

Development of a Toolkit for Cost-Benefit Analysis of Specific Winter Maintenance Practices, Equipment and Operations

Western Transportation Institute, Montana State University



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**Development of a Toolkit for Cost-Benefit Analysis of Specific
Winter Maintenance Practices, Equipment and Operations:
Final Report**

by

David Veneziano, Ph.D.
Laura Fay, M.Sc.
Zhirui (Jared) Ye, Ph.D.
Dan Williams
Xianming Shi, Ph.D., P.E.

Western Transportation Institute
College of Engineering
Montana State University

and

Lisa Ballard P.E.
Current Transportation Solutions

Prepared for the Wisconsin Department of Transportation and
the Clear Roads Program

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16. Abstract The operators and maintainers of highway networks are facing increasing demands and customer expectations regarding mobility and transportation safety during inclement weather, while confronting budget and staffing constraints and environmental challenges related to chemical and material usage. It is desirable to use the most recent advances and best practices to improve the effectiveness and efficiency of winter operations, optimize material usage, and reduce annual spending, corrosion and environmental impacts. Determining the benefits and costs of various winter maintenance practices, equipment and operations is a difficult and time consuming proposal for winter maintenance managers. This project developed a toolkit which would facilitate such a benefit-cost analysis to address this need. The toolkit items included anti-icing, deicing, carbide blades, front plows, underbody plows, zero velocity spreaders, Maintenance Decision Support Systems, Automatic Vehicle Location and Geographic Positioning Systems, Road Weather Information Systems, and mobile pavement or air/pavement temperature sensors. The developed toolkit is a website which receives parameter inputs from a user and generates a benefit-cost ratio for the item of interest.			
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EXECUTIVE SUMMARY

The operators and maintainers of highway networks are facing increasing demands and customer expectations regarding mobility and transportation safety, especially during inclement weather, while confronting unprecedented budget and staffing constraints and a growing awareness of environmental challenges related to chemical and material usage. Maintenance agencies are also continually challenged to provide a high level of service (LOS) and improve safety and mobility in a cost-effective manner. These factors, along with others, may conflict or complement one another. To this end, it is desirable to use the most recent advances, as such best practices are expected to improve the effectiveness and efficiency of winter operations, to optimize material usage, and to reduce associated annual spending and corrosion and environmental impacts.

In light of this, the Clear Roads pooled fund identified the need for a research project to develop a toolkit which would facilitate cost-benefit analysis for a series of winter maintenance practices, equipment and operations. The purpose of this toolkit would be to streamline the cost-benefit process and assist maintenance managers in meeting the demand of maximizing the benefits accrued versus the costs incurred when adopting a new practice, equipment or operation in a more efficient manner and justify the expenditures they propose. The toolkit could also be used to examine the costs and benefits of existing practices, equipment and operations. With the availability of this toolkit, maintenance managers should be able to more efficiently use scarce financial resources by identifying a set of best practices employed by an agency to *apply the right type and amount of materials in the right place at the right time* for winter maintenance activities.

The research discussed in this document developed such a toolkit. The toolkit that has been developed by this project is the result of input from the Clear Roads Technical Advisory Committee (TAC) and winter maintenance practitioners. The project consisted of a number of sequential activities which culminated in the development of the web-based toolkit. Initial efforts focused on a literature review and state-of-the-practice practitioner surveys. The literature review established past and ongoing research and agency reports which reported benefit-cost ratios, quantified and non-quantified cost and benefit information, and general effectiveness related to winter maintenance practices, equipment and operations.

The practitioner surveys sought to obtain further information related to the costs and benefits observed by agencies, as well as determine the preferences for the toolkit itself. This input was solicited primarily through an online user survey, as well as through direct communication with the TAC. As the result of this input, the preference indicated by all parties was that the toolkit should take the form of a website (other alternatives included an Excel spreadsheet application and a stand-alone desktop program). Based on feedback from practitioners and the TAC, an initial series of ten items were selected for inclusion in the toolkit. Toolkit items include:

- Anti-icing
- Deicing
- Carbide blades
- Front plows
- Underbody plows
- Zero velocity spreader
- Maintenance Decision Support Systems (MDSS)
- Automatic Vehicle Location and Geographic Positioning Systems (AVL/GPS)

- Road Weather Information Systems (RWIS)
- Mobile pavement or air/pavement temperature sensors

Once available information related to costs, benefits and effectiveness, as well as the preference for a web-based platform was collected, the development of the toolkit website began. The website was developed with open source tools to minimize the cost of development while maximizing functionality and providing a means for easier future expansion. It used the Joomla Content Management System (CMS), which was chosen because it was easy to use and was free open source software. It runs on the common LAMP (Linux, Apache, MySQL, PHP) and allows for relatively easy updates to the content by non technical personnel. Finally, it possesses a built in user management system which will ease in the expansion of the toolkit in the future.

Following completion of the toolkit website, it underwent testing and validation to verify that it was functioning correctly and producing reliable, accurate benefit-cost ratios. Discrepancies were corrected within the toolkit as identified during this process. Concurrent with testing, training materials, primarily a User Manual, were developed. These training materials were developed to walk the user through the toolkit step by step for each of the ten items. In addition to the User Manual, training in the use of the toolkit was conducted by the project team on July 29, 2010 (with the project Technical Advisory Committee, via webinar) and August 10, 2010 (in person at the summer Clear Roads meeting).

1. INTRODUCTION

The operators and maintainers of highway networks are facing increasing demands and customer expectations regarding mobility and transportation safety, especially during inclement weather, while confronting unprecedented budget and staffing constraints and a growing awareness of environmental challenges related to chemical and material usage. Maintenance agencies are also continually challenged to provide a high level of service (LOS) and improve safety and mobility in a cost-effective manner. These factors, along with others, may conflict or complement one another. To this end, it is desirable to use the most recent advances in the application of anti-icing and deicing materials, winter maintenance equipment and vehicle-based sensor technologies, and road weather information systems (RWIS) as well as other decision support systems. Such best practices are expected to improve the effectiveness and efficiency of winter operations, to optimize material usage, and to reduce associated annual spending and corrosion and environmental impacts.

Despite dwindling or flat budgets, significant expenditures are still made with respect to winter road maintenance activities. The U.S. spends \$2.3 billion annually to keep roads clear of snow and ice (1); in Canada, more than \$1 billion is spent annually on winter road maintenance (2). In addition to labor costs, these funds are spent on a variety of materials and equipment, each featuring its own unique set of costs and benefits. Just as the conflicting objectives faced by agencies make the task of cost-benefit analysis difficult, so do the multiple alternatives of practices, equipment, and operations employed in winter maintenance activities. For instance, some products for snow and ice control may cost less in materials, equipment and labor, but cost more in the long run as a result of their corrosion and environmental impacts.

To achieve the benefits that various winter maintenance practices, equipment and operations present, agencies must first determine which of these offer the most significant benefits given their costs. The process required in order to make such a determination is cost-benefit analysis. In a winter maintenance context, where the various costs and benefits of practices, equipment and operations vary greatly and are only sporadically reported (particularly quantified benefits), cost-benefit analysis may present a significant challenge to winter maintenance managers. These personnel are already charged with a host of managerial tasks and often lack the time to track down the requisite information to complete a thorough cost-benefit analysis to justify the addition of a new practices, equipment and operations to their existing

In light of this, the Clear Roads pooled fund identified the need for a research project to develop a toolkit which would facilitate cost-benefit analysis for a series of winter maintenance practices, equipment and operations. The purpose of this toolkit would be to streamline the cost-benefit process and assist maintenance managers in meeting the demand of maximizing the benefits accrued versus the costs incurred when adopting a new practice, equipment or operation in a more efficient manner and justify the expenditures they propose. The toolkit could also be used to examine the costs and benefits of existing practices, equipment and operations.

With the availability of this toolkit, maintenance managers should be able to more efficiently use scarce financial resources by identifying a set of best practices employed by an agency to *apply the right type and amount of materials in the right place at the right time* for winter maintenance activities. The simplified nature of such a toolkit will also allow for a reevaluation of materials and procedures to be made on a frequent basis, as well as provide for the inclusion of additional information to account for new and emerging practices, equipment and operations in the future.

functioning in a similar manner to the cost component of the toolkit. Based on the benefits selected, the next step is the quantification of those benefits. The toolkit concludes with a presentation of cost and benefit results, including the cost-benefit ratio. For users that wish to have more information for reference or presentation, a brief white paper is also provided summarizing the results of research related to the particular item.

1.2. Report Overview

This report consists of six chapters. Chapter 1 has introduced the need for and purpose of the project summarized in this report. Chapter 2 summarizes the findings of a practitioner survey which sought input from winter maintenance professionals regarding the form of the toolkit to be developed, as well as what items they would like to see included in it. Chapter 3 presents a summary of cost, benefit and effectiveness literature pertaining to the items selected by practitioners for inclusion in the toolkit. Chapter 4 provides an overview of the toolkit, including a discussion of cost-benefit analysis, assumptions, website development and other aspects. Chapter 5 presents a discussion of implementation recommendations. Finally, Chapter 6 presents conclusions and recommendations that may be drawn from this project and also presents lessons learned.

2. PRACTICIONER SURVEY

2.1. Background

A survey conducted was a part of the project and was designed to gather a variety of information on winter maintenance tools, equipment, and procedures currently used by agencies. It also surveyed maintenance operations personnel about what they would like to see included in a cost-benefit toolkit, and whether their agency had conducted any previous cost-benefit assessments related to tools, equipment and procedures. The objective of the survey was to identify the top ten winter maintenance tools, procedures, and practices currently used by agencies so that they may be prioritized for inclusion in the cost-benefit toolkit.

The survey consisted of four multi-part questions and was posted on the Snow and Ice Listerserv for 35 days. The survey questions posed to respondents are presented in Appendix A. A total of 65 responses were received and processed to provide the information in this document. Figure 2-1 displays the geographic distribution of respondents, while Table 2-1 presents the respondent states, provinces and countries by name.

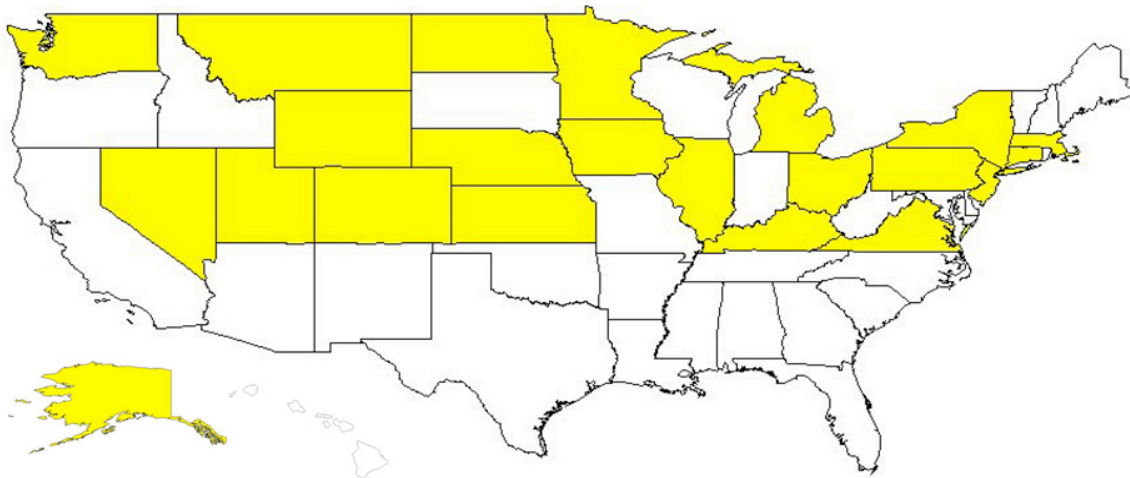


Figure 2-1: Respondent states (highlighted)

Table 2-1: Survey respondent locations

Montana	Kentucky	New York
Utah	Nevada	Iowa
New Jersey	Illinois	Alaska
Virginia	Massachusetts	Colorado
Kansas	Connecticut	Michigan
N. Dakota	Wyoming	Alberta
Washington D.C.	Ohio	New Brunswick
Washington State	Pennsylvania	Sweden
Nebraska	Minnesota	Denmark

2.2. Results

2.2.1. Tools Employed

Survey respondents were asked to provide information on tools, processes, and procedures that are currently used.

2.2.2. *Maintenance Management System (MMS)*

Survey respondents were asked if they used MMS to track spending in winter maintenance activities. A total of 29 people responded with GPS/AVL being used most frequently (n=12) followed by TAPER logs (n=7). Respondents were provided with an “Other” category, and three responded that they were implementing GPS/AVL as MMS this coming winter season (2009-2010). Other forms of MMS referenced were Work Management System (WMS) (n=2) and Resource Management System (n=1). One respondent indicated that their organization uses a custom designed program that integrates the cost of materials, equipment and personnel, while another respondent state that their organization uses a MMS but did not provide any further information. One respondent indicated that their organization tracks winter maintenance costs through timesheets using the People Soft Financial System, as well as manual and vehicle reports, and a final respondent stated that their organization uses crew information cards.

2.2.3. *Plow Configuration*

Survey respondents were asked what type of plows they use, with a total of 54 responses obtained. Figure 2-2 shows that front plows (n=53) were most common, followed by underbody plows (n=29), wing plows (n=18), and then rear plows (n=9)². Based on the total number of survey respondents multiple types/configurations of plows were used on the same vehicle.

² Note that multiple plow types may be employed in combination. Hence, number of responses will not add up to the respondent sample size.

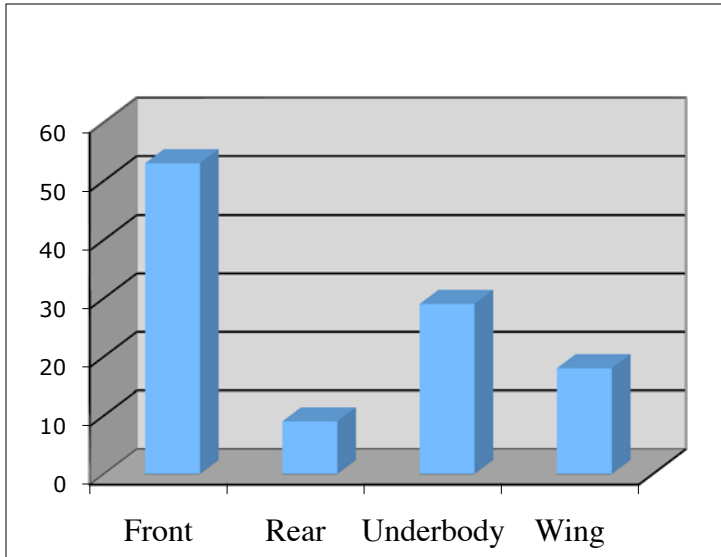


Figure 2-2: Plow configurations currently used by survey respondents

2.2.4. *Plow Blades*

Survey respondents were asked what types of plow blades they use. There were a total of 51 responses. Table 2-2 shows that the top three blade types used are carbide, underbody, and wear plates. Based on the total number of survey respondents multiple blade types were used on the same vehicle. In the “Other” category, the use of a 12ft main plow with a wing plow was recommended by one survey respondent for urban areas because a 14ft plow was suggested to be too large for traffic.

Table 2-2: Blade types used by survey respondents

Blade Types	n
Carbide	47
Underbody Blade	24
Wear Plates	19
Double/Triple Edge	9
14+ ft	9
Rubber	4
Triple Blade	2
Tow Blade	2
Carbide w/ Steel Backer	2
Steel	1

2.2.5. *Informational Technology*

Survey respondents were asked to provide information on the types of information technology used. There were 48 responses to this question. Road Weather Information System (RWIS) was most commonly used (n=43), followed by GPS (Global Positioning System, n=26), AVL (Automatic Vehicle Location, n=26), and MDSS (Maintenance Decision Support System, n=24) (Figure 2-3). In the “Other” category, free web-based

information provided by the National Oceanic and Atmospheric Administration (NOAA) was cited as being used, as was the use of Full Mobile Data Computing.

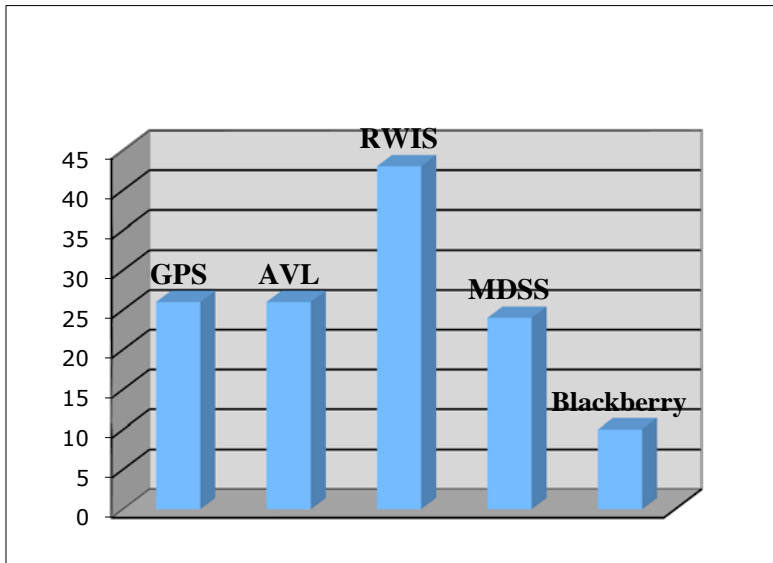


Figure 2-3: Information technology used by survey respondents

2.2.6. Windshield Wipers

Survey respondents were asked to provide information on the types of windshield wipers they use. There were 51 responses. Standard equipment was listed as most frequently used (n=47), with SlapMe, Clear Fast, and Hot Shot windshield wiper each garnering ten or less responses (Figure 2-4).

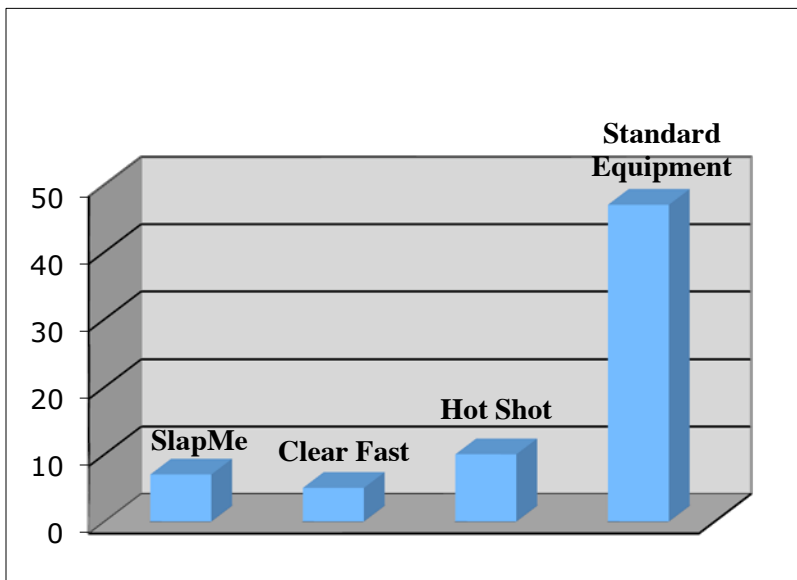


Figure 2-4: Types of windshield wipers used by survey respondents

2.2.7. *Deicing & Anti-icing*

Survey respondents were asked if they deiced and anti-iced with solid and or liquid products. There were a total of 54 responses. In general deicing was conducted with solids (n=47) and anti-icing with liquids (n=50). Deicing with liquids was used by more than half of the survey respondents (n=38), and anti-icing with solids was used by just less than half of the survey respondents (n=22). Pre-wet systems were listed by respondents in the “Other” category as being used to enhance solid deicing products.

2.2.8. *Application Methods*

Survey respondents were asked to provide information on the types of application methods used to apply deicing chemicals. There were a total of 52 responses. Figure 2-5 shows that spinner applications were by far the most common used to apply solid deicers, followed by stream and spray methods for liquid deicing products.

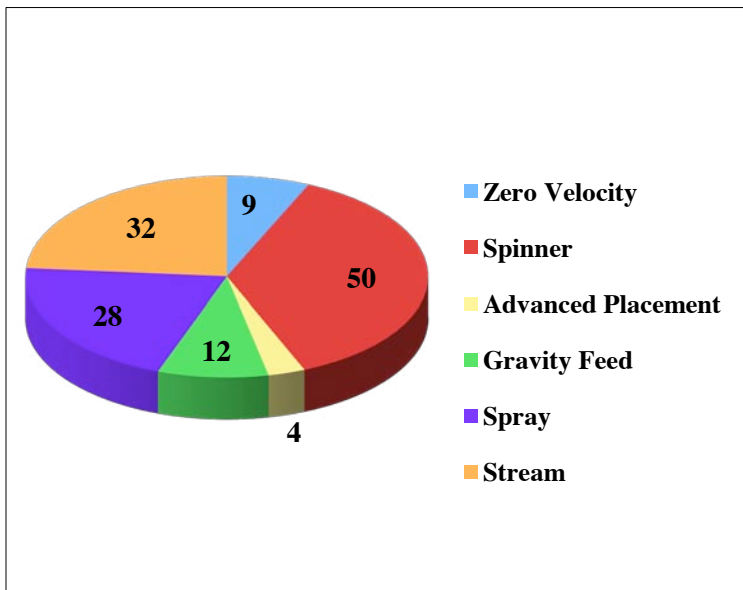


Figure 2-5: Application methods used for deicers and anti-icers provided by survey respondents

2.2.9. *Add on Vehicle Accessories and Training*

Survey respondents were asked what type(s) of add-on vehicle accessories they used and what type(s) of training they used. There were a total of 40 responses. Specialized lighted packages were the most common add on followed by back-up cameras, and air foils. Driver simulator training was the only training method listed. Survey respondents were provided with an “Other” category, but no details were provided in terms of what agencies used in this category.

Table 2-3: Types of add-ons and training used and frequency provided by survey respondents

Add on/Training	n
Specialized Lighting Packages	26
Other	14
Back-up Cameras	11
Vehicle Airfoils	11
Driver Simulator Training	9
Vehicle Deflectors	8
Vehicle Moldboards	7

2.2.10. Vehicle Sensors

Survey respondents were asked to provide the types of vehicle sensors used. There were 48 responses. Pavement temperature sensors were listed as most commonly used (n=48), followed by air temperature sensors (n=39). Based on the number of responses, some respondents use both pavement and air temperature sensors.

2.3. Top Ten Items for a Cost-Benefit Toolkit

The ten most valuable items to include in a cost-benefit tool kit based on survey responses are listed in Table 2-4.

Table 2-4: Top ten most useful items to include in a cost-benefit toolkit.

	Ranking	% of respondents	n
Anti-Icing	1	64	41
Front & Underbody Blades	2	59	38
AVL	3	56	36
Pavement Temperature Sensor	4	55	35
RWIS	5	48	31
Deicing	6	45	29
GPS	7	45	29
MDSS	8	44	28
Carbide Blades	9	38	24
Air Temperature Sensor	10	30	19

2.4. Previous Assessments

Survey respondents were asked if they or their agency had performed any cost-benefit, cost effectiveness, or general assessment studies for any of the tools, processes, and procedures listed in the Tools Currently Used section.

The vast majority of the tools, processes, and procedures had been assessed by agencies to some degree using a cost-benefit analysis. Deicing and anti-icing and plow blades were listed as most commonly assessed, followed by application methods, sensor types, and information technology. Table 2-5 shows that anti-icing liquids have been assessed most frequently, followed by deicing solids and liquids. Carbide plow blades were the most

frequently assessed blade type. RWIS was the most frequently assessed information technology, with GPS, AVL, and MDSS also assessed quite frequently. Pavement temperature sensors have also been assessed

When you compare the top 10 list of items that would be useful to agencies to include in a cost-benefit toolkit (Table 4) with the list of items that have been assessed (Table 5), it is evident that there is quite a bit of overlap. Anti-icing was ranked as the number one item to include in a cost-benefit toolkit and anti-icing with liquids was listed as being most frequently assessed.

Table 2-5: Top ten items that have been previously assessed with a cost-benefit analysis

Ranking	Assessment Category	Number of Previous Assessments
1	Anti-icing Liquid	15
2	Carbide Blade	12
3	RWIS	10
4	Deicing Solid	10
5	Deicing Liquid	10
6	Pavement Temperature Sensor	9
7	GPS (used as standalone)	8
8	AVL	8
9	MDSS	7
10	MMS	6

When survey respondents were asked what form they would like the toolkit to take, the majority favored a web-based tool (n=32), followed by an Excel spreadsheet (n=12). Survey respondents were also asked to provide information on emerging technologies, equipment, and procedures they would like included in a cost-benefit toolkit. These included:

- Heads-up displays for snowplow operations and GPS location,
- Liquid anti-icing products,
- EpoSat (trade name)- satellite/spreader controlled operations,
- Mobile active freezing point sensors,
- Weather forecasting services,
- Friction wheels,
- Standard methods to measure winter operations that would include weather, materials, equipment, and performance to measure the effectiveness of operations from year to year,
- Tools to show or calculate residual salt on the road, and
- Wing plows.

2.5. Conclusions

The survey results provide a list of the top ten items to include in a cost-benefit toolkit. Most of these items were listed as used most frequently by maintenance personnel and have been previously assessed to some degree using a cost-benefit analysis. As such, the research team will develop a second survey to target the ten identified items and obtain relevant information for their cost-benefit analysis.

3. LITERATURE REVIEW

3.1. Introduction

One of the most useful points of reference available to winter road maintenance managers and others charged with decision-making are the costs, benefits, and effectiveness associated with winter maintenance of practices, equipment, and operations. However, a significant level of effort may be required to track down this information, and access to published reports and papers is not always guaranteed. As a result, part of the work undertaken during this project was a comprehensive literature review which brings such information together in one place. For the purposes of brevity however, the entire literature review compiled during the course of this project is not presented in this chapter. Rather, the information presented here pertains to the top ten items of interest identified in the previous chapter through the practitioner survey. Results of that survey indicated the top ten items in order of interest were:

- Anti-icing;
- Front and underbody blades;
- Automatic Vehicle Location (AVL)/Global Positioning System (GPS);
- Pavement Temperature Sensor;
- Road Weather Information System (RWIS);
- Deicing;
- Maintenance Decision Support System (MDSS);
- Carbide blades;
- Air temperature sensors; and
- Zero velocity spreaders.

The literature review focused on recent (post 1995) publications and older documents of longstanding relevance to determine the tangible and intangible costs, benefits and effectiveness of several winter maintenance tools, equipment, and procedures currently used by agencies. These included the abovementioned items, as well as vehicle-based sensors, fixed friction prediction sensors, in-pavement sensors, lighting packages, backup cameras, material placement systems, windshield wiper systems, and driver simulation training. A summary of these additional items, along with a more detailed summary of the literature presented in this chapter, is presented in the interim Literature Review project deliverable (3).

3.2. Anti-icing and Deicing

Anti-icing and deicing practices are the most visible winter maintenance activities to the general public, aside from plowing. These activities provide some of the greatest benefits, but also, depending on the material(s) employed, impose the greatest costs. Chemical usage has direct impacts on not only roadway surface conditions, but also the environment, air quality, water quality, and wildlife. As one would suspect, a wealth of research has been conducted related to various aspects of anti-icing and deicing materials and practices.

Many agencies providing winter maintenance services are faced with the need to improve their levels of service, with less money, while reducing their impact on the environment. One area that received particular focus with respect to environmental impacts is the use of anti-icers and/or deicers. Another focus area examines the different materials used for anti-icing/deicing and abrasives.

Work in the areas of anti-icing and deicing has been published by Boselly (4), Basu et al. (5), Yang et al. (6), Fischel (7), Luker et al. (8), Algiers and Haase (9), Sooklall et al. (10), NCHRP (11), O'Keefe and Shi (12), Nixon (13), Vitaliano (14), Shi et al. (15), Shi (16), and Environment Canada (17). An overview of the information provided by these documents is presented in Table 3-1.

In examining past anti-icing and deicing literature, it is evident that while some specific cost information is available, the primary costs identified have been those which are difficult to quantify. These include items such as environmental and societal impacts. Conversely, quantified costs were typically those associated with materials labor and maintenance.

Benefits identified were primarily those non-quantified. Some limited attempts have been made to value fuel and travel time savings resulting from better maintained roadways, but most benefits were general in nature such as the potential for material and labor savings. Interestingly, only limited documents discussed the effectiveness of anti-icing and deicing, with these being primarily negative in nature. Given the limited quantified costs and benefits cited, none of the documents computed a cost-benefit ratio.

Table 3-1: Summary of anti-icing and deicing research

Title	Author(s)	Year	Locale	Costs	Benefits	Effectiveness	C-B Ratio (if developed)
Winter Road Maintenance Activities and the Use of Road Salts in Canada: A Compendium of Costs and Benefits Indicators	Environment Canada	2006	Canada	Direct winter maintenance costs/km - \$530 ¹ Direct winter maintenance cost/ton of salt - \$320 Materials costs/ ton - \$50 Equipment costs/vehicle-hour - \$30 Labor	Private vehicle fuel saving/100km - \$1.88 ¹ Decreased travel time/vehicle per hour - \$11 Decreased crashes	N/A	N/A
The Use of Road Salts for Highway Winter Maintenance: An Asset Management Perspective	Shi	2005	National	Corrosion and environmental costs/ton of salt - \$469	N/A	N/A	N/A
Winter Road Maintenance Activities and the Use of Road Salts in Canada: A Compendium of Costs and Benefits Indicators	O'Keefe and Shi	2005	Canada	N/A	Less product and sand used Decreased maintenance costs Improved road friction Reduced accident rates Pre-wetting increased product performance and kept product on the road longer Improved safety	N/A	N/A
An Economic Assessment of the Social Costs of Highway Salting and the Efficiency of Substituting a new Deicing Material	Vitaliano	2001	N/A	Costs to society per ton of salt - \$800 ² Costs to society per ton of CMA - \$615	N/A	N/A	N/A
Evaluation of Selected Deicers Based on a Review of Literature	Fischel	2001	Colorado	Environmental and human health effects Corrosion Sand can impact air and water quality Chloride deicers contaminate surface, ground water, and soil Deicer additives can be toxic	Perform at low temperatures Less harm to vegetation (Acetate) Sand and chloride based deicers generally inexpensive	N/A	N/A

Table 3-1 cont'd: Summary of anti-icing and deicing research

Title	Author(s)	Year	Locale	Costs	Benefits	Effectiveness	C-B Ratio (if developed)
Laboratory Melting Performance Comparison, Rock Salt With and Without Prewetting	Luker et al.	2004	N/A	N/A	Pre-wetting appears to improve the performance on solid salt deicers	N/A	N/A
Analysis of the Benefits of Bulk Pre-Wetting Solid NaCl with Several Different Liquids	Algiers and Hasse	2005	Michigan	N/A	N/A	No benefit was observed from pre-wetting bulk solid salt	N/A
Effectiveness of Pre-Wetting Strategy for Snow and Ice Control on Highways	Sooklall et al.	2006	Canada	N/A	N/A	Contradictory results were found between the two years data	N/A
Guidelines for the Selection of Snow and Ice Control Materials to Mitigate Environmental Impacts	National Cooperative Highway Research Program (NCHRP)	2007	National	Water quality impact Air quality impact Aquatic life impact Soil impact Vegetation impact Animal impact	N/A	N/A	N/A
Use of Abrasives in Winter Maintenance	Nixon	2001	Iowa	Sand did not remain on the road long Air quality impact Stormwater quality impact	N/A	N/A	N/A
Evaluation of Alternative Anti-Icing and Deicing Compounds Using Sodium Chloride and Magnesium Chloride as Baseline Deicers Phase I	Shi et al.	2009	Colorado	Infrastructure impact Environmental impacts	N/A	Anti-icers and Deicers may detrimentally effect Portland cement concrete and asphalt pavement	N/A

¹ All numbers are presented as 1998 Canadian dollars

² All numbers are presented as 1992 US dollars

3.3. Front and Underbody Plows

Plow blades are an important aspect in winter maintenance as they impact the safety and dictate the level of effort required to clear a roadway. This includes both the positioning of the blades (front, underbody, etc.), as well as the material the blades are comprised of. As noted in the introduction, practitioners expressed an interest in including cost and benefits related to front and underbody blades, as well as carbide blades in the toolkit under development. However, little research quantifying the costs, benefits or effectiveness specific to these items has been published recently. Therefore, the work in this section covers broad aspects of plows, including configuration, composition and strategies. What has been published consist of the work of Etheridge and Shankwitz (18), Lannert (19), Macfarlane (20), Nixon (21), Becker (22), Nixon and Wei (23), Roosevelt and Cottrell (24), and Gruhs (25). An overview of the information provided by these documents is presented in Table 3-2.

The research related to plow blades and configurations provided limited quantified cost information, specifically equipment costs. Remaining, non-quantified costs cited were related to potential damages caused by changes to plowing equipment and practices.

Extensive benefits for blades and configurations were identified, although only limited dollar figures related to labor and material savings were quantified. Non-quantified benefits included items related to efficiency gains, safety improvements, and added equipment versatility.

Effectiveness information for blades and configurations indicated both positives and negatives. While many of the items discussed showed promise or were proven in the field, they also presented drawbacks that should be considered. Given the limited quantified costs and benefits cited, none of the documents computed a cost-benefit ratio.

Table 3-2: Summary of blade research

Title	Author(s)	Year	Locale	Costs	Benefits	Effectiveness	C-B Ratio (if developed)
Quick Edge: Rapid Underbody Plow Cutting Edge Changing System	Etheridge and Shankwitz	2006	Minnesota	Blade - addt'l \$1799 in addition to cost of traditional blade	Labor and material savings - \$62 - \$233 Minimized risk of injury during replacement	System proved to be feasible and facilitated faster replacement of plow blades	N/A
Plowing Wider and Faster on 21 st -Century Highways by Using 14-ft Front Plows and Trailer Plows Effectively	Lannert	2008	Missouri	Conversion to 14 ft plow - \$400/foot Trailer plows could reduce equipment investment by 20-30%	Reduced passes required Fuel savings Reduced labor required	Allowed for faster clearing of the roadway	N/A
Plow Truck with Reversible Plow and Wing	Macfarlane	1995	New Brunswick	N/A	Improved plowing efficiency Equipment versatility Reduced collisions Improved visibility for operators	Drivers disoriented when carrying left-hand wings Wing change must be performed in the yard or shop	N/A
Improved Cutting Edges for Ice Removal	Nixon	1993	Iowa	N/A	Improved ice removal capabilities	Blade developed during the research cut more ice while using less downforce	N/A
Snow Plow Cutting Edge Cost Effectiveness	Becker	1994	South Dakota	CAT ¹ without a frontal blade - \$9.86/foot Pacal without a frontal blade \$10.91/foot CAT with a ½ inch frontal blade - \$16.54/foot Pacal with a ½ inch frontal blade - \$17.59/foot	Carbide insert cutting edge blades resulted in potential savings of 53 cents per vehicle mile	Higher costs encountered per mile when using CAT and Pacal frontal blades	N/A

¹ The research did not indicate what CAT stood for

Table 3-2 cont'd: Summary of blade research

Title	Author(s)	Year	Locale	Costs	Benefits	Effectiveness	C-B Ratio (if developed)
Final Report of Snow Plow Cutting Edge Test and Evaluation (T&E) Program	Nixon and Wei	1999	National	N/A	N/A	Cutting edges exhibited failure in one of two ways: carbide inserts could be broken away from the cutting edge blade, or wear of the carbide was relatively rapid	N/A
Evaluation of Urethane and Carbide-Tipped Blades on Wheel-Supported Snow Plows	Roosevelt and Cottrell	1997	Virginia	Carbide tip plow blade w/ wheels - \$900/year Urethane tip plow blade w/ wheels - \$2700/year	Carbide tip - less impact on pavement markings	Carbide-tipped blades prolonged retroreflectivity and life of pavement markings and effectively removed loose, but not packed snow	N/A
The High-Speed-Environmental Snowplow	Gruhs	2006	Sweden	Potential damage to roadside features from higher speed plowing	Reduced chemical usage Reduced plow noise Improved safety Higher speed plowing on bridges due to flexible cutting edge Reduced pavement marking	N/A	N/A

3.4. Automatic Vehicle Location/Global Positioning Systems

AVL/GPS has emerged as a technology with significant promise for meeting the challenge of simultaneously increasing productivity, quality, and environmental stewardship while maintaining a constant or improved level of service on roads. Subsequently, a sizable body of literature exists documenting its costs, benefits, and effectiveness. Those who have examined AVL/GPS for winter maintenance include Meyer and Ahmed (26), Hille and Starr (27), Allen (28), Andrey, et al. (29), McClellan (30), Henry (31), Owen (32), McCullough et al. (33,34), Anderson (35), Shi et al. (36), Roosevelt et al. (37), and Anthony (38). An overview of the information provided by these documents is presented in Table 3-3.

Varying AVL/GPS cost information was provided by different sources, with quantified costs being identified for units, installation, communications, software, and maintenance. Non-quantified costs also cited these same items as those an agency could expect to incur.

Limited quantified benefit information was provided by the literature, with that provided specifically pertaining to the savings expected from reduced paperwork, improved management and reduced crashes. Non-quantified benefits were widely identified and consisted of the potential for labor and material savings, the creation of electronic reports and records, fuel and time savings, and improved planning.

The effectiveness of AVL/GPS was generally found to be favorable. Some elements were identified as necessary for the system to be effective (training). It appears that as the technology has matured, with its benefits and effectiveness increasingly becoming better understood and accepted. Only one reference conducted a cost-benefit analysis, with results indicating a favorable ratio of between 2.6 and 28.4 for such a system, depending on the scenario.

Table 3-3: Summary of AVL/GPS research

Title	Author(s)	Year	Locale	Costs	Benefits	Effectiveness	C-B Ratio (if developed)
Benefit-Cost Assessment of Automatic Vehicle Location (AVL) in Highway Maintenance	Meyer and Ahmed	2003	Kansas	Radio Communications - \$750,000 - \$6,000,000 In Vehicle unit - \$3,500 Vehicle sensors - \$600 Training - \$3,000/site System integration - \$15,000/site Software - \$5,000-\$25,000 Repair and maintenance - \$4,000/year/site	Paperwork savings - \$67,908 ¹ Better fleet mngt - \$398,864 ¹ Reduced crashes - \$5,865,296 ¹	Timelier response Improved resource management Reduced tort claims Improved roadway inventories Near real-time information for travelers	2.6 to 28.4
Design and Implementation of Automated Vehicle Location and Maintenance Decision Support System for the Minnesota Department of Transportation	Hille and Starr	2007	Minnesota	Hardware and software - \$2,000/unit Operating costs - \$40/month/unit	More efficient dispatching Optimized chemical application Service level enhancements Automated material usage reporting	Integration of multiple information sources	N/A
Fighting winter storms: a GIS approach to snow management	Allen	2006	N/A	N/A	Route prioritization Reduced deadheading Better material staging	N/A	N/A
Using Classification Trees to Build Flexible and Intuitive Winter Weather Indices	Andrey et al.	2009	Ottawa	Real-time treatment application rates displayed oscillation	Historical records by location Easy to use data	Provides accurate material usage information	N/A
Winter Maintenance Alphabet Soup	McClellan	2007	Indiana	Limited data transmission via radio Recurring cost for cellular communications	Well received by drivers	Requires driver training to achieve potential	N/A

¹ Annual statewide estimates

Table 3-3 cont'd: Summary of AVL/GPS research

Title	Author(s)	Year	Locale	Costs	Benefits	Effectiveness	C-B Ratio (if developed)
Intelligent Transportation Systems Concepts for Rural Corridor Management	Henry and Wendtland	2007	Arizona	High capital costs On-going maintenance and up-keep Training requirements Communications needs and availability for data transmission Privacy concerns	Effective equipment use and mobility Increased safety of drivers and all roadway users Flexibility to expedite immediate changes to assignments and routes Real-time vehicle feedback Monitoring of vehicle mechanical and efficiency Fuel savings	Historical record of activities Precise real time vehicle tracking	N/A
Arizona Intelligent Vehicle Research Program - Phase Two (b): 2001-2002	Owen	2000 - 2002	Arizona	Poor cellular coverage Low system capacity	N/A	Additional training r	N/A
Using a Statewide Wireless Data Network for Maintenance Activities, and Utilizing Wireless Data Network for AVL and Mobile RWIS	McCullouch et al.	2006	Indiana	In Vehicle unit - \$500 - \$900 Service fee - \$45 - \$60/month GPS - \$130 Modem - \$1900 Laptop - \$1200 Unit software - \$125 Base station - \$5000 Mapping software - varies	N/A	N/A	N/A
Southeast Michigan Snow and Ice Management System Final Evaluation at End of Winter Season Year 2004	Andersen	2004	Michigan	N/A	Better supervision Lower material usage improved communications for vehicles	System requires fine tuning over time	N/A

Table 3-3 cont'd: Summary of AVL/GPS research

Title	Author(s)	Year	Locale	Costs	Benefits	Effectiveness	C-B Ratio (if developed)
Vehicle-Based Technologies for Winter Maintenance: The State of the Practice	Shi et al.	2006	National	Per installation (Alberta) - \$2000 GPS, hardware (Colorado) - \$1250 Per installation (Iowa) -\$3500 – \$4000 Per installation (Utah) -\$3000 Per installation (Washington) -\$1250 Per installation (Howard CO. Maryland) -\$4800 Cellular plans/month/vehicle (Alberta, Colorado and Virginia) - \$40 - \$60 Data administration and management (Alberta) - \$1300 General costs/vehicle/year (Howard County, Maryland) - \$100	Faster assistance in storm response Storm event planning based on historical information Simplified tracking and reporting Reduced paperwork	AVL brands cannot be readily exchanged between vehicles because of the lack of standardization	N/A
Lessons Learned from a Pilot Study of an Automatic Vehicle Location System in an Urban Winter Maintenance Operations Setting	Roosevelt et al.	2001	Virginia	Unit acquisition and installation Operating costs - communications Maintenance costs	Labor equipment and materials. Reduced crashes Streamlined report generation Reduced reliance on radio communications	Operational and institutional issues, system problems, and mild winters limited effectiveness	N/A
Winter Maintenance in Vaughan: Improving Operations and Communication Through an AVL System	Anthony	2000 - 2001	Ontario	N/A	Better management of services Information on operations Timelier information for residents	Town council provided accolades on winter maintenance operations	N/A

¹ Annual statewide estimates

3.5. Air and Pavement Temperature Sensors

Mobile temperature sensors (i.e. those fixed to snow plows) are intended to provide a real-time measurement of road surface temperature for a particular point of roadway. The primary use of such information is to provide real-time information regarding surface temperature in order to adjust material application rates as necessary. Such sensors have become more widely applied to plows as the technology matures, to the point that some agencies consider them essential equipment. Their data may be interfaced with material spreaders so that application rates may be adjusted up or down given changes in temperature variables. Research by SRF Consulting Group (39) and Tabler (40) examined mobile sensors, while SRF Consulting Group (39) and Marosek (41) examined in-situ sensors. An overview of the information provided by these documents is presented in Table 3-4.

Only limited air and pavement temperature sensor information related to costs was presented in the literature. Specifically, maintenance cleaning of sensors was cited as a cost, although it was not quantified. No benefit information was presented for such systems. As a result, no cost-benefit ratios have been developed to date. Despite the lack of cost and benefit information, the sensor systems discussed were all found to work effectively to some extent, with only limited problems reported.

Table 3-4: Summary of air and pavement temperature sensor research

Title	Author(s)	Year	Locale	Costs	Benefits	Effectiveness	C-B Ratio (if developed)
Laboratory and Field Studies of Pavement Temperature Sensors	SRF Consulting Group	2005	N/A	N/A	N/A	Mobile sensors found to be effective, reporting temperatures similar to in-pavement sensors Sensors more accurate on concrete In-pavement sensors found to be accurate within one to two degrees F	N/A
Comparison of RoadWatch and Control Products, Inc., Model 999J Infrared Sensors	Tabler	2003	Colorado	N/A	N/A	Sensors gave comparable readings to one another Sensors had trouble measuring air temperature in timely manner	N/A
Evaluating the Accuracy of RWIS Sensors	Marosek	2005	N/A	Maintenance cost for cleaning sensor	N/A	In-pavement sensors accurately reported wet/dry conditions Could not identify slush and snow/ice conditions Infrared sensor performed well and could detect snow/ice and dry conditions	N/A

3.6. Road Weather Information System (RWIS)

RWIS is one of the most widely applied systems that DOTs employ in making decisions related to treatment during winter storms. RWIS provides information related to pavement and air temperatures that support decision-making with respect to deicing chemical applications, anti-icing strategies, and material, staff and equipment optimization. As expected for such a mature application, the costs, benefits and effectiveness of RWIS have been widely examined. Among the available literature related to RWIS costs, benefits and effectiveness is the work of Bosley (4), Sullivan (42), Lasky et al. (43), Ballard et al. (44), Strong and Shi (45), Ye et al. (46), Boon and Cluett (47), McKeever et al. (48), and Ye and Strong (49). An overview of the information provided by these documents is presented in Table 3-5.

Given its widespread application, both quantified and non-quantified cost information for RWIS were provided in several documents. Quantified costs focused on complete site installations, while non-quantified costs focused on maintenance, power, and communications. The benefits cited in the literature were solely non-quantified, consisting of labor and material savings, improved level of service, safety improvements, lower insurance costs, and fuel savings.

RWIS systems have been found to be an effective tool for winter maintenance operations and are expected to produce cost savings throughout the lifetime of the installation. Given the extensive cost and benefit information available, several cost-benefit ratios were provided in the literature, ranging between 1.1 and 11.0.

Table 3-5: Summary of RWIS research

Title	Author(s)	Year	Locale	Costs	Benefits	Effectiveness	C-B Ratio (if developed)
Road Weather Information System Phase I	Sullivan	2004	Alaska	Per site- \$30,000-\$50,000 Training Warranty Power Communications	N/A	N/A	N/A
Benefit/Cost Study of RWIS and Anti-Icing Technologies	Bosley	2001	N/A	System acquisition Installation Maintenance Development of new agency protocols	Safer travel for motorist Improved level of service Cost savings Provides maintenance response information Reduced wear on equipment and infrastructure	N/A	1.1 to 5.0
Development and Field-Operational Testing of a Mobile Real-Time Information System for Snow Fighter Supervisors	Lasky et al.	2006	California	N/A	Cost savings Reduced crashes Lower insurance premiums Improved level of service	N/A	N/A
Benefit-Cost Analysis of Weather Information for Winter Maintenance	Strong and Shi	2008	Utah	N/A	N/A	N/A	11.0-material cost savings
Evaluation of the Effects of Weather Information on Winter Maintenance Costs	Ye et al.	2009	Iowa, Nevada, Michigan	RWIS maintenance cost Private-sector weather forecast services	Reduced material usage Reduced staffing Reduced equipment usage	N/A	1.8-Iowa 3.2-Nevada N/A-Michigan
Road Weather Information Systems: Enabling Proactive Winter Maintenance Practices in Washington State	Boon and Cluett	2002	Washington	N/A	Reduced equipment costs Improved labor productivity More timely road maintenance Labor savings Higher level of service Increased safety Reduced material costs	N/A	1.4 to 5.0

Table 3-5 cont'd: Summary of RWIS research

Title	Author(s)	Year	Locale	Costs	Benefits	Effectiveness	C-B Ratio (if developed)
A Life Cycle Cost-Benefit Model for Road Weather Information Systems	McKeever et al.	1998	Texas	Per site-\$10,000-\$40,000 Plus \$35,000 for additional equipment	Reduced patrol, labor, equipment, and material costs	A savings of \$923,000 could be accrued over a 50 year period	N/A
Cost-Benefit for Weather Information in Winter Maintenance: Technical Memorandum 4: Secondary RWIS Benefits (Draft)	Ye and Strong	2009	N/A	Communication hardware and software Winter operations equipment, maintenance and staff Hardware Establishment and maintenance of a delivery platform Establishing a network and maintenance	Reduced vehicle delay Less fuel consumption Ability to coordinate and pool resources Improved cost effectiveness Improved safety Reduced crashes and crash severity	N/A	N/A
Assess Caltrans Road Weather Information Systems (RWIS) Devices and Related Sensors	Ballard et al.	2002	N/A	N/A	N/A	Agency personnel perceive RWIS to be a useful tool for snow/ice operations and to provide traveler information	N/A

3.7. Maintenance Decision Support System (MDSS)

MDSS is an integrated software application that provides users with real-time road treatment guidance for each maintenance route, addressing the fundamental questions of *what*, *how much* and *when* according to the forecast road weather conditions, the resources available and local rules of practice (50). In addition, MDSS can be used as a training tool as it features a *what-if* scenario treatment selector that can be used to examine how the road condition might change over a 48-hour period with the user-defined treatment times, chemical types, or application rates. A general overview of MDSS is presented by Smithson (51), the National Center for Atmospheric Research (52), NCHRP (53), Mewes et al. (54), Hart et al. (55), with literature specifically discussing the costs, benefits, and effectiveness of MDSS presented by the work of Ye et al. (56,57), Cluett and Jenq (58), and Sugumaran et al. (59). An overview of the information provided by these documents is presented in Table 3-6.

Surprisingly little published cost information was provided for MDSS in the literature. What cost information was provided consisted primarily of the cost of entire systems. Benefits were better documented, although they consisted primarily of non-quantified items. Identified benefits included reduced labor, equipment and material costs, improved level of service, better decision making capabilities, and improved analysis and training.

MDSS systems have been found effective in producing cost savings, with the literature indicating these savings running into the millions of dollars. Cost-benefit ratios for MDSS were subsequently favorable, ranging between 1.33 and 8.67, depending on the particular scenario.

Table 3-6: Summary of MDSS research

Title	Author(s)	Year	Locale	Costs	Benefits	Effectiveness	C-B Ratio (if developed)
Analysis of Maintenance Decision Support System (MDSS) Benefits & Costs	Ye et al. (a,b)	2009	New Hampshire Minnesota Colorado	New Hampshire- \$332,879 Minnesota- \$496,952 Colorado- \$1,497,985 Software and operations costs In-vehicle computer hardware cost Communications costs Training cost Administrative cost	Reduced material usage Reduced traffic delay Improved traffic safety	New Hampshire- \$2,367,409 to \$2,884,904 Minnesota- \$1,369,035 to \$3,179,828 Colorado- \$1,985,069 to \$3,367,810	7.11 to 8.67- New Hampshire 2.75 to 6.40- Minnesota 1.33 to 2.25- Colorado
A Case Study of the Maintenance Decision Support System (MDSS) in Maine	Cluett and Jenq	2007	Maine	N/A	GIS radar and National Weather Service (NWS) forecasts provided additional information and enhanced capabilities Provided a consolidated set of treatment recommendations New data allowed for better decision making Useful training tool	N/A	N/A
Web-Based Implementation of Winter Maintenance Decision Support System Using GIS and Remote Sensing	Sugumaran et al.	2005	N/A	N/A	Cost savings Improved snow and ice removal Widespread access of modeling and analysis tools for personnel	N/A	N/A

3.8. Zero Velocity and Gravity Material Placement Systems

Material placement systems are the front line in the application of anti-icing and deicing chemicals to the roadway surface. It is of great interest to agencies to apply the right amount of materials in the right location at the right time, and advanced material placement systems can assist in meeting these goals. Such systems use input from sensors (friction, pavement temperature, etc.) to adjust the amount of material being applied “on the fly”, resulting in cost savings through reduced material usage. These systems are likely to see more widespread application as the technologies mature and the results of their evaluation/application become more widely disseminated. Those who have published cost, benefit or effectiveness information related to these systems include Sharrock (60), Nantung (61), Colson (62) and the Iowa DOT (63). An overview of the information provided by these documents is presented in Table 3-7.

Costs associated with placement systems included quantified equipment costs, as well as items pertaining to maintenance and calibration which were not quantified. While estimated benefits were quantified in the form of expected savings by one document, most benefits fell into the non-quantified category. These included material savings, improved material placement, and higher treatment speeds. The effectiveness of such systems was only indicated by one document, which found such systems to be effective in producing bare pavement in a timelier manner. Given the limited quantified costs and benefits cited, none of the documents computed a cost-benefit ratio.

Table 3-7: Summary of zero velocity and gravity material placement systems research

Title	Author(s)	Year	Locale	Costs	Benefits	Effectiveness	C-B Ratio (if developed)
Zero Velocity and Salt Brine: One State Garage's Experience	Sharrock	1998	Ohio	N/A	Decrease in salt consumption (up to 70%) Enabled treatment at higher speeds Savings of \$70,000 over two years	Bare pavement achieved in half the time	N/A
Evaluation of Zero Velocity Deicer Spreader and Salt Spreader Protocol	Nantung	2001	Indiana	More extensive maintenance requirements	Accurate placement of materials resulting in lower usage	N/A	N/A
An Evaluation of Winter Maintenance Material and Metering and Placement Equipment	Colson	1997	Maine	Equipment calibration and additional maintenance required	Material savings through improved application metering	N/A	N/A
Anti-icing Equipment: Recommendations and Modifications	Iowa DOT	2000	Iowa	Gravity feed system - \$400 (excluding storage tanks) Pressurized system - \$1000	N/A	N/A	N/A

3.9. Conclusion

This chapter has presented an overview of existing literature related to the costs, benefits, and effectiveness of the top ten practices, equipment, and procedures of interest to winter maintenance practitioners. These included anti-icing and deicing, front and underbody blades and configurations, AVL/GPS, temperature sensors, RWIS, MDSS, and zero velocity spreaders (note that this list does not add up to ten because some categories have been combined). A more comprehensive discussion of existing literature, including a review of literature pertaining to as vehicle-based sensors, fixed friction prediction sensors, in-pavement sensors, lighting packages, backup cameras, material placement systems, windshield wiper systems, and driver simulation training can be found in Appendix B of this report.

Costs identified for anti-icing and deicing include those associated with materials, labor and maintenance, while benefits include potential material or labor savings. Costs identified for plow blades and configurations were limited to equipment, while the benefits were well defined. Non-quantified costs and benefits for plow blades and configurations included damages, safety, efficiency and versatility. The costs for AVL/GPS have been well documented while defined benefits remain non-quantified. Air and pavement temperature sensors had limited cost information reported, with no benefits cited. Costs and benefits for RWIS have been widely documented, but in general, cited benefits were non-quantified. Little cost information on MDSS has been published, with the focus on system costs; benefits have been extensively defined but remain non-quantified. Costs for material placement systems were provided for equipment and benefits were quantified as expected savings or were non-quantified.

The lack of cost-benefit ratios was not as surprising as the fact that in many cases, quantified values related to the costs and benefits of specific items had not yet been identified. For example, RWIS, which is a fairly mature application, has a complete absence of valued benefit information. Certainly this gap could be addressed through the tracking of material and crash cost savings by agencies, with results published as they become available.

Even in the case of more straightforward technologies, such as mobile air and pavement temperature sensors, costs and benefit information is lacking. This technology represents a case where a straightforward cost-benefit study could be conducted. Costs for the technology would include the price of the sensors and installation/maintenance labor. Benefits stemming from the availability of continuous temperature data could be tracked through savings accrued by reduced material usage.

4. TOOLKIT OVERVIEW

This chapter discusses the various aspects of toolkit development. As discussed in Chapter 2, practitioners indicated that the preferred form for the toolkit was a website. This chapter discusses the toolkit developed as a result of that preference. Included is a discussion of cost-benefit³ analysis, the input data employed by the toolkit (e.g. data a user will need to input), the assumptions employed behind the toolkit items in determining costs and benefits, the development of the toolkit itself, and the process and outputs of the toolkit.

4.1. Benefit-Cost Analysis

In order to determine whether a practice, equipment, or operation should be implemented, the value of the costs associated with it, as well as the value of the resulting benefits must be considered. After researching the methodologies developed elsewhere, a standard methodology was designed in which costs and benefits were grouped by whether they applied to the government agency, the user (motorist), or society in general. As is typical in cost-benefit analysis, it was found that costs were easily identified and accounted for, but monetary values were hard to establish for many of benefits associated with winter maintenance items. Benefits were defined as tangible if a monetary value could easily be assigned and intangible if one could not; all benefits, tangible and intangible, are presented to the user in the toolkit. This approach employed by the toolkit in treating benefits is not complete, but it sets a starting point for the winter maintenance community to quantitatively assess choices.

When a financial value can be assigned to most of the costs and benefits, it becomes possible to compute a benefit-cost ratio. This approach is termed Benefit-Cost Analysis or BCA. Such procedures are traditionally employed to show the extent to which an investment will result in a benefit to the investor. Benefit-cost ratios greater than 1.0 are generally desired. Given that many of the items under consideration for winter maintenance possess long lives that incorporate present (e.g., initial capital expenditure) and future (e.g., annual maintenance) costs and benefits, there is a need to bring the values of all future costs and benefits accrued to a present value. A discount rate is employed to accomplish this. The discount rate is an opportunity cost value or the time value of the money⁴. Simply stated, it helps to determine how much the money to be potentially invested in a practice, equipment or operation could make if it was invested in another way.

In conducting the cost-benefit analysis within this toolkit, a series of steps are undertaken. These are typically transparent to the user, aside from the provision of inputs (a discount rate, the cost of an item, maintenance, etc. and key assumptions for calculating benefits). However, the overall process is summarized in the following to provide a better idea of the overall approach employed by the toolkit.

³ Note that beginning in this chapter, the terms cost-benefit analysis and benefit-cost ratio will be used interchangeably. While they essentially refer to the same result in this document, the term benefit-cost ratio more appropriately reflects the nature of the analysis being conducted, as benefits are divided by costs to produce the ratio of interest.

⁴ Please refer to the following section (4.1.1) for a discussion of appropriate discount rates.

The key step (aside from providing the inputs for cost calculations) is to convert costs (or benefits) into annual and present value forms. Using the project life and discount rate supplied in the project parameters, these values are converted to both a present value and an annual value (or annual equivalent costs) by the following:

Present value = initial costs + the present value of the annualized cost $PV(A)$, where

$$PV(A) = \frac{A}{i} * \left[1 - \frac{1}{(1+i)^n} \right], \text{ where}$$

A = present value of annualized cost

i = the discount rate, and

n = number of years

If the discount rate is zero, then the annualized cost is simply $PV(A) = A*n$. The toolkit also determines annualized value, which employs the same equations, but instead solves for A as opposed to $PV(A)$.

Users can input annual benefits, which are also converted into both annual and present value form. Present values are employed because some benefits will be obtained during some year in the future, but must be accounted for during the present. The process and equations employed match those discussed for determining cost values. The present value is the total cost of the choice in today's dollars; the annualized value allows for better comparison between choices with different life spans.

Once present and annual values are available for costs and benefits, it is possible to calculate the benefit-cost ratio. This is calculated by dividing present value benefits by present value costs, or annual equivalent benefits by annual equivalent costs. The benefit-cost ratio is calculated for agency-specific costs and benefits, as well as total costs and benefits. Total costs and benefits include both those accrued by the agency, as well as from other sources, such as road users and the overall society (via crash reduction, travel time savings, etc.).

4.1.1. Discount Rates

As stated in the previous section, the discount rate is an opportunity cost value, or, alternatively stated, the time value of the money, which indicates how much money could be worth if invested alternative ways. The challenge from a winter maintenance perspective and for transportation agencies in general, is that money cannot be invested in an alternative manner (i.e. stocks, bonds, or a savings account). Rather, agencies are charged with spending their current budget allocations rather than investing them for future use. As a result, the selection of an appropriate discount rate is often a challenge for agency personnel.

In the absence of the ability to select an alternative investment precisely, agency personnel may take two approaches in selecting a discount rate. The first is to consider the Consumer Price Index (CPI) in establishing the discount rate. The use of the CPI in estimating discount rates is performed by removing the rate of inflation (measured by the CPI) from a market interest rate for government borrowing. Traditionally, the Office of Management and Budget has recommended this governmental borrowing rate be 7 percent. The average CPI inflation rate over the past 10 years has been 2.79 percent (the user may employ an average figure over time or the most recent

rate, at their discretion). Consequently, the toolkit user would arrive at a discount rate of $7.0 - 2.79 = 4.21$ percent through this approach.

The second approach would be to employ the Office of Management and Budget (OMB) “Discount Rates for Cost Effectiveness, Lease-Purchase, and Related Analyses” guidance for a discount rate figure (64). The discount rate figures provided by OMB are updated annually (at the time of this document’s writing, the most recent update was December, 2009) and forecast the expected interest rate for the coming year on Treasury notes and bonds. For example, information compiled in December 2009 related to the nominal discount rate ranged from a 2.3 percent for a 3 year period to 4.5 percent for a 30 year period. The rates provided by the OMB are those employed in Federal projects to determine present value, and therefore should be considered reliable in their application to cost-benefit analysis. For the purposes of winter maintenance benefit-cost analysis, the user would select the rate which most closely matches the expected lifespan of the particular item to be analyzed.

4.2. Input Data

As one might expect, the varied items included in the toolkit have different data requirements. These range from minimal data needs for an item like mobile temperature sensors to more extensive inputs for an item like AVL. To inform the reader, a general overview of the various data needs for the toolkit is as follows:

- Number of trucks to equip
- Number of garages or sheds (may only be one, unless area of coverage is larger)
- Loaded labor rate per hour (ex. the typical cost of shop labor per hour, including benefits)
- Average labor hours per storm per vehicle (ex. the average time a plow is out operating)
- Annual material costs (anti-icer, deicer, abrasives, etc.)
- Annual number of storm events (average or estimate)
- Lane miles covered per storm by all maintenance vehicles
- Total storm-related crashes (estimate if actual figures are unavailable)
- Total number of winter maintenance vehicles in fleet
- Type of deicer to be used (please select granular or liquid)
- Measure used in recording the lifespan of blades (miles, storms or hours)
- Routes covered by plows (Interstate or secondary)
- Miles covered by a plow over the course of a winter season
- Average time to change blade inserts (current time spent per plow)
- Average plowing duration (hours) per storm event
- Blade insert lifespan (average number of storms between replacement)
- Annual storm-related crashes and crash values
- Estimated hours to install and maintain spreader equipment
- Number of computers that MDSS software would be installed on
- Number of vehicles equipped with Mobile Data Collection
- Number of computers that AVL software would be installed on
- Number of vehicles equipped with AVL
- Operating cost per mile (if known)
- Hours per vehicle per storm spent on paperwork/reporting
- Current weather information costs (if any, ex. forecasts)

- Number of planned/existing RWIS stations
- Expected or existing number of RWIS users
- Annual hours of RWIS training required (expected or current) per user

These points are listed to provide the reader with a broad overview of the data that is required for the various toolkit items. Definitions of many of these items are provided in Appendix B. Note that not all of the points in this list are required inputs for each toolkit item. It is understood that different agencies collect different data and maintain different records. As such, a user may find that a piece of information required as an input for a specific toolkit item may not be available. In such a case, an estimate made by the user may be acceptable. In other cases, such as crashes, the user would be advised to not enter data rather than enter an estimate (i.e. default to a value of zero).

4.3. Cost Information

Information provided in the toolkit related to the cost of specific practices, equipment and operations is presented by various information buttons/icons. The information presented came from a variety of manufacturers either through direct contact (telephone call) or information presented on the internet (manufacturer website). In some cases, limited cost information was provided by practitioners via the internet surveys conducted during this project. The information provided in this toolkit is for user reference and guidance only. *The user is strongly encouraged to obtain individual cost quotes specific to the application they plan to evaluate/analyze using this toolkit.*

4.4. Web Site Development Environment

The Cost Benefit Analysis toolkit was developed with open-source tools to minimize the software licensing costs while maximizing functionality and providing a means for easy expansion. Open source tools provide for freely distributable, tested software created by a community of developers which share a common problem. The toolkit uses the Joomla Content Management System (CMS), which was chosen because it is easy to use, has existed for a few years so it is relatively stable, and is free open-source software. Joomla runs on the common LAMP (Linux, Apache, MySQL, PHP) configuration which is comprised of all open source components. Joomla also allows for relatively easy updates to the content by non technical personnel and possesses a built in user management system which will ease in the expansion of the toolkit in the future.

Fabrik is an open-source module that runs inside Joomla which was used to build the data entry forms. Fabrik has existed for a number of years and is well supported. It provides the tool necessary for saving the form fields to the database without having to write special database access tools. A downside to Fabrik is that it does not employ a very well structured change management system, which was not readily apparent at the beginning of the programming involved in this toolkit. Instead, Fabrik takes an ad hoc approach to making changes to the core software and does not employ much regression testing, which may cause other parts of the system to fail after a change is made to the software. Despite this shortcoming, the open source components used to build the toolkit provide for future expansion and can accommodate other winter maintenance technologies should they be of interest.

4.5. Toolkit Analysis Procedure

The toolkit has been built in a manner that walks the user through a benefit-cost analysis in a series of steps. Based on the practice, equipment or operation selected by the user, they will be presented with a series of web pages that represent the steps of benefit-cost analysis and require various item parameter, cost and benefit values to be entered. These steps are as follows:

- Step 1 of 5: Define Project Parameters – On this page, the user will provide specific parameters related to the application of the item they plan to analyze at their agency. Depending on the toolkit item being examined, this will likely include information such as the number of vehicles the item will be applied to, the total size of the vehicle fleet, annual material expenditures, and so forth.
- Step 2 of 5: Enter Costs – On this page, the user will enter initial and annual costs specific to the agency. Such costs include the purchase price of the item of interest, installation, and so forth. Annual costs pertain to recurring costs such as yearly maintenance, communications, and so forth. In addition, while the developers of the toolkit did not identify any quantified values for them, the user may also enter costs to the user (ex. increased motorist delay) and society (ex. increased environmental harm) on this page.
- Step 3 of 5: Benefits – This page does not require input from the user. Rather, it presents the user with a list of quantified and non-quantified benefits that may be achieved by the agency, user and society through the use of the item being examined. The intention of this page is to make the user aware of all benefits that may be achieved, although many of these have no dollar value associated with them (i.e. non-quantified).
- Step 4 of 5: Benefit Quantification – On this page, the user will enter values related to the determination of benefits that use of an item will produce for the agency, user and society. In most cases, only the agency benefits can be quantified. For example, the item may produce an expected percent reduction in material use, resulting in a benefit to the agency. In some cases, the user may also receive a quantified benefit, such as a reduction in crashes occurring over a season. In no case did the toolkit developers encounter any information related to quantified benefit values for society. However, if the user has such values to enter, the toolkit provides a mechanism to do so.
- Step 5 of 5: Results – The final page the user will see presents the results of their analysis. This report includes an overview of the item being examined, related items that it may be used with, a summary of all the parameter, cost and benefit values they have entered, as well as the benefit-cost ratios that the toolkit has calculated.

4.6. Key Toolkit Points

When using the toolkit, a few specific points should be kept in mind. These include:

- Benefit-cost ratios much greater than 1.0 are generally desired. A ratio exceeding 1.0 indicates that for each one dollar an agency spends on a particular item (cost), a benefit of greater than one dollar is accrued by the agency (and/or users and society).
- An agency-specific benefit-cost ratio has been included, recognizing agencies sometimes must make purchasing decisions based on their internal benefit-cost ratio. A total benefit-cost ratio is also included, as this reflects a comprehensive analysis

- that takes into account user and societal costs and benefits in addition to those of the agency.
- When entering numbers the user should not enter commas and dollar signs, as the software supporting the toolkit calculations does not function properly when these are used.
 - The user is strongly encouraged to obtain individual cost quotes specific to the application they plan to evaluate/analyze using this toolkit
 - Results show cost-benefit ratios for tangible values; sometimes intangible, non-quantified benefits can be significant and justify a choice where the quantified benefit-cost ratio is below 1.0.

4.7. Known Gaps and Issues

As one might expect, some items have less information (particularly related to quantified benefits) than others. The more widely adopted or employed an item is, the more likely good quantified cost and benefit values are to exist (e.g., RWIS). This disparity of quantified values is one of the toolkit's shortcomings and is expected to be addressed by future research. While every attempt has been made to achieve a quantified value for costs and benefits associated with an item, the fact is that some significant potential values associated with benefits have not been developed. For example, the use of AVL is likely to reduce storm-related crashes and produce a cost avoidance or savings (through reduced injuries, property damage, etc.). However, no existing research has quantified the contribution by AVL to reduced crashes when used in conjunction with other winter maintenance practices (plowing, deicing, etc.). As such, a benefit-cost ratio less than 1.0 in some cases does not necessarily disapprove the investment in a certain practice, equipment, or operations, where significant intangible benefits may be achieved.

During the course of toolkit testing and validation, some issues have been identified which may potentially impact the user. For example, while developed to function in all of the most up-to-date web browsers, in Internet Explorer the toolkit may not automatically populate all necessary fields when a data input calculator is opened the first time. In such an instance, the user will need to exit and reenter the calculator a couple of times before the field is populated. This issue stems from the content management system running the overall program behind the scenes. The issue does not impact the calculations once the fields are populated.

Some minor formatting issues also exist that vary from browser to browser. These primarily consist of the alignment of certain data items on the screen. A built-in pdf creator and export to Word function would allow flexibility beyond the current print function. While every attempt has been made to address this issue, it may still exist depending on the browser version employed by the user. A future version of the toolkit would address such issues, along with implementing critical improvements suggested by users.

If this toolkit is refined in the future, user management should also be considered. The content management system allows an administrator to update built-in default values and tooltip information, but a user management module to interface with the data in an even more simplified manner, including a method to easily add a new equipment, operation, or practice, should be developed. The user management module would further be enhanced by a data mining capability, to produce reports comparing user values and results. The system has been built in a

way to easily incorporate these sort functions. Finally, a maintenance plan to manage user-input data, should be developed, along with an administrative user manual.

4.8. Conclusion

This chapter has presented an overview of the different aspects related to development of the toolkit. It began with an overview of benefit-cost analysis, with a discussion of the selection of a discount rate. Next, the input data required of users was briefly presented, with detailed definitions provided in Appendix B. The chapter continued by discussing the sources of cost information and assumptions employed in the toolkit. It followed with an overview of the aspects related to website development and the general procedure for completing benefit-cost analysis using the website. Finally, the chapter concluded with a discussion of key points a user should know when using the toolkit, as well as known gaps and issues present in the toolkit.

5. IMPLEMENTATION

The following recommendations are related to users, agencies, and data, in light of findings and lessons learned from this project.

5.1. Users

The primary recommendation for implementation related to users is the need for initial training. It is not possible for the research team to train each potential user of the toolkit from a cost and time standpoint. In a broad sense, the toolkit, its user guide, and training materials have been developed in a manner that allows them to be used by any winter maintenance personnel to conduct cost-benefit analysis with minimal training and effort. This manual is designed to provide high-level training for toolkit users, although its primary purpose is to walk users through the use of each specific item in an example cost-benefit analysis scenario. The applications being examined are going to vary from state to state, and every conceivable scenario which may be encountered cannot be addressed in this manual. While the toolkit has been designed in such a manner that it is easy to use with minimal training, the user should perform some practice analyses in order to become familiarized with the toolkit.

In light of this fact, it is recommended that each member state in Clear Roads designate one or more users to be their “expert”. This user would endeavor to learn the intricacies of the toolkit in such a manner that they could then undertake the training of other users in their state. The training materials generated by the research team for this project would also be provided to these users for use in their subsequent training sessions.

Aside from these, users are encouraged to learn more about the specific costs and benefits associated with the toolkit item they are interested in evaluating. This, in part, is facilitated by the toolkit through the provision of various information sheets throughout the website itself. However, the user should also educate themselves to the extent that time permits on the existing practice employed by other agencies through discussions with peers. Finally, if the user proceeds with cost-benefit analysis of a specific toolkit item, they are encouraged to obtain manufacturer price quotes specific to their application. As costs vary based on the units being purchased (e.g., volume discounting), the values provided in the toolkit itself represent only general values, and these are likely to change over time due to inflation and other factors.

5.2. Agencies

As stated in the prior section, agencies that intend to use the toolkit will need to conduct training for their staff. To accomplish this, one or more “experts” for a state should endeavor to learn the toolkit extensively in order to lead training sessions. These sessions would allow for more detailed training to occur beyond the capabilities of this project’s time and budget.

Secondly, from the agency standpoint of Clear Roads, a decision must be made regarding the short and long term hosting of the toolkit website. Consideration of issues such as available bandwidth, expected number of concurrent users and other issues must be taken into consideration when making the hosting decision.

Aside from website hosting, Clear Roads must also decide who will be able to access the website. A significant amount of funds have been spent to develop this toolkit, and Clear Roads members may want to limit access to it based on that investment. Conversely, the toolkit

provides a tool that is of benefit to all winter maintenance professionals, and limiting its use minimizes the potential benefits it could provide to the community of practice. Clear Roads members will need to discuss these issues and decide whether the toolkit will be restricted or not.

Finally, as the next section will discuss, agencies should consider the collection of additional data items that will facilitate future benefit-cost analysis. During the course of this work, the research team identified several data elements that are not presently collected by agencies but which would greatly facilitate such analysis.

5.3. Data

One of the issues encountered during the course of development and testing of the toolkit is that the data measured and collected by agencies varies greatly. In some cases, agencies keep detailed records, while in other cases, information is tracked sporadically. The states employed as example case studies in the User Manual did an excellent job of tracking information; however, even they did not collect all of the information required for input in the toolkit. Rather, assumptions were required in a number of cases.

In the future, agencies should consider tracking additional data, if they do not already do so. In the context of what has been learned in developing the toolkit, this additional tracking might include:

- Average labor hours associated with all storm event activities – how many hours, on average, are spent by all personnel handling a storm?
- Average labor hours per truck associated with storm event activities – what is the average duration of field maintenance activities per truck?
- Average hours spent annually maintaining specific equipment items – how much time is dedicated to performing maintenance on specific items, such as material spreaders?
- Average annual number of storm-events requiring winter maintenance – how many storms does an agency respond to per storm season?
- Storm-related crashes on roads maintained by the agency – how many crashes are happening during and after a storm as the direct result of a storm event?
- Storm-related damage tort claims – how many claims are filed for vehicles and property damaged by plows and what is the average value of those claims?
- Quantified/observed benefits accrued (e.g. material savings) – what are the savings when changes in practices, equipment or operations are made, even if these are tracked in a rudimentary manner? Such information would provide baseline data for valuing benefits.
- Lane miles covered per storm (i.e. entire mileage covered during a storm duration) per truck and all trucks – what mileage is being maintained cumulatively during a given storm?
- Lifespan of blade inserts in miles, storms or both – how long are blade inserts lasting and under what type of operating conditions (secondary versus interstate routes)?
- Average time associated to change an item (e.g. blade inserts) – how much time is spent making an equipment change such as blade inserts? How many personnel are involved?
- Paperwork hours associated with a storm event – how much time is spent per storm completing paperwork at a specific level (i.e. a shed, garage or district)?

- Storm intensity or another measure/ranking of a storm event – employing common criteria to rank storm intensity, allowing for the toolkit to more accurately estimate specific benefits, such as potential labor and material savings.
- Operating cost per mile (with or without loaded labor rate include) – how much does it cost to operate a plow per mile during a storm event?

The toolkit itself was developed using the best information available related to costs and benefits; however, as this information was sometimes obtained from research sources, it did not necessarily conform to standard agency practice regarding the information presently being recorded. Generally, information related to the average labor hours expended per storm, the average time spent on paperwork and similar information was where data was lacking. However, if the toolkit is to be used by an agency and they do not presently record a necessary data input, they will need to devise some estimate in the place of hard data. The use of this estimate must be documented and presented to decision-makers if the toolkit is being used to justify a purchase.

Aside from existing data input needs, one of the foremost lessons learned during the course of this project is that cost-benefit analyses have not been performed for a number of items included in this toolkit. Instead, bits and pieces of cost information, and to a much more limited extent, benefit values were available to incorporate into the toolkit. In light of this, the toolkit required the use of reasonable assumptions in order to place a monetary value on many benefits, as well as costs in some cases.

To address this issue in the future, two approaches are recommended. First, agencies are encouraged to move toward the recording of more detailed storm-related cost information. This would be facilitated by the use of technologies gaining greater acceptance/application, such as AVL and on-vehicle sensors and controllers. Secondly, it is clear that basic research which quantifies the specific costs and benefits of various winter maintenance practices, equipment and operations is necessary in order to conduct cost-benefit analysis that is free of extensive assumptions. More research is needed to fully analyze and quantify the cost benefits of winter road maintenance practices, equipment and operations so as to properly justify such investments and educate the related stakeholder groups (e.g., policy makers and general public).

6. CONCLUSIONS AND RECOMMENDATIONS

This project has developed a web-based tool to assist winter maintenance managers in computing benefit-cost ratios. Such information would be presented to decision-makers to justify budget expenditures related to a winter maintenance practice, equipment or operation under consideration. Justification of such expenditures would exist when the tool reports benefit-cost ratios greater than 1.0, which indicate that for each dollar of cost incurred for an item, greater than one dollar in benefits would be accrued. Of course, intangible benefits also are accrued through the use of many winter maintenance items, and these may justify use in cases where benefit-cost ratios less than 1.0 exist.

The project consisted of a number of sequential activities which culminated in the development of the web-based toolkit. Initial efforts focused on a literature review and state-of-the-practice practitioner surveys. The literature review established past and ongoing research and agency reports which reported benefit-cost ratios, quantified and non-quantified cost and benefit information, and general effectiveness related to winter maintenance practices, equipment and operations. The practitioner surveys sought to obtain further information related to the costs and benefits observed by agencies, as well as determine the preferences for the toolkit itself. Based on the feedback received, a series of ten items of interest for inclusion in the toolkit were identified by practitioners, as well as the form that the toolkit should take: a web-based platform.

Once available information related to costs, benefits and effectiveness, as well as the preference for a web-based platform was collected, the development of the toolkit website began. The website was developed with open source tools to minimize the cost of development while maximizing functionality and providing a means for easier future expansion. It used the Joomla Content Management System (CMS), which was chosen because it was easy to use and was free open source software. It runs on the common LAMP (Linux, Apache, MySQL, PHP) and allows for relatively easy updates to the content by non technical personnel. Finally, it possesses a built in user management system which will ease in the expansion of the toolkit in the future.

Following completion of the toolkit website, it underwent testing and validation to verify that it was functioning correctly and producing reliable, accurate benefit-cost ratios. Discrepancies were corrected within the toolkit as identified during this process. Concurrent with testing, training materials, primarily a User Manual, were developed. These training materials were developed to walk the user through the toolkit step by step for each of the ten items. In addition to the User Manual, training in the use of the toolkit was conducted by the project team on July 29, 2010 (with the project Technical Advisory Committee, via webinar) and August 10, 2010 (in person at the summer Clear Roads meeting).

6.1. Lessons Learned

Based on the work completed during the course of this project, a number of lessons learned may be drawn. The first is that there is a clear absence of documented information, both in the literature and in the practitioner community that spells out quantified values for the costs and benefits of winter maintenance. This is particularly true for benefits, which have often been identified but remain non-quantified. This made the development of the toolkit presented here somewhat challenging and required the use of assumptions in order to bridge the information gap and establish benefit-cost ratios.

As discussed in an earlier section, there are several data items that agencies should consider tracking in the future to address this information shortcoming. Some of this information is basic, such as the average time a vehicle is out in the field during/after a storm event performing maintenance. Other data that should be tracked can be more complex; for example, the tracking the number and severity of storm-related crashes. This may be a challenge depending on the collection methodology employed by a particular state (how a police officer records crash data), as well as how a storm-related crash that occurs after the storm is defined (at what point is a crash no longer related to the storm and/or road conditions). Regardless of the issues that may be inherent to specific items, agencies should consider revising the winter maintenance information they currently collect if a more rigorous understanding of the costs and benefits associated with practices, equipment and operations is desired.

A second lesson drawn from this work is that it is a challenge to develop a standardized approach to benefit-cost analysis for items as widely disparate as winter maintenance practices, equipment and operations. In other words, developing an analysis methodology that shares a common approach between items such as mobile temperature sensors and anti-icing can present challenges. For example, the costs of equipment, maintenance required and so forth greatly differ between these items. However, in order to facilitate usability, a common approach to the benefit-cost analysis for each of these items had to be established. This challenge was ultimately addressed through the use of features such as user input calculators, but it required consideration early in the development process.

A third lesson drawn from this work is that there are trade-offs with respect to website development environments. For this toolkit, ease of use and maintainability were considered important. As a result, an open source code tool was selected to alleviate software costs and minimize maintainability once the toolkit was transitioned to Clear Roads management. While the tool employed does allow for ease of maintenance (non-experts who are not programmers can access the toolkit code and change/update cost and benefit information), it also held drawbacks. The most notable of these was the challenges presented by the coding language to handle characters such as commas and dollar signs in calculations and presentation. While these are perhaps inconsequential in most applications, they are quite necessary when conducting and presenting benefit-cost analysis. The trade-offs between aspects such as maintainability and functionality/presentation need to be carefully considered at the onset of a project to ensure that development can proceed in an optimized manner.

Finally, different users will have different levels of familiarity and/or experience with benefit-cost analysis. From a development perspective, the toolkit produced by this project largely focused on the user that would have limited or no experience with benefit-cost analysis. The approach taken in developing a toolkit for such users was to require input information from them to be fairly basic, i.e. number of vehicles in a fleet, number of devices to purchase, and so forth. In taking this approach, the toolkit attempts to minimize user confusion over what information is being sought. Of course, there will still be instances where a user is unsure of the data they are being asked for; in such an event, a glossary of terms and definitions is provided to guide them. Conversely, a user may understand what data they are being asked to input, but their agency may not collect it; i.e. average number of storm events per season, average hours a vehicle spends in the field during/after a storm, and so forth. In such cases, reasonable assumptions would likely need to be entered by the user.

6.2. Recommendations

The tool which has been developed represents an initial approach to winter maintenance benefit-cost analysis. Since it is an initial analysis platform, it represents a tool that can be built and improved upon. As the true costs and benefits of winter maintenance are better tracked and recorded in the future, improvements should be made to the toolkit. These improvements should include both the addition of new items for analysis, as well as the revision of cost and benefit data inputs provided with existing toolkit items. Finally, as new quantified values become available, particularly benefits, these should be incorporated into the existing analysis procedures of the toolkit.

In the near term, the toolkit website should be disseminated to Clear Roads members for them to employ both in a learning and analysis capacity. In a learning capacity, potential users would practice using the toolkit, either through a follow-through of the examples provided in the User's Manual, or through the use of data specific to their agency. Once familiar and comfortable with the use of the toolkit, it may be employed in an analysis capacity, providing answers regarding benefit-cost ratios for items of interest. These results may be used at an agency's discretion in justifying potential expenditures to decision-makers.

In addition to individual user familiarization, agencies might consider training users in groups. The particular format this would take is up to an agency, but it would allow for the training of a large number of users in a common way. This common training should result in uniform interpretation of data inputs and project parameters. The requirement for such training would be the presence of "expert" users who have worked with the toolkit within an agency and that are willing to champion and lead such training.

Future phases/revisions/versions of the project and website should include deployment throughout the Clear Roads consortium as a project task. At present, the deployment of this initial version of the toolkit is in the hands of Clear Roads itself. As a result, the members of the organization may not necessarily have the time available to devote to deploying the toolkit in addition to their day to day job functions. Deployment might encompass identifying volunteer users to test the toolkit, employ it in actual agency use, and publicize the successes achieved through use of the toolkit. All of these items were beyond the scope of this initial phase, but should be taken into consideration if future phases are pursued.

Finally, upgrades to the toolkit in the future should be considered. These might include a mechanism to record the input of agency users in order to serve as a data collection platform for improving the assumptions employed in the toolkit. Upgrades would also include those suggested by users during the course of reviewing the initial toolkit. For example, a mechanism to convert toolkit to a Word-format file has been cited as a needed inclusion.

7. APPENDIX A: PRACTITIONER SURVEY

Introduction

This survey is designed to gather information from winter maintenance professionals for a Clear Roads research project entitled “Development of a Toolkit for Cost-Benefit Analysis of Specific Winter Maintenance Practices, Equipment and Operations”. The toolkit will facilitate a streamlined cost-benefit analysis approach for agency personnel in justifying the use of new tools, procedures and practices to decision makers and plow drivers.

The objective of this survey is to identify the top ten winter maintenance tools, procedures and practices presently employed by agencies in order to prioritize their inclusion in the proposed toolkit. A follow-up survey will focus in greater detail on these top ten items as identified by the present survey.

If you have any questions pertaining to this survey, please contact Xianming Shi, Ph.D. P.E. at Xianming_s@coe.montana.edu or Phone 406-994-6486.

Please provide your Name, Job Title, Organization, Email and Phone Number. (This information will be kept confidential.)

State of Practice

What current tools, processes and procedures does your agency currently employ (check all that apply)?

Maintenance Management System (MMS) to track spending in winter maintenance activities

- TAPER logs GPS/AVL

Other (please specify)

Plow Configurations

- Front Rear Underbody

Other (please specify)

Plow Blades

- Carbide
- Wear Plates
- Triple Blade
- Underbody Blade
- Tow Blade
- Double/Triple Edge
- 14+ Foot

Other (please specify)

Informational Technology

- GPS
- AVL
- RWIS
- MDSS
- Blackberry

Other (please specify)

Windshield Wipers

- Slap Me
- ClearFast
- Hot Shot
- Standard Equipment

Other (please specify)

Deicing and Anti-icing

- Deicing**
 - Deicing and Anti-icing Deicing Solid
 - Liquid
- Anti-icing**
 - Anti-icing Solid
 - Liquid

Application Methods

- Zero Velocity
- Spinner
- Advanced Placement
- Gravity Feed
- Spray
- Stream

Other (please specify)

Add-On Vehicle Accessories and Training

- Back-Up Cameras
- Driving Simulator Training
- Specialized Lighting Packages
- Vehicle Deflectors
- Vehicle Moldboards
- Vehicle Airfoils

Other (please specify)

Vehicle Sensors

- Pavement Temperature
- Air Temperature

Other (please specify)

Most Useful Information in a Cost-Benefit Toolkit

In your opinion, which ten (10) of the following items would be most useful to you if included in a cost benefit toolkit such as that described in the introduction of this survey? (check only ten)

Maintenance Management System (MMS) to track spending in winter maintenance activities

- TAPER logs
- GPS/AVL

Other (please specify)

Plow Configurations

- Front
- Rear
- Underbody

Other (please specify)

Plow Blades

- Carbide
- Wear Plates
- Triple Blade
- Underbody Blade
- Tow Blade
- Double/Triple Edge
- 14+ Foot

Other (please specify)

Informational Technology

- GPS AVL RWIS MDSS Blackberry

Other (please specify)

Windshield Wipers

- Slap Me ClearFast Hot Shot Standard Equipment

Other (please specify)

Deicing and Anti-icing

- | | Solid | Liquid |
|-------------------|---|---------------------------------|
| Deicing | <input type="checkbox"/> Deicing and Anti-icing Solid | <input type="checkbox"/> Liquid |
| Anti-icing | <input type="checkbox"/> Anti-icing Solid | <input type="checkbox"/> Liquid |

Application Methods

- Zero Velocity Spinner Advanced Placement Gravity Feed Spray Stream

Other (please specify)

Add-On Vehicle Accessories and Training

- Back-Up Cameras
- Driving Simulator Training
- Specialized Lighting Packages
- Vehicle Deflectors
- Vehicle Moldboards
- Vehicle Airfoils

Other (please specify)

Vehicle Sensors

- Pavement Temperature
- Air Temperature

Other (please specify)

Previous Cost-Benefit Analysis

Have you or your agency performed any cost-benefit, cost effectiveness or general assessment studies for any of the following tools, processes and procedures (check all that apply)?

Maintenance Management System (MMS) to track spending in winter maintenance activities

- TAPER logs
- GPS/AVL

Other (please specify)

Plow Configurations

- Front
- Rear
- Underbody

Other (please specify)

Plow Blades

- Carbide
- Wear Plates
- Triple Blade
- Underbody Blade
- Tow Blade
- Double/Triple Edge
- 14+ Foot

Other (please specify)

Informational Technology

- GPS
- AVL
- RWIS
- MDSS
- Blackberry

Other (please specify)

Windshield Wipers

- Slap Me
- ClearFast
- Hot Shot
- Standard Equipment

Other (please specify)

Deicing and Anti-icing

- | | Solid | Liquid |
|-------------------|---|---------------------------------|
| Deicing | <input type="checkbox"/> Deicing and Anti-icing Solid | <input type="checkbox"/> Liquid |
| Anti-icing | <input type="checkbox"/> Anti-icing Solid | <input type="checkbox"/> Liquid |

Application Methods

- Zero Velocity
- Spinner
- Advanced Placement
- Gravity Feed
- Spray
- Stream

Other (please specify)

Add-On Vehicle Accessories and Training

- Back-Up Cameras
- Driving Simulator Training
- Specialized Lighting Packages
- Vehicle Deflectors
- Vehicle Moldboards
- Vehicle Airfoils

Other (please specify)

Vehicle Sensors

- Pavement Temperature
- Air Temperature

Other (please specify)

Input

What form would you like the proposed toolkit to take (check one)?

- Excel Spreadsheet
- Standalone Software Application
- Web-Based Tool

Other (please specify)

Is there any new or emerging technology, equipment or procedure that you would like to see considered for the proposed toolkit? If so, please describe:

6. THANK YOU!

8. APPENDIX B: TOOLKIT ASSUMPTIONS

The research team strove to identify all available information related to the quantified costs and benefits of the ten toolkit items. However, in several cases, such as underbody plows, quantified information, particularly pertaining to benefits, simply does not exist. In such cases, assumptions had to be employed in order to develop a quantified value to assign to a cost or benefit. The following paragraphs discuss the assumptions employed by the toolkit for reader familiarization.

In general, it is assumed that the base case for many toolkit items is the *do-nothing* scenario. In other words, the agency is not presently using a practice, equipment or procedure, but is considering doing so. However, in some cases, it is assumed that an agency is employing at least a base case. The base case for anti-icing is considered to be deicing and/or sanding/gritting. Similarly, deicing assumes that the base case for an agency is sanding/gritting. However, if an agency does not employ any of these strategies, parameter data inputs to the toolkit would be entered as zeros.

The toolkit assumes that the base case for carbide blade inserts is that an agency is presently using steel blade inserts. This assumption was made using the logic that if plowing is being performed, some basic type of blade insert, likely steel, is being used on plows.

The toolkit evaluation of wider front plows refers to equipment that is wider than the standard 10 to 12 foot plows typically used. For example, a wider plow evaluated by the toolkit would be 14 feet wide. Note that the evaluation of wider plows is not related to equipment such as wing plows. As no published benefits for wider front plows was available, additional assumptions were employed to quantify potential benefits. The first assumption was that a wider plow covers slightly more lane per pass. This results in an estimated reduction of between 20% and 25% passes (e.g. reducing 5 passes to 4 or 4 passes to 3). The second assumption was that the reduction in passes achieved through the use of wider plows would produce a material savings of up to 5%, as less passes result in less opportunity to spread treatment materials. Note that 5% is a conservative figure employed by the toolkit researchers. If an agency were to have quantified data related to the actual percent material use reduction that they might expect, they are encouraged to use that value in the toolkit.

The evaluation of zero velocity spreaders assumes that the base case for an agency is the use of other types of spreaders or brine sprayers. Of course, if an agency is not spreading any materials, the toolkit user would enter a zero value to represent the do nothing case.

Both the Maintenance Decision Support System and Road Weather Information System toolkit items assume that an agency is currently purchasing weather information from a vendor. If the agency is not purchasing weather information at present or has no cost associated with the weather information it is using, the toolkit user would enter a zero value to represent the *do-nothing* case.

The pavement temperature and pavement/air temperature sensors included in the toolkit are mobile devices as opposed to fixed sensors. It was assumed that fixed temperature sensors would be incorporated with RWIS stations, thus the toolkit evaluating mobile sensors only. Mobile sensors are mounted to a winter maintenance vehicle in order to provide temperature readings continuously along a route.

Automatic Vehicle Location employs assumptions developed previously by researchers in Kansas (26), as no work quantifying the actual benefits of AVL has occurred to date. For AVL, it was assumed that benefits included a 5 percent reduction in all winter storm-related crashes and a 5 percent reduction in operating costs per season. A reduction of 25 percent in administrative costs was also assumed, based on the work of Ye et.al. related to MDSS (46).

For MDSS, annual maintenance and administrative costs for the system had to be assumed, as these are not directly tracked by agencies. It was assumed that system maintenance was 10 percent of the capital cost of the system, while administrative costs were 25 percent of the direct costs of the system. Capital costs are those associated with the initial purchase of the system components (hardware, software, etc.). Direct costs include capital costs, as well as annual costs such as maintenance, communications and training.

Underbody plows had no quantified benefit information available, so two assumptions were required to value expected benefits. First, based on general guidance related to observed reductions in injury and property damage crashes when a new winter maintenance practice is employed, it is logical to assume conservative reductions in crashes through the use of underbody plows may be expected. For underbody plows, assumed values of crash reductions were 1 to 5 percent for injury crashes and 1 to 10 percent for property damage crashes. What this means is that use of an underbody plow could potentially reduce the total number of storm-related injury crashes in a jurisdiction between 1 and 5 percent. Second, based on feedback received from the New York Department of Transportation, underbody plows have been observed to reduce material usage by 31 to 43 percent. While these values have been observed through field operation, they remain the only evidence of reductions from the use of underbody plows; as a result, these figures are treated as assumed values by the toolkit developers.

In general, material savings are assumed to be attributed only to the proportion of the vehicle fleet equipped with the item under analysis. Material savings are calculated in terms of dollars. The approach taken to calculate material savings in equation form is:

$$\text{Material Savings} = \text{annual material cost} * (\text{equipped vehicles}/\text{total vehicles}) * \text{expected percent material use reduction}$$

The expected percent of material use savings is assumed to be uniform across the equipped vehicle fleet, although this may not be the case, as local road conditions and storm severity will vary. As a result, some material use reductions may occur, while in other cases, more materials would need to be used. This approach to calculating material savings is used for all applicable toolkit items.

A final assumption employed by the toolkit is related to the annual cost of deicing activities. This cost is calculated by the toolkit through the following equation:

$$\text{Deicing Cost} = (\text{annual material cost} + \text{annual storm-related labor cost}) * \text{percentage of vehicles equipped for deicing}$$

The annual cost of materials is related to the materials used at present, assumed to be sand/grit and perhaps anti-icers, if employed. It does not include the cost of deicers, as the use of this practice is being considered by the toolkit analysis. The labor portion of the equation requires a brief description. Labor costs are those associated with storm activities on an annual basis, including plowing, material (brine) production, and so forth. The product of this equation is ultimately multiplied by the expected savings accrued through the use of deicing for motorists.

9. APPENDIX C: GLOSSARY OF TERMS

This appendix presents a summary of terms used by the toolkit, along with their definitions.

[Additional] Annual hours per vehicle to maintain [item of interest] – This is an estimate of the hours expected to be spent per vehicle maintain the specific item being analyzed.

Additional hours to install (per vehicle) – The time required to install the item on a vehicle.

Agency costs – costs incurred by an agency through the use of an item.

Analysis period – The expected lifetime for the toolkit item to be analyzed.

Annual hours of training for each user – The expected number of hours that will be spent each year training Road Weather Information System users.

Annual material costs – This is the annual winter maintenance material expenditure for a unit. The user should use an expenditure that coincides with the scale of their analysis. For example, if an item is being examined for use at the shed level, then the annual material expenditure for that shed should be employed.

Annual number of storm events – This is the average number of storms experienced by a jurisdiction (state, garage, shed, etc.) that require winter maintenance activities.

Annual operating and maintenance costs – The annually recurring costs associated with the use of an item (ex. maintenance).

Annualized benefits – The value of benefits achieved in some future year stated as a present dollar value.

Annualized costs – The value of costs incurred in some future year stated as a present dollar value.

Average application rate – This is the average amount of treatment materials applied per unit (typically lane mile). This is expressed by the user in gallons or tons per mile, depending on the treatment currently being applied or analyzed.

Average cost per crash – This is the average value of crashes in a state. Typically, most crashes are PDO or involve minor injuries, hence this value is generally below \$50,000. For some toolkit items, this value is set to the default of \$33,700 employed in MDSS research. The user should consult their state's safety engineer if they are unsure of what value to employ. NOTE: this average value does not take into account outside factors, such as the cost of traffic delays related to an accident.

Average labor hours per storm to produce materials – This is the average time spent producing brine or other liquid treatment materials prior to a storm event.

Average labor hours per storm event [per vehicle] – This is the average time that an operator spends out in the field per storm performing winter maintenance activities.

Average plowing duration – the average number of hours a plow is in the field performing plowing functions per storm event.

Benefit-Cost ratio – A ratio showing the value of benefits achieved for every dollar of cost incurred on an item. It is employed to show the extent to which an investment will result in a benefit to the investor. Cost-benefit ratios greater than 1.0 are generally desired. May also be referred to as a cost-benefit ratio.

Cost Benefit Analysis – The process employed to calculate a benefit-cost ratio. May also be referred to as cost-benefit analysis/

Blade lifespan – This is the observed and/or expected time duration that a blade will last between changes, expressed in miles.

Chosen measure of lifespan – Some toolkit items, such as blade inserts, have lifespans that can be measured in multiple ways, including miles, fractions of a season, hours or snow events. Miles refers to the average number of miles a blade lasts between changes. Fractions of a season refers to the proportion of the season that a blade lasts, for example 1/4th. Hours are the average number of vehicle operating hours between blade changes, while snow events are the average number of storms between blade changes.

Current annual material costs – This is the annual winter maintenance material expenditure for a unit. The user should use an expenditure that coincides with the scale of their analysis. For example, if an item is being examined for use at the shed level, then the annual material expenditure for that shed should be employed.

Current weather information costs – This is the cost that an agency is presently paying for weather forecasts or similar information.

Discount rate - The discount rate is an interest rate at which funds that might be spent on the toolkit item to be analyzed could be alternatively invested (for example, in a certificate of deposit, etc.).

Estimated minutes doing paperwork per storm (power vehicle) – This is the total time that may be required following a storm to record information such as material used, fuel used and other reporting requirements for each plow vehicle.

Expected number of users – The number of users expected to work with Road Weather Information Systems in some fashion. This input is required to estimate user training needs per year.

Fatal crash – A crash that involves at least one fatality. An average value from the FHWA for such a crash is approximately \$3,391,000.

Hours to [perform activity] – This input refers to the average time (may be an estimate) to perform installation or maintenance for the item being analyzed.

Initial costs – The initial expenses related to the purchase of an item.

Injury crash – A crash that involves at least one injury to a vehicle occupant. Note, some states classify injury crashes as major (hospital treatment necessary) and minor (bumps and bruises). An average value from the FHWA for such a crash is approximately \$102,000.

Intangible benefits – A benefit that is achieved but that a value cannot or has not been assigned to (ex. reduced environmental harm).

Intangible costs – A cost that is incurred but that a value cannot or has not been assigned to (ex. degraded mobility).

Lane miles covered per jurisdiction – The lane miles that are maintained by the jurisdiction being employed in the analysis.

Lane miles covered per storm (all vehicles) – This is the total number of lane miles covered by all operations during a storm. Note that if a particular route is covered more than once, those miles need to be included. For example, if a route is two lanes, two miles long and covered twice during a storm event, the total lane mile entered by the user would be 2 lanes*2 miles*2 passes = 8 lane miles. This input is the sum of all vehicle activity.

Lane miles covered per storm (per truck) - This is the total number of lane miles covered one truck during a storm. Note that if a particular route is covered more than once, those miles need to be included. For example, if a route is two lanes, two miles long and covered twice during a storm event, the total lane mile entered by the user would be 2 lanes*2 miles*2 passes = 8 lane miles.

Loaded labor cost – The average hourly pay of labor, including benefits, etc.

Miles per truck per year – this is the average number of miles a vehicle travels performing winter maintenance activities during a season. As most agencies do not track the exact miles attributed to winter maintenance operations versus other activities during a season, a reasonable estimate should be employed.

Non-quantified – An item that does not have a financial value available.

Number of base station computers – This is the number of computer terminals that are expected to be used to view AVL data.

Number of computers per maintenance unit with [item] software installed – The number of computers per garage/shed/other to have software related to the item of interest installed. This is an estimate.

Number of equipped trucks – This is the number of vehicles which would be equipped with the item of interest or perform an operation of interest.

Number of facilities – This refers to the number of sties (ex. garages, sheds) that would be engaged in some aspect related to the item of interest. For example, the number of sheds to be equipped with brink making plants, or the number of garages that will have desktop computers set up to view AVL data.

Number of planned stations – The expected number of deployed Road Weather Information System stations that an agency is considering.

Operating cost per mile – this is the total cost (excluding labor) to operate a plow in winter maintenance activities. For example, the IRS recommends a conservative figure of \$0.50 per mile for the operation of a passenger vehicle.

Present value – the value at the present time of a cost incurred or benefit achieved at a future date.

Property Damage Only (PDO) crash – A crash that involves only damage to a vehicle, but no injury to occupants. An average value from the FHWA for such a crash is approximately \$2,600.

Quantified – An item that has a financial value available.

Society/Societal benefits – The benefits obtained by society through the use of an item (ex. reduced impact on the environment).

Society/Societal costs – The costs inflicted on society as the result of a specific item (ex. increased impact on the environment).

Storm-related labor costs per season – The total value of all labor related to winter maintenance activities throughout an entire season. Such information may not be tracked by an agency; in such a case, an estimate should be employed.

Tangible benefits – A benefit that is achieved and that has had a value assigned to it (ex. material savings).

Tangible costs – A cost that is incurred and whose value is known (ex. the purchase price for an item).

Total trucks – This is the size of the entire vehicle fleet that performs winter maintenance activities before, during and/or after a storm.

Total storm crashes (per season) – This is the total number of storm-related crashes that occurred within a jurisdiction during the most recent winter season. Storm-related crashes are those which occurred during a storm or immediately following a storm that were the direct result of it. The agency will need to define what constitutes the post-storm period. Only crashes occurring along routes maintained by the jurisdiction should be included in this analysis.

User benefits – The benefits achieved by users due to the use of an item (ex. improved mobility).

User costs – The costs incurred by users due to the use of an item (ex. degraded mobility).

10. REFERENCES

- 1 Federal Highway Administration, "How Do Weather Events Impact Roads," Accessed at http://ops.fhwa.dot.gov/Weather/q1_roadimpact.htm on May 11, 2009.
- 2 Transportation Association of Canada, "Salt Management Plans," July 2002; Accessed at <http://www.tac-atc.ca/english/pdf/saltmgmtplan.pdf> on December 15, 2006.
- 3 Veneziano, David, Laura Fay, Zhirui Ye, Dan Williams and Xianming Shi. *Development of a Toolkit for Cost-Benefit Analysis of Specific Winter Maintenance Practices, Equipment and Operations: Cost-Benefit Literature Review*. Western Transportation Institute. Prepared for Clear Roads Pooled Fund, June, 2009.
- 4 Boselly, S.E. *Benefit/Cost Study of RWIS and Anti-Icing Technologies*. Weather Solutions Group. Prepared for National Cooperative Highway Research Program. 20-7(117), March 2001.
- 5 Basu, R., J.S. Breshears, E.C. Clausen, J.L. Gaddy, L.D. Gaines, C.W Ko, R. Murphy, and C.V. Wikstrom. *Calcium Magnesium Acetate (CMA) at Lower Production Cost: Production of CMA Deicer from Biomass*. Publication No. FHWA-RD-98-055, Federal Highway Administration, Washington, D.C., January 1999.
- 6 Yang, S-T, Y-L Huang, Z. Jin, Y. Huang, H. Zhu, and W. Qin. *Calcium Magnesium Acetate at Lower Production Cost: Production of CMA Deicer From Cheese Whey*, Publication No. FHWA-RD-98-174, Federal Highway Administration, Washington, D.C., April 1999.
- 7 Fischel, M. *Evaluation of Selected Deicers Based on a Review of Literature*. Colorado Department of Transportation Research Branch, January 2001.
- 8 Luker, C., B. Rokosh, and T. Leggett. *Laboratory Melting Performance Comparison, Rock Salt with and without Pre-wetting*. Sixth International Symposium on Snow Removal and Ice Control Technology. Spokane, Washington, June 2004.
- 9 Algiers, R. and J. Haase. *Analysis of the Benefits of Bulk Pre-wetting Solid NaCl with Several Different Liquids*. Michigan Department of Transportation, July 2005.
- 10 Sooklall, R., L. Fu, and M. Perchanok. *Effectiveness of Pre-Wetting Strategy for Snow and Ice Control on Highways*. Annual Conference of the Transportation Association of Canada, Charlottetown, Prince Edward Island, 2006.
- 11 National Cooperative Highway Research Program (NCHRP). *Guidelines for the Selection of Snow and Ice Control Materials to Mitigate Environmental Impacts*, Report No. NCHRP 577, Transportation Research Board, Washington D.C., 2007.
- 12 O'Keefe, K. and X. Shi. *Synthesis of Information on Anti-icing and Pre-wetting for Winter Highway Maintenance Practices in North America*. Final Report. Prepared for the Pacific Northwest Snowfighters Association in Collaboration with the Washington State Department of Transportation, August 2005.
- 13 Nixon, W. *The Use of Abrasives in Winter Maintenance*. Iowa Highway Research Board Technical Report 416, March 2001.

-
- 14 Vitaliano, D. An Economic Assessment of the Social Costs of Highway Salting and the Efficiency of Substituting a New Deicing Material. *Journal of Policy Analysis and Management*, 2001, Vol. 11, No. 3, pp. 397- 418.
- 15 Shi, X., L. Fay, C. Gallaway, K. Volkening, M.M. Peterson, T. Pan, A. Creighton, C. Lawlor, S. Mumma, Y. Liu, and T.A. Nguyen. *Evaluation of Alternate Anti-icing and Deicing Compounds Using Sodium Chloride and Magnesium Chloride as Baseline Deicers Phase I*. Final Report for the Colorado Department of Transportation Denver, CO. Report No. CDOT-2009-01, February 2009. <http://www.dot.state.co.us/Publications/PDFFiles/antiicing.pdf>
- 16 Shi, X. *The Use of Road Salts for Highway Winter Maintenance: An Asset Management Perspective*. ITE District 6 Annual Meeting, Kalispell, Montana, July 10-13, 2005.
- 17 Environment Canada. *Winter Road Maintenance Activities and the Use of Road Salts in Canada: A Compendium of Costs and Benefits Indicators*, 2006 [Online]. Available <http://www.ec.gc.ca/nopp/roadsalt/reports/en/winter.cfm>, Accessed 26 May 2009.
- 18 Etheridge, M. and C. Shankwitz. *Quick Edge: Rapid Underbody Plow Cutting Edge Changing System*. University of Minnesota. Minnesota Department of Transportation. Report No MN/RC-2006-19, July 2006.
- 19 Lannert, R.G. *Plowing Wider and Faster on 21st-Century Highways by Using 14-ft Front Plows and Trailer Plows Effectively*. Seventh International Symposium on Snow Removal and Ice Control Technology. Indianapolis, Indiana, June 2008.
- 20 Macfarlane, D. *Plow Truck with Reversible Plow and Wing*. American Public Works Association. APWA Reporter, 2001, Vol. 68 No. 10.
- 21 Nixon, W.A. *Improved Cutting Edges for Ice Removal*. Iowa Institute of Hydraulic Research, University of Iowa. Report No SHRP-H-346, 1993.
- 22 Becker, J.. *Snow Plow Cutting Edge Cost Effectiveness*. South Dakota Department of Transportation. Report No SD89-04-X, March 1994.
- 23 Nixon, W.A., and Y-C. Wei. *Final Report of Snow Plow Cutting Edge Test and Evaluation (T&E) Program*. Iowa Institute of Hydraulic Research, University of Iowa. FHWA Work Order DTFH71-96-TE028-IA-43, February 1999.
- 24 Roosevelt, D.S., and B.H. Cottrell, Jr. *Evaluation of Urethane and Carbide-Tipped Blades on Wheel-Supported Snow Plows*. Virginia Department of Transportation. Report No FHWA/VA-97-R10, February 1997.
- 25 Gruhs, P. *The High-Speed-Environmental Snowplow*. Proceedings: Seventh International Symposium on Snow Removal and Ice Control Technology. Indianapolis, Indiana, June 2008.
- 26 Meyer, E., and I. Ahmed. *Benefit-Cost Assessment of Automatic Vehicle Location (AVL) in Highway Maintenance*. Proceedings: 2003 Mid-Continent Transportation Research Symposium, Ames, Iowa, August 2003.
- 27 Hille, R. and R. Starr. *Design and Implementation of Automated Vehicle Location and Maintenance Decision Support System for the Minnesota Department of Transportation*. 15th World Congress on ITS, New York City, November 2008.
-

-
- 28 Allen, J.. *Fighting Winter Storms: A GIS Approach to Snow Management*. Public Works, 2006.
- 29 Andrey, J., A. Brenning, B. Mills, D. Kirchhoff, A. Abulibdeh, and M. Perchanok. *Using Classification Trees to Build Flexible and Intuitive Winter Weather Indices*. Proceedings: 88th Annual Meeting of the Transportation Research Board, Washington D.C., 2009.
- 30 McClellan, T. Winter Maintenance Alphabet Soup. *Roads & Bridges*, October 2008, pp. 28-31.
- 31 Henry, M. *Intelligent Transportation Systems Concepts for Rural Corridor Management*. Arizona Department of Transportation, Report No. FHWA-AZ-07-615, September 2007.
- 32 Owen, S. *Arizona Intelligent Vehicle Research Program - Phase Two(b): 2001-2002*. Arizona Department of Transportation Report No. FHWA-AZ-03-473(3), September 2003.
- 33 McCullouch, B., J.H. Lee, W. Kang, M. Leung, and D. Belter. *Using a Statewide Wireless Data Network for Maintenance Activities*. Proceedings: 11th Annual AASHTO-TRB Maintenance Management Conference, Charleston, South Carolina, July 2006.
- 34 McCullouch, B., J. Lee, W. Kang, and M. Leung. *Utilizing Wireless Data Network for AVL and Mobile RWIS*. Proceedings: 2007 Mid-Continent Transportation Research Symposium, Ames, Iowa, August 2007.
- 35 Anderson, E. *Southeast Michigan Snow and Ice Management System Final Evaluation at End of Winter Season Year 2004*. Road Commission for Oakland County, August 2004.
- 36 Shi, X., C. Strong, R. Larson, D. Kack, E. Cuehlo, N. El Ferradi, A. Seshadri, K. O'Keefe, and L. Fay. *Vehicle-Based Technologies for Winter Maintenance: The State of the Practice*. National Cooperative Highway Research Program Report 20-7 (200), September 2006.
- 37 Roosevelt, R., R. Hansen, and W. Campenni. *Lessons Learned from a Pilot Study of an Automatic Vehicle Location System in an Urban Winter Maintenance Operations Setting*. Virginia Department of Transportation, April 2002.
- 38 Anthony, B.. *Winter Maintenance in Vaughan: Improving Operations and Communication Through an AVL System*. APWA Reporter, Vol. 71 No. 10, 2004.
- 39 SRF Consulting Group. *Laboratory and Field Studies of Pavement Temperature Sensors*, Final report: The Aurora Consortium, May 2005.
- 40 Tabler, D. R., *Comparison of RoadWatch® and Control Products, Inc., Model 999J Infrared Sensors*, 2003 [Online]. Available: <http://www.control-productsinc.com/PDFs/comparison.pdf>, Accessed 3 February 2009
- 41 Marosek, C.. *Evaluating the Accuracy of RWIS Sensors*. Western Transportation Institute, June 2005.
- 42 Sullivan, J.. *Road Weather Information System Phase I*. Alaska Department of Transportation & Public Facilities, Federal #ITS-9802(1), November 2004.
- 43 Lasky, T.A., K.S. Yen, M.T. Darter, H. Nguyen, and B. Ravani. *Development and Field-Operational Testing of a Mobile Real-Time Information System for Snow Fighter Supervisors*.
-

California Department of Transportation, AHMCT Research Report UCD-ARR-06-12-31-07, December 2006.

44 Ballard, L., A. Beddoe, J. Ball, E. Eidswick, and K. Rutz. *Assess Caltrans Road Weather Information Systems (RWIS) Devices and Related Sensors*. Western Transportation Institute, July 2002.

45 Strong, C. and X. Shi. Benefit-Cost Analysis of Weather Information for Winter Maintenance. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2055, 2008, pp.119-127.

46 Ye, Z., X. Shi, C. Strong, and T. Greenfield. Evaluation of the Effects of Weather Information on Winter Maintenance Costs. *Transportation Research Record*, No. 2107, 2009, pp. 104-110.

47 Boon, C., and C. Cluett. *Road Weather Information Systems: Enabling Proactive Winter Maintenance Practices in Washington State*. Washington State Transportation Center. Research Project T1803, Task 39. March 2002.

48 McKeever, B., C. Haas, J. Weissmann, and R. Greer. *A Life Cycle Cost-Benefit Model for Road Weather Information Systems*. Proceedings: 77th Annual Meeting of the Transportation Research Board, Washington D.C., 1998.

49 Ye, Z. and C. Strong. *Cost-Benefit for Weather Information in Winter Maintenance: Technical Memorandum 4: Secondary RWIS Benefits*. Western Transportation Institute, February 2009.

50 Ye, Z., C. Strong, X. Shi, and C. Steve. *Analysis of Maintenance Decision Support System (MDSS) Benefits & Costs*. Report No. SD2006-10-F, South Dakota Department of Transportation, 2009.

51 Smithson, L. *MDSS-the U.S. Success Story*. Presented at the 2007 Annual Conference of the Transportation Association of Canada, Saskatoon, Saskatchewan, 2007.

52 National Center for Atmospheric Research (NCAR). *The Maintenance Decision Support System (MDSS) Project, Technical Performance Assessment Report, Colorado Field Demonstration-Winter 2007-2008, Version 1.0*. Prepared for the City and County of Denver, October 2008.

53 National Cooperative Highway Research Program (NCHRP). *Guidelines for the Selection of Snow and Ice Control Materials to Mitigate Environmental Impacts*, Report No. NCHRP 577, Transportation Research Board, Washington D.C., 2007.

54 Mewes, J, R Hart, L. Osborne, and B. Podoll, The Pooled Fund Study Maintenance Decision Support System: A Functional Overview. *American Meteorological Society Preprint, the 21st International Conference on Interactive Information Processing Systems (IIPS)*, San Diego, CA, Paper 6.6., 2005.

55 Hart, R.D., J.J. Mewes, B.W. Hershey, L.F. Osborne Jr., and D.L. Huft. *An Overview of Implementation and Deployment of the Pooled Fund Study Maintenance Decision Support System*. Proceedings: Seventh International Symposium on Snow Removal and Ice Control Technology. Indianapolis, Indiana, June 2008.

-
- 56 Ye, Z., C. Strong, X. Shi, and C. Steve. *Analysis of Maintenance Decision Support System (MDSS) Benefits & Costs*. Report No. SD2006-10-F, South Dakota Department of Transportation, 2009.
- 57 Ye, Z., X. Shi, C. Strong, S. Conger, and D. Huft. Benefit-Cost Analysis of Maintenance Decision Support System. *Transportation Research Record*, 2009, Vol. 2107, 95-103.
- 58 Cluett, C., and J. Jenq. *A Case Study of the Maintenance Decision Support System (MDSS) in Maine*. Report No. FHWA-JPO-08-001, ITS Joint Program Office, U.S. Department of Transportation, Washington, D.C., September 2007.
- 59 Sugumaran, R., M.D. Salim, T. Strauss, and C. Fulcher. *Web-based Implementation of a Winter Maintenance Decision Support System Using GIS and Remote Sensing*. Midwest Transportation Consortium; Research and Special Programs Administration, May 2005.
- 60 Sharrock, M. Zero Velocity and Salt Brine: One State Garage's Experience. *APWA Reporter*, 2002, Vol. 69 No. 10.
- 61 Nantung, T. *Evaluation of Zero Velocity Deicer Spreader and Salt Spreader Protocol*. Purdue University/Indiana Department of Transportation Joint Transportation Research Program, 2001.
- 62 Colson, S. *An Evaluation of Winter Maintenance Material and Metering and Placement Equipment*. Maine Department of Transportation, 1997.
- 63 Iowa Department of Transportation. *Anti-icing Equipment: Recommendations and Modifications*. Iowa Department of Transportation, 2000.
- 64 Office of Management and Budget. "Discount Rates for Cost Effectiveness, Lease-Purchase, and Related Analyses". Office of Management and Budget, Washington, D.C., December 2009. Available at: http://www.whitehouse.gov/omb/circulars_a094_a94_appx-c/ Accessed 1 August 2010.



research for winter highway maintenance

Lead state:

Wisconsin Department of Transportation

4802 Sheboygan Ave.

P.O. Box 7965

Madison, WI 53707-7965