile freeze-point detection devices.

Although the HMCV project concluded with the publication of the final report in 2002, other state DOTs and FHWA have sponsored research that builds on the accomplishments of the project as follows:

> Friction measurements; During the winter of 2006-2007, Ohio DOT sponsored research on Halliday Technologies, Inc., friction-measuring equipment. This equipment was currently being used to friction on auto race tracks. Results of the Ohio research were the equipment was capable of distinguishing changes in roadway traction conditions with high resolution and good repeatability [18]. Ohio uses this technology in their current snow and ice control operations to indicate segments with pavement conditions that require greater maintenance treatment and those that have acceptable traction. FHWA in their Connected-Vehicle project are using information from the vehicles Cam-Bus to determine traction and road condition.
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> Salinity sensors; ASFT of Sweden have developed a mobile freezing point surveillance system which uses two Frensor freezing point sensors which have been redesigned to overcome the problems experienced with the Frensors in the HMCV project. The Yamada Giken Company Limited located in Japan has developed an On Vehicle Salinity Sensor System using refractometer technology for measuring freezing point of surface moisture. The Clear Roads Consortium is considering both of these technologies for further field testing during their 2013 program year.

The Evolution of Chemicals in Winter Operations and Their Impact on the Receiving Environment

As mentioned in the abstract for this paper, prior to the 1990s, winter maintenance agencies usually relied on brute force and abrasives for their snow and ice control operations. Now snow and ice control chemicals play a significant role in assuring the safety of winter driving. Ideally, chemicals are applied before precipitation arrives to prevent snow or ice from bonding. This anti-icing process minimizes the amount of chemicals required and increases the safety of the road. Even though improvements have been made in weather forecasting, decision support systems, snow and ice control methods, and equipment, every winter, millions of tons of snow and ice control chemicals are applied to roadways and bridges. Snow and ice control chemicals are having a negative effect on the receiving environment in a variety of ways. Mountainous areas in the Western U.S. are experiencing damage to pine trees, states in the Midwest the chemicals are getting into lakes and in the Eastern U.S. these chemicals are finding their way into shallow wells. About ten years ago the National Cooperative Highway Research Program (NCHRP) began studying the problem. In May 2007 NCHRP released Report 577, "Guidelines for the Selection of Snow and Ice Control Materials to Mitigate Environmental Impacts" [19]. This report evaluated the environmental and corrosion impacts of 42 frequently used anti-icing and deicing chemicals. The report presents three valuable tools for winter maintenance operations: a decision tool to select the most suitable snow and ice control chemicals, a purchase specification, and a monitoring program for quality assurance, including procedures and standard test methods. The material selection tool is designed to be customized to reflect local area ecological uniqueness and infrastructure and governmental priorities and values into the analysis and can develop a variety of scenarios for comparison. The material selection tool enables rational, informed and objective decision making about the choices of chemicals considering the locally determined balance of costs, performance, and handling methods as well as the probable impacts on the environment and infrastructure.

To ensure the winter maintenance was properly trained in the methods and equipment used in pro-active snow and ice control operations and evolving associated sciences with advanced chemistry and its impact on the receiving environment, the American Association of State Highway and Transportation Officials (AASHTO) developed a suite of eight training modules for group or individual application. The training suite was developed by Technical Working Groups of individuals from state and local governments with extensive experience in winter maintenance operations from all regions of the United States and Canada and individuals experienced in delivering training in classroom and distant learning applications. Funding for the million dollar project came from voluntary contributions from 34 state DOTs, American Public Works Association (APWA) and the National Association of County Engineers (NACE). The title of each module indicates the area on winter maintenance being addressed. These titles are: Anti-icing/RWIS; Selecting Snow & Ice Control Materials to Mitigate Environmental Impacts; Equipment Maintenance; Proper Plowing Techniques; Deicing; Blowing Snow Mitigation; Winter Maintenance Management; and Performance Measures for Snow and Ice Control Operations. Further details about each module are available at http://transportation.org/?siteid=88&pageid=2173 . Used in an individual training mode this computer-based training is self-paced and accommodates multiple learning styles. The material has been available since 2003 and several modules have been updated as new research was published. State DOTs have included these modules in their training and certification programs. Currently the computer-based training is being updated, made SCORM (Shareable Content Object Reference Model) compatible, enabling the CBT to launch from and work with, a standard SCORM Learning Management System (LMS) and web-based delivery. The web-based version will be completed in early summer 2012.

Evolving Pathways to Sustainable Operations and Maintenance

The term "sustainability" seems like a recent consideration in highway development, operations, and maintenance. In reality, the concept of sustainable development dates back to a 1981 White House Council on Environmental Quality report, "If economic development is to be successful over the long term, it must proceed in a way that protects the natural resource base…" [20]. The Brundtland Commission of the United Nations (1987) further defined sustainable development as "development which meets the needs of current generations without compromising the ability of future generations to meet their own needs." [20].

About two years ago AASHTO, FHWA, and APWA began efforts to set up programs to address environmental excellence and sustainability. AASHTO established their Center for Environmental Excellence to provide technical assistance, training, information exchange, partnership-building-opportunities and quick and easy access to environmental tools. Their website at http://environment.transportation.org is designed to be a one stop source of environmental information to transportation professionals.

FHWA began an effort to develop a practical, web-base, collection of best practices that would assist the state DOTs with integrating sustainability into their transportation system practices. One of the project outcomes was a tool entitled INVEST (Infrastructure Voluntary Evaluation Sustainability Tool). A Beta Version of INVEST was released in the fall of 2010 and was pilot tested in the summer and fall of 2011 [21]. Version 1.0 is scheduled to be released in late 2012. The author of this paper currently is surveying each state DOT to determine if they have used INVEST and if so was it helpful in measuring the sustainability of their maintenance operations. Results of the survey will be analyzed in April 2012 and be presented in conjunction with this paper.

American Public Works Association established the APWA Center for Sustainability to provide guidance for anyone interested in moving towards sustainability. The principles of sustainability are based on the idea that people and their communities are made up of integrated social, economic and environmental systems that must be kept in balance. The Center's leadership group developed a framework to help local governments make balanced choices. The "Framework for Sustainable Communities" addresses five distinct community needs to assure a balanced/sustainable community outcome: Ecology (How does it impact the community); Economy (How does it directly impact the local economy and at what short and long term costs?); Empowerment (How does it impact relationships, effective government, and social justice?); Efficiency (How does it impact the delivery of infrastructure we provide?); and Health (How does it impact the well-being of people?). This framework can be found at http://www.apwa.net/centerforsustainability/Process/-Framework-for-Sustable-Communities .

Conclusions

This paper has documented: how the winter maintenance community and the meteorological communities were connected and integrated resulting in the development of surface weather forecasting and the winter maintenance decision support system; how the Highway Maintenance Concept Vehicle (HMCV) project was created to identify, design and assemble the ideal platform for mobile winter maintenance operations; how research produced a material selection tool to enable the winter maintenance community in rational, informed and objective decision making about the choices of chemicals considering the locally determined balance of costs, performance, and handling methods as well as the probable impacts on the environment and infrastructure; how new group and individual training techniques were developed to ensure winter maintenance personnel are properly trained in the methods and equipment used in pro-active snow and ice control operations and evolving associated sciences with advanced chemistry and its impact on the environment; and the courses of action used during the past two decades to take winter maintenance research results from theory to a pro-active operational state-of-the-practice. The paper also presented some tools and resources available to help decision makers integrate the concepts of sustainability into their winter maintenance operations. The paper also listed two research needs that were identified in 1995 by the HMCV focus groups that remain important unmet research needs. Those were the measurement of road surface friction and the measurement of the freezing point of pavement surface moisture. Both are needed to determine the efficiency and effectiveness of treatment outcomes and subsequent treatment recommendations. Without these field measurements, optimization is just a best guess process.

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