# Development of a Toolkit for Cost-Benefit Analysis of Specific Winter Maintenance Practices, Equipment and Operations Phase 2:

# Final Report

by

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August 7, 2013

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# ACKNOWLEDGEMENTS

The researchers wish to thank the Clear Roads pooled fund research project and its sponsor states of California, Colorado, Idaho, Illinois, Iowa, Kansas, Maine, Massachusetts, Michigan, Minnesota, Missouri, Montana, Nebraska, New Hampshire, New York, North Dakota, Ohio, Pennsylvania, Rhode Island, Utah, Vermont, Virginia, Washington, West Virginia, Wisconsin and Wyoming for the funding of this project. They also thank the numerous Clear Roads representatives for their feedback and input throughout the course of this project. The researchers also thank Cameron Holbert for his assistance with the development of the website.

## Technical Report Documentation Page

<table>
<tr><td>1. Report No.</td><td>2. Government Accession No</td><td colspan="2">3. Recipient's Catalog No</td></tr>
<tr><td colspan="2" rowspan="2">4. Title and Subtitle<br>Development of a Toolkit for Cost-Benefit Analysis of Specific Winter Maintenance Practices, Equipment and Operations<br>Phase 2 Final Report</td><td colspan="2">4. Report Date<br>June, 2013</td></tr>
<tr><td colspan="2">5. Performing Organization Code</td></tr>
<tr><td colspan="2">7. Authors<br>David Veneziano, Laura Fay, Xianming Shi* and Lisa Ballard</td><td colspan="2">8. Performing Organization Report #</td></tr>
<tr><td colspan="2" rowspan="2">9. Performing Organization Name & Address<br>Western Transportation Institute<br>Montana State University<br>PO Box 174250, Bozeman, MT 59717</td><td colspan="2">10. Purchase Order No.</td></tr>
<tr><td colspan="2">11. Contract No.</td></tr>
<tr><td colspan="2" rowspan="2">12. Sponsoring Agency Name & Address<br>Clear Roads Pooled Fund<br>Minnesota Department of Transportation<br>Consultant Services Section, Mail Stop 680<br>395 John Ireland Boulevard<br>St. Paul, Minnesota 55155-1800</td><td colspan="2">13. Type of Report & Period Covered<br>Final Report,</td></tr>
<tr><td colspan="2">14. Sponsoring Agency Code</td></tr>
<tr><td colspan="4">15. Supplementary Notes<br>* Principal Investigator (Email: xianming_s@coe.montana.edu)</td></tr>
<tr><td colspan="4">16. Abstract<br>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 enhanced and expanded a toolkit that was previously developed to facilitate benefit-cost analysis for winter maintenance. The toolkit items included comparing flexible blades to traditional blades, pre-wetting at the spreader, spreader calibration, slurries, tow plows, contracted truck (private or municipal) versus a state-owned truck, open versus closed loop spreader controls, remote cameras for monitoring remote sites locations, laser guides, and tailgate versus hopper spreaders. The toolkit is a website which receives parameter inputs from a user and generates a benefit-cost ratio for the item of interest.</td></tr>
<tr><td colspan="2">17. Key Words<br>Benefit-Cost Analysis<br>Winter Maintenance<br>Winter Maintenance Practices<br>Winter Maintenance Equipment<br>Winter Maintenance Operations<br>Benefit Cost Toolkit</td><td colspan="2">Distribution Statement<br>No restriction. This document is available to the public through the Clear Roads Organization and the<br>Minnesota Department of Transportation<br>395 John Ireland Boulevard<br>St. Paul, Minnesota 55155-1800</td></tr>
<tr><td>19. Security Classification (this report)<br>Unclassified</td><td>20. Security Classification (this page)<br>Unclassified</td><td>20. No. of pages<br>70</td><td>21. Price</td></tr>
</table>

**Form DOT F 1700.7** (8-72) Report of completed page is authorized

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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 the development of a toolkit which would facilitate cost-benefit analysis for a series of winter maintenance practices, equipment and operations. The purpose of this toolkit was 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 would also be used to examine the costs and benefits of existing practices, equipment and operations. To this end, an initial project conducted between 2008 and 2010 developed an initial version of the proposed toolkit that conducted benefit-cost analysis on ten different items. The work discussed in this report is a follow-up to that initial project that entailed improvements to the original toolkit and the addition of ten new items for analysis.

The toolkit that has been enhanced and expanded 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 expansion and enhancement of the web-based toolkit. Initial efforts focused on a survey to obtain winter maintenance practitioner’s preferences on the new toolkit items to be added and a literature review pertaining to the top ten items identified. 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.

Based on feedback from practitioners and the TAC, an initial series of ten items were selected for inclusion in the toolkit. Toolkit items include:

- Comparing flexible blades to traditional blades
- Pre-wetting at the spreader
- Spreader calibration
- Slurries
- Tow plows
- Contracted truck (private or municipal) versus a state-owned truck
- Open vs. closed loop spreader controls
- Remote cameras for monitoring remote sites locations
- Laser guides

- Tailgate vs. hopper spreaders

Once available information related to costs, benefits and effectiveness, as well as the preference for a web-based platform was collected, their addition to the toolkit website was made. 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.

Concurrent with the addition of new toolkit items, enhancements and improvements were also made to the existing website. These were the result of feedback received from users following the initial development of the toolkit during the first project phase. The key improvement made to the toolkit is the capability to create a Word or HTML version of the project report that is final step of the toolkit. This option allows the user to create a version of the project report that can have text and tables cut and paste as needed by the user. At this time, the toolkit does not have the direct capability to save files in a .pdf format. The Content Management System was also updated to use the latest libraries. A final enhancement made to the toolkit was providing the ability for users to save their worksheets and revisit their scenarios in the future. To accomplish this, a new login system was implemented that allows users to save worksheets. It utilizes built-in user management and data management capabilities in Joomla! and Fabrik.

Following expansion and enhancement 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, both by the project team and by the TAC. Concurrent with testing, the user manual was updated and expanded. 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 May 8, 2013 in person at the spring 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 workload.

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.

To date, work quantifying the costs and benefits of various aspects of winter maintenance has been completed to various degrees. The result is that it is now feasible to develop a toolkit that brings such information together in one place and provide maintenance managers with a platform on which to not only quantify the expected cost-benefit ratio of selected practices, equipment, and operations. To this end, the research discussed in this document developed such a toolkit.

## 1.1. Background

The continued development of the toolkit in this project, specifically the addition of ten new items for analysis, is the result of input from the Clear Roads Technical Advisory Committee (TAC) and winter maintenance practitioners. This input was solicited primarily through an online user survey, as well as through direct communication with the TAC. During the initial phase of the work, a website was created to facilitate cost benefit evaluations for an initial set of ten items, including:

- 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

Based on feedback from practitioners and the TAC during the current phase of the work, an additional ten items were selected for inclusion in the toolkit. Toolkit items include:

- Comparing flexible blades to traditional blades
- Pre-wetting at the spreader
- Spreader calibration
- Slurries
- Tow plows
- Contracted truck (private or municipal) versus a state-owned truck
- Open versus closed loop spreader controls
- Remote cameras for monitoring remote sites locations
- Laser Guides
- Tailgate versus hopper spreaders

Based on their selection, information was gathered from research results, agency reports and vendors in order to quantify[1] the various cost and benefits associated with each item.

The website itself was developed and tested to function across multiple browsers (i.e. Internet Explorer, Firefox, Chrome, etc.). Data elements are input via a series of text boxes. In some cases, conservative default values are already entered; the user is free to change these to whatever value is warranted in their particular case. Information buttons and calculators are present throughout the toolkit to assist the user in determining when particular elements might be included, as well as what the financial implications might be.

The initial step in the toolkit seeks project parameter information, or the basic information required to complete the analysis (ex. analyst name, number of vehicles in fleet, etc.). Next, cost information associated with the toolkit item of interest is entered, with the user selecting specific costs that will be incurred (in some cases, different elements of a practice, equipment, and operation are not required, so their costs can be excluded). This is followed by the selection and entry of specific anticipated benefits, functioning in a similar manner to the cost component of the toolkit. Depending on the specific toolkit item, different user and agency benefits are assigned and quantified by the user. The toolkit concludes with a presentation of cost and benefit results, including the benefit-cost ratio. For users that wish to have more information for reference or presentation, a brief white paper is also provided summarizing the different aspects discussed in literature 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 next ten items that should be added to the existing toolkit. Chapter 3 presents a summary of cost, benefit and effectiveness literature pertaining to the ten selected toolkit items. Chapter 4 provides an overview of the updated and revised 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.

[1] Quantify as used in this document refers to the assignment of a financial value to a cost or benefit associated with a toolkit item.

# 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 prospective toolkit items that practitioners would like to have added to the website. The survey also sought information pertaining to any information, particularly previous cost-benefit assessments related to tools, equipment and procedures that were presented for consideration in the survey. The survey itself consisted of five multi-part questions and was distributed to Clear Roads members via the organization's email list. A link to the survey was also posted on the Snow and Ice Listerserv. The survey questions posed to respondents are presented in Appendix A. A total of 54 responses were received and processed to provide the information in this document. Responses were received from all Clear Roads members except California, Utah and Vermont. Figure 2-1 displays the geographic distribution of respondents, while Table 2-1 presents the respondent states, provinces and countries by name. Note that Figure 2-1 does not include the Canadian provinces of Alberta and Ontario, which also responded to the survey.

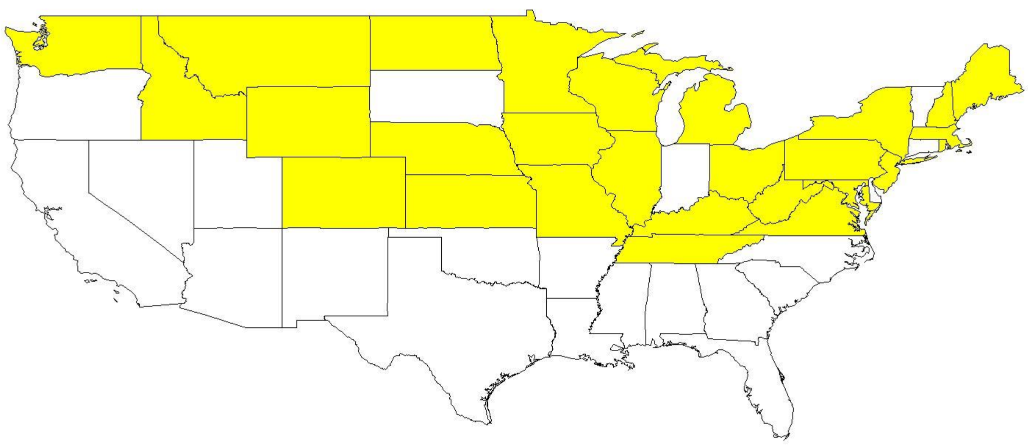

Figure 2-1: Respondent states (highlighted)

Table 2-1: Survey respondent locations

| | | |
|---|---|---|
| Alberta | Colorado | Idaho |
| Illinois | Iowa | Kansas |
| Kentucky | Maine | Massachusetts |
| Maryland | Michigan | Minnesota |
| Missouri | Montana | Nebraska |
| New Hampshire | New Jersey | New York |
| North Dakota | Ohio | Ontario |
| Pennsylvania | Rhode Island | Virginia |
| Washington State | West Virginia | Wisconsin |
| Wyoming | | |

## 2.2. Survey Items of Interest

Survey respondents were asked to select ten toolkit items of interest from a list developed by the TAC that included:

- Comparing flexible blades to traditional blades
- Plow guards
- Pre-wetting at the spreader
- Slurries
- Spreader calibration
- Tow plows
- Open vs. closed loop spreader controls
- Laser guides
- Abrasives (sand/aggregates in different types or weights/sizes)
- Remote cameras for monitoring remote sites locations
- Contracted truck (private or municipal) versus a state-owned truck
- Tailgate vs. hopper spreaders
- Other (please specify)

The “Other” category provided an opportunity for respondents to provide additional items that were of interest to them but not included in the existing survey list. Results of the selections made by respondents to the survey are presented in the next section.

## 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 2-2.

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

| | Ranking | % of respondents | n |
|---|---|---|---|
| Comparing flexible blades to traditional blades | 1 | 87 | 47 |
| Prewetting at the spreader | 2 | 85 | 46 |
| Spreader calibration | 3 | 81 | 44 |
| Slurries | 4 | 76 | 41 |
| Tow Plows | 5 | 63 | 34 |
| Contracted truck (private or municipal) versus a state-owned truck | 6 | 59 | 32 |
| Open versus closed loop spreaders | 7 | 57 | 31 |
| Remote cameras for monitoring remote sites/locations | 8 | 57 | 31 |
| Laser guides | 9 | 46 | 25 |
| Tailgate versus hopper spreaders | 10 | 44 | 24 |

In addition to these items, plow guards (22 votes) and abrasives (sand aggregates) (20 votes) fell outside of this list. A total of twenty responses to the “Other” category were also received, with suggestions including:

- Salt enhancements both liquid and applied to salt; mobile rwis service
- Effect that roadway cross-section (ie: rutting) has on winter costs(ie: salt)
- Assoloni type plows
- **RWIS sites**
- Salt in different types or weights/sizes
- Pavement co-efficient friction and chemical concentration reading/**AVL-GPS systems**
- Wireless weather sensors
- higher plowing and spreading speeds, centerline spreading, various types of winter liquid
- The benefits of reducing the amount of sand applied during the winter to other operations such as roadway sweeping, drainage system maintenance, environmental impacts, etc.
- Coefficient of friction testing
- Live and temporary snow fences
- FIXED AUTOMATED SPRAY SYSTEM & THIN-BONDED OVERLAY (e.g. Safelane)
- site specific weather forecasting and direct access to forecaster
- **AVL Cost / Benefits**
- Blade Savers (power float option for the snow plow)
- Agricultural based chemicals vs. non-agricultural based chemicals
- **MDSS**, FAST, Tankers for liquid applications
- **Slurry Generating Hoppers**, **AVL equipment**, Mobile Weather Station, Hoppers with crushers, Salt specifications more consistent sized material

- Plow lights; **prewetting on tailgate spinner vs prewetting in tailgate spreader** & application rate
- Fixed Automated Spray Technology and **Maintenance Decision Support Systems**

Note that items in **bold** are those which were already incorporated into the first phase of the toolkit or that were available in the existing survey list (and were sleected for addition during phase two). Of the remaining items, only Fixed Automated Spray Technology (FAST) appeared with recurrence. This would suggest that this toolkit item is on that would likely be added in any future phase of the toolkit's development.

## 2.4. Previous Assessments

Survey respondents were asked if they or their agency had performed any cost-benefit, cost effectiveness, or were aware of any general assessment studies for any of the prospective toolkit items provided in the survey. Many of the listed items were listed as being assessed by agencies or that the respondent was aware of some form of assessment to some degree. Flexible blades, Tow Plows, prewetting and spreader calibration were the items that a number of respondents indicated as having some form of assessment completed. Note however, that a respondent indicating that they were aware of an assessment does not indicate an individual assessment was completed. For example, the 13 responses indicating the awareness of information related to Tow Plows does not indicate that 13 separate evaluations or articles on that item have been completed. Rather, one study may have been completed and 13 respondents were aware of it. Table 2-3 shows the number of respondents aware of information pertaining to each toolkit item that was ranked in the top ten previously.

Table 2-3: Top ten items that have been previously assessed with a cost-benefit analysis

| **Ranking** | **Assessment Category** | **Number of Previous Assessments** |
|---|---|---|
| 1 | Comparing flexible blades to traditional blades | 19 |
| 2 | Tow Plows | 13 |
| 3 | Prewetting at the spreader | 11 |
| 4 | Spreader calibration | 11 |
| 5 | Slurries | 9 |
| 6 | Laser guides | 6 |
| 7 | Contracted truck (private or municipal) versus a state-owned truck | 6 |
| 8 | Remote cameras for monitoring remote sites/locations | 4 |
| 9 | Open versus closed loop spreaders | 2 |
| 10 | Tailgate versus hopper spreaders | 1 |

The final survey questions asked respondents whether they had access to any reports or other information relevant to the work that they could share and if they had any other thoughts and comments relevant to the work. Most who responded to these questions provided website links to existing reports or contact information for the researchers to follow up with in obtaining information. The information provided in response to these questions was used by the researchers during the development of benefit-cost analysis approaches for the respective toolkit items.

## 2.5. Conclusion

A survey of Clear Roads members and practitioners in the winter maintenance community was conducted in order to determine new items were of interest for addition to the existing toolkit website. The survey results provided a list of the top ten items to include in the updated toolkit. The majority of these items were selected by a large portion of survey respondents, indicating a strong interest. As such, the research team expanded the existing toolkit to incorporate these items.

# 3. LITERATURE REVIEW

## 3.1. Introduction

One of the most useful points of reference available to winter 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. 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 were:

- Comparing flexible blades to traditional blades
- Pre-wetting at the spreader
- Spreader calibration
- Slurries
- Tow plows
- Contracted truck (private or municipal) versus a state-owned truck
- Open versus closed loop spreader controls
- Remote cameras for monitoring remote sites locations
- Laser Guides
- Tailgate versus hopper spreaders

The literature review focused on various publications (research reports, journal articles, etc.) and documents of longstanding relevance to determine the tangible and intangible costs, benefits and effectiveness of the toolkit items of interest.

## 3.2. Comparing Flexible Blades to Traditional Blades

There are many cutting edge blades available for use in plowing. These include blades made of different materials to facilitate different performance features, such as extended wear or added flexibility. With respect to flexibility, flexible cutting edges use a segmented blade system which mounts a series of individual blades to the plow board. The use of these flexible blades allows the cutting edge to conform to the surface of the road, allowing for better snow and ice removal. The following sections discuss the findings of work completed examining flexible blades compared to traditional ones.

Figure 3-1: Flexible blade system (photo: Clear Roads)

**Existing Cost-Benefit Evaluation/Research**

The Ohio Department of Transportation summarized their experiences with Joma flexible blades, which incorporate tungsten carbide inserts encased in rubber (3). The benefits associated with these blades included:

- No metal to metal or metal to roadway contact, reducing impact and producing longer wear life.
- Reduced noise and vibration resulting in less operator and equipment fatigue.
- Better blade conformity to the roadway surface.
- Reduced maintenance and labor needs.

Blades in use in Ohio were reported to last 4 to 5 times longer than their traditional counterpart. Additionally, there was an 85 percent decrease in labor hours required to maintain/replace Joma blades. This equaled maintenance staff spending seven times longer per year repairing and replacing traditional blades. Additional information cited in the report from Pennsylvania indicated that Joma blades lasted over 3,000 miles compared to traditional blades that wore out after 650 miles.

Mastel evaluated different plow blade systems in North Dakota, including traditional single carbide blade sections, stacked carbide blade sections, a Joma flexible blade and a Polar Flex flexible blade (4). Evaluation criteria included service life, effectiveness and efficiency, and equipment maintenance needs (labor and time). The different types of blades were installed on 15 trucks for testing during the winter of 2010-2011. For single carbide steel blade plows, a total of 21 blade sections (4 foot length) were initially installed on 7 trucks, with 64 blades replaced throughout the winter. For stacked carbide steel blade plows, a total of six blade sections were initially installed on 1 truck, with 9 blades replaced throughout the winter. Joma flexible blades had a total of 12 blade sections initially installed on 4 trucks, with 3 blades replaced throughout the winter. Finally, 9 Polar Flex blades were initially installed on 3 trucks, with 3 blades replaced throughout the winter. As these figures indicate, the flexible blade systems had a much longer service life, lasting 3 to 4 times longer than traditional blades. This resulted in cost savings over the course of the winter from reductions in time and materials required for blade replacement. For reference, the cost per foot of each blade option is as follows:

- Single carbide blades - $44.60 per foot
- Stacked carbide blades - $89.20 per foot
- Joma flexible blades - $143.75 per foot
- Polar Flex flexible blades - $99.36 per foot

Based on the costs of each blade per foot, single carbide blades had a cost of $2166 per truck, stacked carbide blades had a cost of $2676, Joma flexible blades had a cost of $2156 and Polar Flex blades had a cost of $1589. Both types of flexible blades offered a lower cost over the entire season on a per truck basis, and these figures do not include the labor savings achieved by reduced replacement of traditional blades (requiring two persons 30 minutes to complete).

Nixon discussed factors to consider in selecting snow plow blades, including those for a life cycle cost analysis (5). These included

- Overall life of blade
- Replacement cost of blade
- Time and labor cost for replacement
- Need for blade adjustment between replacement
- Reduced vehicle fuel efficiency (friction)
- Wear and tear on the vehicle from vibration

It was also noted that considerations such as type of pavement and pavement markings (raised) play a role in selecting blades. If the pavement surface or pavement markings can be damaged by a blade, alternatives should be considered, such as rubber blades.

The Iowa Department of Transportation reported that its evaluation of Joma flexible blades showed they lasted six times longer than traditional blades and required only one person to install/replace (6).

Work completed for the Clear Roads Pooled Fund developed a prototype plow that used multiple blades to attack varying road conditions (7). These prototypes incorporated flexible blades, scarifiers and squeegees. Field testing in different states produced differing experiences. Iowa indicated that their experience with flexible blades showed they conformed better to the roadway surface and lasted longer; however, other states reported some concerns with blade wear and loose fasteners. Results from Iowa’s testing indicated that on a typical road, a flexible blade removed up to 99 percent of the test material (sand, as tests were performed in summer), while a traditional blade only removed 76 percent of material. No figures on blade life were reported by this work.

## 3.3. Contracted Plows versus State Owned Trucks

Contracted plowing entails snow and ice control being conducted for an agency (DOT, county, municipal, etc.) by a private contractor(s). This maintenance may be conducted solely by the contractor, or in conjunction with the highway agency. An agency establishes the roles, instructions and procedures for winter maintenance operations with the contractor performing operations along designated highways. While the contracted approach to winter maintenance is a more recent practice, it has been shown to provide a number of benefits, although careful attention to administration and execution of such programs is needed to ensure success.

### 3.3.1. Existing Cost-Benefit Evaluation/Research

The state of Massachusetts, specifically the Massachusetts Department of Transportation (MassDOT) offers a comprehensive example of the overall process of contracted plowing. At present, MassDOT's contracts run for two year periods, with an interested party filing an application to be part of the pool of approved contractors (8). The applicant must meet the state's requirements before being approved, with the equipment a contractor proposes to operate meeting certain requirements (age, dimensions, etc.). An applicant can consist of a single vehicle operator to a contractor with a multi-vehicle fleet. The specific requirements for equipment (types, attachments, material applicators, etc.) vary depending on the needs and goals of the specific area. Material spreaders and liquid applicators are required to be calibrated by a MassDOT-approved calibrator before a specific date each year in order to ensure a consistent application of materials.

Under the MassDOT approach, when a winter storm event occurs, MassDOT uses their equipment first, and then moves to calling contractors from an equipment list (8). Districts only call out the equipment they need using this approach. Contractors are required to report to a designated location (ex. maintenance depot) to check in, with each piece of equipment also required to report to the same location at the end of a shift in order to confirm their departure time. The equipment sequence used during a storm begins with spreaders and then moves on to plows. In Massachusetts, contractor compensation for performance delivered is based on the equipment used and the activities performed. [Note that later discussions in this section present alternative contracting and payment approaches.] This is based on hourly rental rates and equipment codes laid out in the established contract. Equipment categories will vary depending on an agency's needs. For MassDOT, equipment categories include:

- Vehicles (large and smaller trucks)
- Loaders
- Spreaders/chemical trucks
- Plows (type and width)
- Accessories
- Specialty equipment

Additionally, contractors are encouraged to consider more recently developed equipment and technologies, such as closed loop spreader control systems, that offer the opportunity to improve efficiency or save materials.

MassDOT's program pays contractors for a base of four hours for each event they are called to work in order to account for short duration activities that may sometimes occur. An equipment/contractor rotation process is used to ensure that the multiple contractors employed receive a fair and equitable balance of hours to work. Prior to and throughout the winter season, each contractor must ensure that all equipment is operable or repaired in a timely manner while meeting various licensing, registration and insurance requirements. Contractors are responsible for ensuring that their personnel are properly licensed and trained.

Originally, MassDOT's approach employed shorter contract language, but as time has gone by the contract has evolved and grown more complex. The reason for this complexity stems from the need to cover different aspects of winter maintenance that were not originally considered, as well as to address aspects of the system that were being taken advantage of. While contracting can cost money, it also has the benefit of making everyone responsible and accountable for what they are doing. Advanced tools such as GPS/AVL and closed loop spreader controls are being used more to monitor contractor performance and ensure things are being done the way they are supposed to be (8).

As a result of contracted plowing, MassDOT has reduced the cost of their snow and ice control by approximately 33 percent per hour (8). There has also been a reduction in the pieces of equipment that the state owns (8). Consequently, there are also financial savings accrued from reductions in equipment purchases and maintenance. Perhaps the biggest benefit achieved is having the right equipment available and having it in the right places when needed.

There are initial/start up costs associated with contracted maintenance, including contract review, modification and so forth. There is also training for supervisory personnel each year, since they have to be made aware of any changes, difficulties from past practices, roles and responsibilities for the current year of winter maintenance. All equipment contracted must be inspected for proper operation, which requires time and related expense. This includes verification of equipment attachments, safety reviews and calibration verification. There are also costs for tracking equipment, methods of payments, software to manage snow and ice operations for consistency, and overseeing procurement and tracking of material use. These are significant costs, but they are indirect and not easily identified or quantified. Consequently, until an approach to establishing the financial values of these items is available, they cannot be accounted for in cost-benefit analysis.

To date, there has also been a limited discussion of different approaches to contracted winter maintenance/plowing in reports and literature. These discussions outline different contracting approaches, as well as the advantages and disadvantages that each approach entails. The following sections provide an overview of this work.

Burlarley-Hyland evaluated three methods for delivery of winter maintenance contracting used by the Virginia DOT. These included a full asset maintenance contract (lump sum monthly fee), a line item contract (payment by the hour per piece of equipment operated), and a hybrid contract (fixed payment fee up to a certain snow depth and reimbursement per inch beyond that point) (9). Advantages and disadvantages of the lump sum monthly fee contract for the DOT/agency and contractor included:

- Advantages
    - Budget costs are fixed so contractor absorbs any additional costs in years of extreme winter events (Agency)

  - Oversight of operations is reduced so that the agency does not need to track hours of operations for equipment for payment (Agency)
  - Poor performance can be penalized, ensuring that services not provided are not paid (Agency)
  - The contractor assumes the majority of the risk (Agency)
  - Agency no longer has a large capital investment in equipment (Agency)
  - Ability to manage operations (Contractor)
  - Ability to utilize new technologies or methods (Contractor)
- Disadvantages
  - Staff is no longer in direct control of operations (Agency)
  - Agency may be competing with the contractor for staff or materials for which they would normally be the sole source of procurement (Agency)
  - Once staff and equipment are lost to subcontracting it is frequently difficult, if not impossible, to increase to prior staff and equipment levels if the contract is not renewed (Agency)
  - There is no reduction in cost for mild winters (Agency)
  - Need to train and keep staff available for events that are infrequent (Contractor)
  - Assumption of risk (Contractor)
  - The possibility of high penalties for poor performance (Contractor)
  - No additional payment for severe winters (Contractor)
  - Higher cost for procurement of materials purchased from an agency (Contractor) (9)

Advantages and disadvantages of the line item contract for the DOT/agency and contractor included:

- Advantages
  - Agency in complete control of how winter events are managed (Agency)
  - Agency can adjust operations to accommodate changes in conditions (Agency)
  - Very little risk (Contractor)
  - Capital expenses can be covered by mobilization fees (Contractor)
  - Use of agency infrastructure, including equipment yards and salt storage (Contractor)
- Disadvantages
  - Agency runs the risk of significantly overrunning winter budget during severe winters (Agency)
  - All risk is assumed by the agency (Agency)
  - Agency can be subjected to pressure from constituents to perform at a higher level than snow plan dictates (Agency)
  - Agency routinely has to guarantee minimum payments once contractor is notified to respond, as well as pay an annual mobilization for each piece of equipment (Agency)

  - Tracking hourly equipment usage takes significant resources and staff to manage to verify invoices for payment (Agency)
  - Need to train and keep staff available for events that are infrequent (Contractor)
  - Need to keep large complements of equipment in good working order for a worst case scenario winter event (Contractor)
  - Few opportunities to make a profit during mild winters (Contractor) (9)

Advantages and disadvantages of the hybrid contract for the DOT/agency and contractor included:

- Advantages
  - Budget costs are fixed for the majority of winter events (Agency)
  - Oversight of operations is reduced for the majority of events (Agency)
  - Poor performance can be penalized, ensuring that services not provided are not paid for (Agency)
  - The contractor assumes the majority of the risk for the majority of winter events (Agency)
  - Decreased risk (Contractor)
  - Less opportunity for penalties (Contractor)
- Disadvantages
  - Staff is no longer in direct control of most winter operations (Agency)
  - May be difficult to redirect staff or subcontractors when there is a major event (Agency)
  - Subcontractors who do not routinely work on routes may not be familiar with the winter operations plan or have knowledge of the area and specific issues such as cold spots or bridge joints(Agency)
  - Coordination and communication may be more difficult, especially if there are several contractors who may utilize different technologies (Agency)
  - Increased possibility for safety issues and damage to facilities utilizing contractors who are not familiar with the area (Agency)
  - Costs for major events can have severe impacts on budgets (Agency)
  - Opportunity for poor communication and coordination (Contractor)
  - Lack of ability to control additional subcontractors (Contractor)
  - Risk of safety issues with additional subcontractors (Contractor) (9)

As these points indicate, there are a number of benefits that an agency can achieve through different approaches to contracted plowing. However, these must be carefully considered in light of the potential disadvantages an agency may also face.

Ozbek and de la Garza also discussed one of Virginia's performance-based maintenance contracts that covered all aspects of highway maintenance, including snow and ice removal. A lump sum contract was initially signed in 1996 and renewed in 2001, each contract covering 5 ½ year periods. Unfortunately, aside from specifying the contract type and the activities it covered, this article provide no discussion or evaluation information specific to winter maintenance operations (10).

Otto discussed limited aspects of Alberta's outsourcing of winter maintenance. Geographically based unit-price contracts were used, with contractors given discretion on when to begin winter maintenance operations based on weather forecasts and actual road conditions (11). However, aside from these brief contact details, further information, such as the costs and benefits of contracted plowing operations, were not discussed.

The Niagara region (Canada) is another agency that uses contracted plowing, which began in 2003 (12). The region uses a single contractor, and the contract period is 10 years in length, although the specific type of contract was not specified (ex. lump sum versus event-based payment). The region's 400 miles of roadway are maintained by the contractor's fleet of 14 vehicles, and are complimented by the Niagara region's own 22 vehicle fleet. The region sets the parameters for mobility and safety that the contractor must meet. The contract requires investment in new technologies, and no piece of equipment may be older than 10 years. The contractor dispatches their own patrols, notifying the region's dispatch center when units are called out. The benefits of contracted winter maintenance observed by the region include financial savings, an equivalent level of service to that provided by governmental entities, and an ability to quickly test and implement new technologies. Unfortunately, the discussion did not provide any quantified figures for these benefits.

## 3.4. Tailgate versus Hopper Spreaders

In order to apply granular materials in a uniform manner across a roadway surface, agencies employ material spreaders. More specifically, two types of material spreaders are predominantly used: hopper spreaders and tailgate spreaders. Hopper spreaders are self-contained units mounted in dump-trucks in winter and removed for storage during other seasons so that the trucks may be used for other maintenance work (13). Hopper spreader systems consist of a V-box, conveyor/belt/chain, spinner and drive mechanism. The V-box capacity can vary depending on the size of the dump body of the truck it will be placed in. An example of a hopper spreader installed in a dump body is shown in Figure **3-2**.

Tailgate spreaders, as the name suggests, are spreader units attached to the tailgate (or rear of the dump body) of the plow vehicle. They consist of a small hopper, an auger, a drive system, and a spinner or similar spreader mechanism (13). This type of spreader uses the entire dump body for storage, allowing more material to be carrier than is possible with a V-box. Material is fed into the spreader by slightly raising the dump body, allowing material to slide. Similar to hopper spreaders, tailgate spreaders can be removed after the winter season, allowing the plow vehicle to be used for other purposes throughout the year. An example of a tailgate spreader is shown in Figure 3-2.

Hopper Spreader

Tailgate Spreader

Figure 3-2: Hopper and tailgate spreaders (Washington State Department of Transportation photos)

The use of a tailgate versus a hopper spreader depends on the needs and objectives of an agency. For example, agencies such as cities that encounter low overhead obstacles such as tree limbs, signal lights, bridges, etc. will likely choose a hopper spreader to eliminate the need to raise the dump body to move material to the back into the spreader. Agencies such as counties and state DOT's that do not encounter as many overhead obstacles tend to select tailgate spreaders more frequently.

In addition to clearance issues, there are other reasons why one type of spreader is selected over another. Hopper spreaders typically allow a greater variety of application treatments than tailgate spreaders. Hopper spreaders are also easier to calibrate, while tailgate spreaders (particularly older models) used excessive materials and are/were difficult to keep calibrate. However, tailgate spreaders are a less expensive piece of equipment, which may often be a consideration.

The average life of any spreader ranges from 10 to 20 years, provided appropriate maintenance is conducted on the spreader throughout its lifetime. Spreaders with stainless steel bodies tend to longer overall, accounting for the 20 year portion of lifespans. Installation of hopper spreaders requires 1 or 2 staff and generally takes 20 to 30 minutes. The time required to install and remove a tailgate spreaders depends on a few factors, including whether they are stored on and installed from a stand versus being installed with a lift chain. If stored on a stand, the connection points between the spreader and truck will generally be lined up, and installation (or removal) can take as little as 10 minutes. If a chain and lift are used, installation (or removal) can take up to 30 minutes because of the time required to line connections up.

Regardless of which type of spreader is selected, the application rate that it distributes materials at is reliant on a number of different factors. These include the area of the gate opening on the hopper box or at the bottom of the tailgate hopper, the feed belt or auger speed, and the speed of the plow vehicle itself (13). Most critical of these is the speed of the feed belt or auger, which is controlled in three ways: none, manually, or automatically (open or closed loop control). The selection of control is not considered here; however, another item in the cost-benefit toolkit does compare open and closed loop control. Additionally, spreader calibration is a vital to ensuring that material is being applied at the desired application rates. Spreader calibration is another item included in the cost-benefit toolkit, and the reader is encouraged to review these aspects of winter maintenance.

### 3.4.1. Existing Cost-Benefit Evaluation/Research

To date, no comparison of the performance of hopper spreaders versus tailgate spreaders has been made, specifically with respect to any differences in the quantities of materials each applies under different application rates. In theory, if calibrated correctly and an appropriate quantity of material is reaching the spreader, each spreader should apply the same material at a nearly equal rate/quantity. Therefore, when comparing hopper and tailgate spreaders, one should consider their relative advantages and disadvantages. A Clear Roads Pooled Fund synthesis of practice obtained feedback from practitioners regarding the types of spreaders they used and their general experiences with those spreaders (14). These include the following:

Hopper (V-box) spreader:

- Advantages
  - Does not pose overhead clearance issues (versus a raised dump body)
  - Less potential for material to freeze/clog while in use because of material conveyor system and sloped hopper
  - Entire system can typically be installed/removed via forklift, allowing year round use of vehicle
- Disadvantages
  - Reduced material capacity with V-box.
  - Added maintenance for conveyor system
  - Emptying V-box after use may be necessary to prevent material from freezing/hardening
  - Higher purchase cost because of additional size and equipment complexity

Tailgate spreader:

- Advantages
  - Additional material capacity through use of entire dump body
  - Reduced maintenance needs because of simpler design, primarily focused in the spreader unit itself
  - Easier removal of unused material from the dump body after storm maintenance completed
  - Spreader can be installed/removed easily, allowing year round use of vehicle
  - Lower purchase cost
- Disadvantages
  - May pose overhead clearance issues (slightly raised dump body)
  - Added potential for material to freeze in the dump body
  - More difficult to regulate material flowing to the spreader due to lack of conveyor/chain drive
  - Reduced flow of material into the spreader can affect desired/set application rate

While no direct benefits of one type of spreader versus another have been identified, for the purposes of cost-benefit analysis, it is possible to assume that the use of either spreader will result in an improved level of service for motorists. Specifically, pavements will be better maintained, translating into a reduced number of crashes, albeit somewhat of a lower reduction. General guidance from the "Handbook of Road Safety Measures", indicates that the raising of winter maintenance standards can reduce Injury crashes by 11% and Property Damage Only (PDO) crashes by 30% (15). While the contribution of spreaders in these percentages is not broken out, one could conservatively assume that crash reductions attributed to either a hopper or tailgate spreader is 1% to 5% for both Injury and PDO crashes.

## 3.5. Laser Guides

Laser guides are a relatively new piece of equipment applied to winter maintenance operations. A laser guide is a device which projects a green laser spot ahead of the snow plow vehicle (typically 6 to 8 feet out in front of the plow) to establish where the trailing edge of a wing plow (or tow plow) will be in relation to the roadway surface. In essence, it is showing the plow operator where the furthest point of the plow they are operating will travel. Figure 3-3 provides images illustrating the laser unit and how it works in operation. While still a relatively new piece of equipment, initial evidence from use in different states suggest that laser guides can produce quantifiable benefits for agencies when used in winter maintenance operations. Additionally, laser guides have the advantage of being used in summer operations, such as line striping, which allows for the cost of the unit to be spread over the course of an entire year. The following paragraphs summarize the information available to date regarding the use of laser guides in winter maintenance operations.

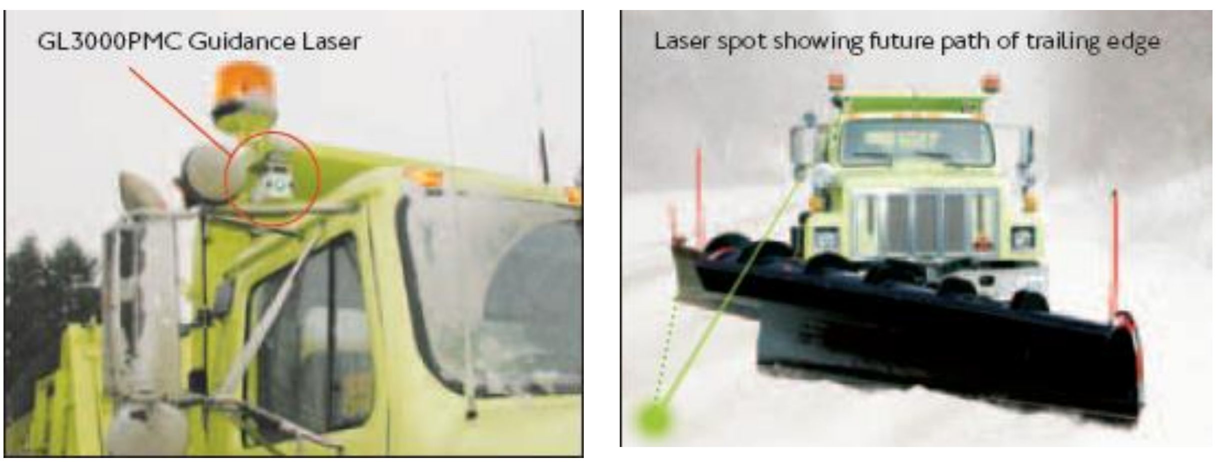


Figure 3-3: Laser Guides (photos: LaserLine Mfg., Inc.)

### 3.5.1. Existing Cost-Benefit Evaluation/Research

The Iowa Department of Transportation has used laser guides on vehicles equipped with wing plows to assist operators in areas with limited right of way or numerous roadside obstacles (16). While the device itself cost $2,400, the costs to repair or replace a damaged wing plow can be as high as $11,000. Field use identified the primary potential benefit from use of the laser lies in its ability to prevent collisions with mailboxes, bridges and other roadside structures, consequently reducing vehicle/equipment downtime and repair costs (17).

The Minnesota Department of Transportation evaluated laser guides on a snow plow in Makato, finding similar benefits to those in Iowa. Benefits identified included improved avoidance of roadside obstacles and improved operator focus (18). In the case of operator focus, the plow operator could concentrate on the road ahead rather than checking side mirrors to determine the location of the wing plow.

The Clear Roads Pooled Fund product feedback experience summary from 2007-2008 included information on laser guides from Utah and Minnesota (19). Utah reported the use of laser guides reduced avoidable hits by 85 percent, while Minnesota reported no accidents with fixed objects occurred when the laser was in use.

Finally, feedback from users to the laser guide manufacturer also offers useful information and metrics for consideration (20). User feedback from the Washington State Department of Transportation indicated that the cost of wing plow accidents ranged from $1,000 to $19,000, but when the laser guide was used on a number of trucks, such crashes were eliminated. The state also cited the benefit of operators being able to focus on driving rather than monitoring the position of the wing plow.

## 3.6. Open and Closed Loop Spreader Controls

In recent years, ground speed controllers have seen increased use in snow and ice control operations. Such controllers automatically adjust hydraulic fluid flow in proportion to ground speed (vehicle speed) (21). This allows vehicles with automatic controllers to maintain a constant material application rate without the operator having to adjust the valve opening to conform to vehicle speed. The only requirement of the operator in such an instance is the selection of an appropriate application rate.

Ground speed controllers consist of two types: open loop or closed loop. Open loop controllers monitor vehicle speed and adjust the control valve to a predetermined setting to provide the correct belt/auger speed for a certain spread rate (21). Closed loop controls monitor vehicle speed and belt/auger speed, adjusting the control valve until a predetermined ratio value between these speeds is achieved (21). Both open and closed loop controllers have the potential to reduce material usage, resulting in financial savings, and minimize environmental impact. The following sections discuss the results of comparisons between open and closed loop controllers.

Figure 3-4: Open and closed loop controllers maintain a constant material application rates (Washington State Department of Transportation photo)

The choice between the use of an open and closed loop controller is one of agency preference. In essence, an open loop controller is basically a manually operated controller, while a closed loop controller is more precise and provides more control on application. Additionally, closed loop controllers have an auger sensor which allows them to monitor the actual rate of the auger, and adjusts the control valve until the correct auger speed is achieved. Closed loop systems are more accurate in the delivery of the material and are easier to calibrate. This translates into savings which far outweigh the cost of a controller. However, it is a little less costly to purchase a system without an auger sensor, possibly the reason for some agencies to select an open loop controller. Note that some newer controllers now have GPS integrated into them, providing the ability to track information. Where open loop controllers are used, it is often done during a storm to spread more materials than typical settings would allow. Outside of such use during one or two runs, closed loop control is generally employed.

Based on feedback from states, a controller has a lifespan of between 10 and 20 years, or generally lasts for the life of a truck. One viewpoint was that the technology changed before the controller wore out.

### 3.6.1. Existing Cost-Benefit Evaluation/Research

Work completed for the Clear Roads pooled fund examined open and closed loop controllers to determine whether the units accurately controlled spreader discharge of materials and if they provided savings compared to manually controlled units. The work employed a yard study and simulated field settings that would be used during different types of storm events to determine the performance of each type of control system. Actual discharge quantities were compared against theoretical discharge rates to establish the differences between controllers and quantify the potential material savings from open and closed loop controller use. The work used eight different controllers operating in open loop, closed loop and manual modes, as shown in Table 3-1. Note that the work did not compare manufacturers or make recommendations on specific products.

Table 3-1: Type/manufacturers of controllers tested and modes used (21)

| State DOT | Controller Manufacturer/Model | Mode of Controller Operation |
|---|---|---|
| Indiana | Muncie Power Products MESP402D | CL, OL |
| Iowa | Cirus Controls SpreadSmart RX | CL, OL, M |
| Minnesota | Dickey-john Control Point | CL, OL |
| Missouri | Component Technology GL-400 | CL, OL, M |
| Ohio | Pengwyn 485 | OL, M |
| Wisconsin | FORCE America<br>Model 2100<br>Model 5100 | <br>OL<br>CL, OL |

Results of the research found that the performance of closed loop systems was less variable than open loop systems. In other words, open loop systems displayed greater variation in the amounts of materials they discharged, while closed loop systems were more accurate in discharging the desired quantity of materials. For instance, an open loop spreader may underapply material compared to a closed loop spreader. The closed loop spreader may be applying the exact 200 pound per lane mile application rate that the controller has been set at, while the open loop controller may be applying only 190 pounds per lane mile at the same setting. While this may result in less material being used (a savings, though not necessarily a desired one), it can also result in a lower level of service than desired. Despite this potential issue, both open and closed loop systems offered greater accuracy and lowered material applications compared to manual controllers. The Clear Roads study found that manually controlled spreaders could overapply material by as much as 47 percent at an application rate of 400 pounds per lane mile compared to closed loop controllers in the same scenario.

## 3.7. Prewetting at the Spreader

Prewetting is the process of coating a solid deicer with a liquid before it is spread on the roadway (22). Prewetting solutions can be made from sodium chloride (NaCl, salt brine), calcium chloride (CaCl2), magnesium chloride (MgCl2), potassium acetate (KAc), or Calcium Magnesium Acetate (CMA). Deicing materials must form brine before melting ice and snow, and prewetting deicers accelerates the brine making process while also reducing material bounce and scatter when applied to the roadway. While prewetting may be done by spraying a pile of deicer material at a storage location, a more direct approach to prewetting is to perform the task at the material spreader on the plow vehicle. Prewetting at the spreader coats the deicer with liquid as it comes from the hopper via the conveyor/auger onto the spinner (22). The benefit of this approach is that liquid is only applied to the material being used when it is used.

Figure 3-5: Schmidt (left) and Monroe (right) prewetting spreaders (Washington State Department of Transportation photos)

### 3.7.1. Existing Cost-Benefit Evaluation/Research

Information from New Hampshire provided general information on prewetting best practices (13). This included guidance on the use of 8 to 10 gallons of prewetting liquid per ton of deicer. The information provided indicated that the use of prewetting in general could reduce material application rates by 15 to 20 percent producing material and cost savings for an agency. Similarly, NCHRP Project 20-07 (Task 117) provided guidance on liquid use in prewetting at the spreader, indicating 8 to 12 gallons per ton of material should be applied, with a solids application rate of 200 pounds per lane mile (23).

Perchanok et al., discussed sustainable winter sanding using prewetting with a hot water sander in Canada (24). In using the hot water sander, a reduction in sand use of 50 percent was achieved. Additionally, the number of operations (trips) to a site to apply materials was reduced by 50 to 80 percent. Finally, the researchers determined that the environmental footprint of the material being applied could be reduced by up to 50 percent over traditional spreading.

Information from the Salt Institute indicated that prewetting could reduce salt application rates by 26 to 30 percent due to more material being retained on the roadway (25). In a case where an agency used 1,000 tons of salt per winter, this could translate into thousands of dollars of savings, even when factoring in the cost of the prewetting brine (ex. CaCl).

Burtwell discussed the performance of prewetted salt spreading from trials in the United Kingdom (26). Prewetted salt that was wet at the spreader was found to be preferable to dry salt because most small salt grains dissolved before being blown off the pavement. It was reported that salt use reductions of 25 to 33 percent were possible using prewetting. However, it was noted that care must be taken when calculating prewetting cost savings because different salt types can be used for the base salt and wetting agent, as well as different proportions of dry salt to wetting agent, having direct impacts on the calculation of costs and benefits.

Nixon, as part of discussing field tests of abrasive delivery systems, discussed some of the advantages of prewetting (27). While prewetting at the different spreader systems were not part of the tests conducted, the advantages of such systems were cited from work completed by Lemon in Michigan (28) and included material savings, as well as the potential to extend the range of the snow plow itself. In the case of extending the plow, this was the result of reduced material usage requiring less stops to reload, resulting in both time savings as well as increased maintenance coverage of the roadway system.

The Federal Highway Administration touches on general aspects of prewetting, including prewetting at the spreader, as part of a larger discussion on effective anti-icing programs (29). Such systems were cited as reducing solid material quantities being used by 30 percent at speeds as high as 40 mph. Prewetting systems at the spreader were also cited as being relatively inexpensive, using electric or hydraulic pumps, in cab controls, nozzles, hoses, tanks and general fittings. However, no cost figures were provided by the report to quantify what was considered inexpensive at the time.

## 3.8. Remote Cameras for Monitoring Remote Sites

Remote cameras, also referred to as Closed Circuit Television Cameras (CCTV), allow a viewer in a remote location to view a particular site in the field. Traditionally, CCTV has been used in transportation to provide traffic monitoring capabilities in both urban and rural locations. This allows an agency to observe traffic and environmental conditions at a location, and typically, the CCTV feed is also posted to a traveler information website for motorists to view pre-trip. The use of CCTV at remote locations holds similar potential for winter maintenance operations, as it allows agency personnel to observe weather/roadway conditions at specific locations of interest, as well as potentially provide that imagery to motorists via the internet. The benefit of using a CCTV camera for remotely monitoring conditions is that it does not require the higher cost (additional sensors) and added maintenance of a Road Weather Information System (RWIS) site. While the detailed information provided by an RWIS may not be available, conditions at a site can be visually interpreted by maintenance staff, providing a similar benefit in terms of determining maintenance requirements during a storm. An example of a CCTV installation is presented in Figure 3-6.

Figure 3-6: CCTV sites provide observation capabilities in remote locations (Kansas Department of Transportation photo)

### 3.8.1. Existing Cost-Benefit Evaluation/Research

The Federal Highway Administration's Intelligent Transportation Systems Joint Program Office has compiled a comprehensive reference document covering the costs, benefits deployment and lessons learned from several different technologies, including CCTV cameras (30). While quantified benefits of CCTV cameras, either specific to winter maintenance uses or in transportation agency uses in general were not specified, cost information provided by the document indicates the installation of a CCTV site will range from approximately $2,000 to $16,000, depending on the specific site, installation/equipment needs, communications requirements, and so forth. Note that recurring costs for communications to the site were not outlined in the document, but depending on the mechanism employed by an agency (telephone line connection, fiber optics, etc.), these may present a cost that an agency needs to account for.

As stated, the primary benefits of using remote CCTV in winter maintenance is the ability for staff to observe and assess conditions and to provide travelers with an image of conditions along a route prior to a trip (or even while en route via a smartphone). To date, no quantified benefits from CCTV cameras specific to winter maintenance have been identified. Such benefits can potentially include enhanced level of service through timelier treatment, and the corresponding improvements to motorist safety and mobility. Of course, such benefits extend along a roadway for a given length beyond the fixed point of the CCTV site. However, that distance is unknown and likely to vary depending on the location itself.

In the absence of any quantified metrics specific to CCTV cameras and winter maintenance, it is reasonable to expect such benefits would be similar to those provided by a full RWIS site, albeit scaled back. Since RWIS is a mature application, its benefits have been widely discussed.

Consequently, these benefit figures will be applied to the case of a remote CCTV site, with conservative downward adjustments applied to account for the reduced capabilities such a site has compared to an RWIS station.

An NCHRP study documented the cost savings and benefits of RWIS technology, finding that the primary benefit offered was safer travel for motorists (31). Other benefits that could also be accrued by a CCTV site include:

- Improved Level of Service
  - Safer travel and improved driver information.
- Cost Savings
  - Reduced patrolling producing material, fuel and labor savings.
- Maintenance Response to Information.
  - Get the right equipment and materials at the right place at the right time.
- Indirect Benefits
  - Shorter travel times for motorists and reduced accident rates.

In addition, the report states that based on the literature/agencies reviewed, a benefit-cost ratio of between 1.1 and 5.0 may be expected from RWIS systems, depending on the application (31). For a standalone CCTV site, it is reasonable to assume this benefit-cost ratio would range between 1.0 and 2.0.

Ye et al. evaluated the effects of weather information on winter maintenance costs by using the methodologies of sensitivity analysis and artificial neural networks (32). As part of this work, the researchers performed a cost-benefit analysis for the states of Iowa, Nevada, and Michigan to determine whether the use of accurate weather information provided by RWIS was effective in reducing winter maintenance costs (32). The direct benefits were found to outweigh the costs of using weather information (costs of the entire system), producing benefit-cost ratios of 1.8 (Iowa) and 3.2 (Nevada)[2]. Adapting these figures to apply to a CCTV site, it is reasonable to once again assume a benefit-cost ratio would range between 1.0 and 2.0.

Boselly developed an implementation guide for RWIS, touching upon some of the costs and benefits that accompany such systems (31). These included:

- Costs – System acquisition, installation and maintenance. These same costs apply to a remote camera site as well.
- Benefits – Reduction in labor, equipment and material costs. Similar benefits would be accrued via a remote camera, namely through reduced patrolling (savings on labor and fuel) and a more efficient use of materials.

Boon and Cluett discussed the use of RWIS in enabling proactive maintenance practices in Washington state (33). Some of the benefits of RWIS identified can also be accrued from remote cameras, including:

- Traveler information – Better prepared drivers; Safer travel behavior; Reduced travel during poor conditions; Fewer crashes, injuries, fatalities and property damage;

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[2] The benefit-cost ratio of the Michigan case study was not recommended as the calculation of costs were not based on statewide numbers.

- Increased customer satisfaction and political support; Improved mobility; Safer, more reliable access (33).

Furthermore, the authors briefly discussed the results of previous studies on RWIS that had developed benefit-cost ratios. These ratios ranged from 1.4 to 5.0 (33). Once again, these ratios can be adjusted for a remote camera case to range between 1.0 and 2.0.

Ye and Strong discussed the potential costs and benefits of weather information in winter maintenance. Specifically, the researchers identified secondary applications of RWIS information, including traveler information (34). These included:

- Traveler information
    - Costs - Establishment and maintenance of delivery platforms (website, 511, etc.).
    - Benefits - Safer and more comfortable driving; Better trip planning for travelers.

As the literature summarized here indicates, complete RWIS stations have been shown to produce high benefit-cost ratios. Consequently, it is reasonable to assume that one component of RWIS systems, CCTV cameras, can reasonably produce benefit-cost ratios of between 1.0 and 2.0. This is based on the findings presented in literature which indicate full RWIS sites have produced benefit-cost ratios ranging between 1.1 and 5.0.

## 3.9. Salt Slurries

Salt slurries are a mix of finer grained salt mixed with liquids that form a brine to cover the roadway surface with more salt particles (35). The liquid aids in helping the salt stick to the roadway and melt ice faster. The generation of the slurry is done by a salt slurry generator equipped on the back of a plow vehicle, as depicted in Figure 3-7. The system operates by transferring dry salt from the hopper (by gravity) onto a conveyor belt or augur. This salt is fed through a roller that grinds it into finer particles. These particles then fall through a spray of water which mixes with them to produce the slurry brine. The resulting slurry is then spread onto the roadway via a spinner. The liquid to solid ratio employed in this process is typically 30:70.


Figure 3-7: Salt slurry generator in operation (Monroe Truck Equipment Inc. photo)

### 3.9.1. Existing Cost-Benefit Evaluation/Research

Data cited by Monroe Snow & Ice Control Inc., manufacturer of one salt slurry generator, indicate that the city of West Des Moines, Iowa, was able to reduce their granular salt application rate by 30 percent. The benefits of salt slurries identified by the manufacturer included:

- Reduced salt usage and buildup on roadways;
- Increased salt effectiveness;
- Faster material activation;
- More material retained on the roadway (35).

The Michigan Department of Transportation has tested the Monroe salt slurry generator beginning with the 2009-2010 winter season (36). The tests compared a truck equipped with a salt slurry generator to one with traditional spreader equipment. Initial results found that the salt slurry generator did not perform as expected owing to the spinner being located too high off the roadway. During 2010-2011 tests, a drop chute was used (replacing the spinner) producing better results. The salt slurry truck used 176 tons of salt that season compared to the 242 tons used by the truck equipped with a traditional spreader, producing a material savings of 37.5 percent. Conversely, the salt slurry truck used 1439 gallons of liquid versus 275 gallons used by the traditional equipment truck, an increase of 523 percent. Note that these figures were generated by each truck during the same sets of storms. At material prices of $54 per ton for salt and $0.83 per gallon for liquid, the salt slurry generator produced a savings of $2600 in materials for the season.

The Maine Department of Transportation examined the performance of Schmidt spreaders using a 30:70 liquid to salt ratio on six plow routes (37). Results indicated that material savings ranging between 4 percent and 33 percent were achieved, depending on the route. On average, fewer pounds per lane mile were used when employing the spreaders.

## 3.10. Spreader Calibration

Different snow and ice control materials must be spread at different rates by different equipment. This requires that spreaders be calibrated for the material that they will spread. Spreader calibration consists of calculating the pounds or gallons per mile of material that should be discharged at different controller settings and vehicle speeds (38). Spreaders must be calibrated individually, as the same models used on two different vehicles can have varying application rates. Different calibrations must also be made for different types of materials for different spreader units. The goal of spreader calibration is to ensure that materials are being discharged at appropriate rates, minimizing wasted materials (and producing cost savings) and reducing environmental impacts. The equipment used for calibration can be quite basic and includes a scale for weighing, a canvas or bucket/collection device, chalk, crayon or other markers, and a watch with second hand (38).


Figure 3-8: Tarp and wheelbarrow being used in calibration (Clear Roads photo (39))

### 3.10.1. Existing Cost-Benefit Evaluation/Research

The Salt Institute's "Snowfighters Handbook" presents an overview of the steps and calculations employed in granular spreader calibration. The steps in the process include:

1. Warm truck's hydraulic oil to normal operating temperature with spreader system running.
2. Put partial load of salt on truck.
3. Mark shaft end of auger or conveyor.
4. Dump salt on auger or conveyor.
5. Rev the truck engine to operating RPM (at least 2000 RPM).
6. Count number of shaft revolutions per minute at each spreader control setting, and record.
7. Collect salt for one revolution and weigh, deducting weight of container. (For greater accuracy, collect salt for several revolutions and divide by this number of turns to get the weight for one revolution.) (38)

The Clear Roads pooled fund developed a calibration guide as part of a larger effort examining ground speed controller units (39). This spreader calibration guide was developed for both ground speed controlled and manually controlled spreaders used to apply granular and liquid materials. The guidelines discuss various aspects of calibration and outline different procedures to use in performing such activities. Guidance is also provided regarding when calibration/recalibration should be performed, including:

- When the spreader/controller unit is first put into service.
- Annually, before snow and ice control operations begin.
- After major maintenance of the spreader truck is performed and after truck hydraulic fluid and filters are replaced.

- After the controller unit is repaired or when the speed (truck or belt/auger) sensors are replaced.
- After new snow and ice control material is delivered to the maintenance garage location (39).

In general, the spreader calibration process can take between 10 minutes and 1 hour, depending on the number of staff involved, the type of controller (open or closed loop), the number of materials calibration is being done for, and even the age of the vehicle (new equipment requires added time to calibrate from scratch). Feedback from states has indicated that 1 to 3 staff are used to complete calibrations, with 2 staff members generally being most widely used.

Despite other reports and articles discussing the need for calibration and the steps/process involved (40, 41, 42), there is no documentation citing specific figures regarding either the material or financial savings produced by the process, nor is there any indication of the percentage of material savings per lane mile, season or other metric that can be achieved through calibration. Consequently, for the purposes of estimating the potential material/financial savings of spreader calibration on a yearly basis, a conservative material use reduction of between 10 percent and 40 percent may be employed. These figures are adapted from the findings of the ClearRoads study related to open and closed loop controllers (42).

## 3.11. Tow Plows

A tow plow is a trailer equipped with a snow plow towed behind a tandem axle truck equipped with a front snow plow. An image of a tow plow is presented in Figure 3-9. In operation, the trailer swings to the right of the towing vehicle to plow a second lane, covering a distance of 25 feet at speeds up to 55 mph (43). The trailer and plow are controlled hydraulically by the driver of the plow truck. In doing so, the work traditionally performed by two plow trucks is accomplished by one, resulting in improved efficiency and economics. While still a relatively new piece of winter maintenance equipment, a number of evaluations and performance information has been generated to date.


Figure 3-9: Tow plow in use in Utah (Utah Department of Transportation photo)

### 3.11.1. Existing Cost-Benefit Evaluation/Research

Griesdorn discussed the results of an evaluation of tow plows during the winter of 2010-2011 on state, U.S. and Interstate highways in northeast Ohio. Reductions in fuel use, labor and materials were achieved (although not reported) while providing a higher level of service (43). A reduction of 75 percent was observed in the time required to plow four lanes on one route. Drawbacks of tow plows that were identified included a lack of adequate space at highway crossovers to turn around (due to vehicle length), difficulty in viewing traffic behind the tow plow (due to blowing snow), trailing traffic being impeded, and obstacles on the roadway shoulder being struck.

A Pennsylvania Department of Transportation research and product summary indicated a fuel savings of 85 to 90 percent would be achievable through the use of a tow plow (44). This savings would be the result of the reduction in traditional snow plows and their related fuel use. Additionally, the summary provided cost figures associated with tow plows. These included a total cost of a basic tow plow of $73,790 and a towing vehicle modification cost of $15,500 (for rear hitch, hydraulic controls, etc.). The addition of anti-icing capability would cost $25,820, while a granular material hopper would cost $18,184.

Corbett and Poitras discussed the use of tow plows near Fredericton, New Brunswick during winters between 2006 and 2009 (45). This use of the tow plow was somewhat unique as it was adopted by a contracted maintenance provider (Brun-Way Highway Operations, Inc.). The experience in New Brunswick showed that tow plows had the potential for reducing vehicle maintenance and produce fuel savings, although the authors noted that the greater weather severities of the test winters provided insufficient evidence to quantify savings. One interesting observation that was made was that the plow cutting edges on the tow plow lasted an entire season compared to the need for two or more blade changes on traditional plow vehicles.

A Missouri Department of Transportation research bulletin discussed the use of 34 tow plows throughout the state (46). Missouri originally developed the first tow plows, using them initially in the Kansas City area in January 2005. Since then, the state has found a 28.6 percent reduction in fuel and labor costs can be achieved when using the tow plow in an urban multilane setting (four or more lanes in each direction). In a rural, divided four lane highway setting, fuel and labor savings of 50 percent have been achieved.

The Maine Department of Transportation purchased a tow plow and evaluated its performance during the winter of 2009-2010. In general, the use of the tow plow was deemed to be a success, although no benefits were quantified during the evaluation. The evaluation did identify one concern that had not been discussed by others previously: the potential for a plow/tow plow unit to stall on hills/grades. While such stalls only occurred on four occasions in Maine (and were addressed by the driver backing down the hill and climbing it again), they did underscore the need for a higher horsepower tow vehicle when employing a tow plow (47).

The American Association of State Highway and Transportation Officials (AASHTO) compiled an overview of the benefits of tow plows, which included those already discussed elsewhere in this section (48). Additional benefits cited included reduced emissions (elimination/reduction of plow vehicles), decreased cycle times for operations, and fewer material application trips. An unexpected benefit that has been observed by operators stemmed from the efficiencies gained from using the tow plow to apply anti-icing materials to additional lanes prior to storm events. The overview indicated that generally a tow plow pays for itself in 4 to 5 years, assuming a reduction in the use of one traditional snow plow for 250 hours per year. Additionally, the overview estimated that the life cycle of a tow plow is 20 to 25 years, providing a useful consideration when calculating a benefit-cost ratio.

In a companion presentation based on the AASHTO Technology Implementation Group's summary of tow plows (48), a straightforward approach to calculating the hours to payoff following the purchase of a tow plow was presented (49). Assuming a tow plow will clear as much roadway as a traditional snow plow (as opposed to a wing plow), this calculation may be made as follows:

$$Hours\ to\ Payoff = \frac{Cost_{Tow\ Plow}}{Cost_{Driver} + Cost_{Truck}}$$

Where:

$Cost_{Tow\ Plow}$ = The purchase cost of a tow plow

$Cost_{Driver}$ = Cost per hour for a traditional plow operator

$Cost_{Truck}$ = Cost per hour to operate a traditional plow

In general, the calculations made by this approach show a payoff period of 4 to 5 years based on 250+ hours of plowing operations per winter season.

A review of tow plows in Wisconsin included qualitative and quantitative evaluations. The qualitative evaluation documented the general experiences of county plow operators using the tow plow (50). In general, this portion of the evaluation identified several concerns, including perceived increased operator workload, increased fuel consumption by the tow vehicle(estimated in one case to increase by 40 percent), and the need for higher horsepower tow vehicles. A quantitative evaluation was also conducted as part of the work, using fuel efficiency, labor and fuel costs, and operational speeds as inputs. While operating to clear two lanes of roadway, the total cost per mile to operate a tow plow was estimated to be $2.87, while the use of two traditional snow plows cost $4.19. The result was that the cost to operate a tow plow was approximately 32 percent lower than using traditional plows. It was assumed that for an average winter requiring 270 hours of plowing, the tow plow could produce a savings of $14,500. Given the $75,000 cost of the tow plow, this would result in a break even period of 5 years.

The North Dakota Department of Transportation evaluated two tow plows in the Fargo and Bismarck areas during the winter of 2010-2011 (51). This included an economic evaluation which used labor and equipment costs (excluding fuel costs) to determine whether tow plows produced cost savings. Regular snow removal operations cost $1,754 using traditional plow equipment and $782 using a tow plow. This resulted in a savings of $972, or approximately 55 percent when using a tow plow versus traditional plows.

## 3.12. 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:

- Comparing flexible blades to traditional blades
- Pre-wetting at the spreader

- Spreader calibration
- Slurries
- Tow plows
- Contracted truck (private or municipal) versus a state-owned truck
- Open versus closed loop spreader controls
- Remote cameras for monitoring remote sites locations
- Laser Guides
- Tailgate versus hopper spreaders

The costs of flexible blades are well known, as is information pertaining to the extended life of the blade versus traditional alternatives. Contracted plowing costs and benefits can vary widely and are specific to each agency, so while some specific cost guidance is available, only anecdotal values for its benefits have been established. The costs of tailgate and hopper spreaders are well defined, but quantified benefit information is still lacking. Laser guide costs and benefits are well known, with estimated reductions in roadside object strikes established. This information can directly estimate the expected reduction in property damage claims associated with roadside strikes.

Open and closed loop spreader controller costs have been documented, and research has also established some of their prospective material savings compared to manual spreader control. Prewetting costs have been well defined, as have the potential benefits of its use. Remote cameras for monitoring have defined cost information, but to date no quantified benefits specific to winter maintenance have been established. Salt slurries are a relatively new treatment technique, but its costs and benefits in terms of reduced salt use are documented. Spreader calibration costs have been defined, but surprisingly, no benefit figures related to material or financial savings have been developed to date. Finally, the costs and benefits of tow plows have generally been well established in literature.

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, closed circuit television cameras, which are a fairly mature application, have limited benefit information in terms of quantified savings, expected crash reductions, and so forth. Certainly this gap could be addressed through a specific evaluation of the technology in a winter maintenance setting by agencies, with results published as they become available.

Even in the case of more straightforward technologies, such as laser guides, costs and benefit information is limited. This technology represents a case where a straightforward cost-benefit study could be conducted aide from the scope of the toolkit. Costs for the technology would include the price of the laser and installation/maintenance labor. Benefits stem from the reduction in the costs associated with wing plows damaging roadside objects.

# 4. TOOLKIT OVERVIEW

This chapter discusses the various aspects of toolkit. The toolkit itself was developed during the initial phase of this project, with the present phase adding additional toolkit items of interest and making enhancements to the website itself. This chapter discusses the toolkit's original development and enhancements. Included is a discussion of cost-benefit[3] 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 money[4]. 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.

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[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 (52). 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 2012 related to the nominal discount rate ranged from a 0.5 percent for a 3 year period to 3.0 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 laser guides to more extensive inputs for an item like flexible blades. To inform the reader, a general overview of the various data needs for the toolkit is as follows:

- Analysis period.
- Number of equipped trucks.
- Total trucks.
- Average tons of material used per truck per storm
- Total storm events per year.
- Cost of salt per ton.
- Cost of brine per gallon.
- Expected gallons of brine used per ton.
- Loaded labor cost per hour.
- Extra installation hours.
- Extra hours to maintain.
- Expected life cycle.
- Current number of maintenance vehicles.
- Annual maintenance expenditure.
- Miles per truck per year.
- Plow width.
- Total storm event injury crashes (per season).
- Total storm event property damage crashes (per season).
- Hours to change traditional blades.
- Average injury cost per crash.
- Average PDO cost per crash.
- Annual operating cost per plow (labor and fuel).
- Average cost of roadside accidents with wing plows.
- Number of roadside accidents with wing plows.
- Hours to install laser unit per vehicle.
- Average or expected application rate (lbs or gal per mile).
- Cost of material per pound or gallon.
- Average lane miles plowed per storm per vehicle.

- Average cost of each winter maintenance vehicle
- Average salvage value per vehicle.
- Annual material costs.
- Annual tons of granular material used.
- Use rate of gallons per ton.
- Flexible blade life (in miles).
- Traditional blade life (in miles).
- Number of spreader units in use.
- Expected number of calibrations per year.
- Total storm events per year.
- Number of planned camera sites.
- Average crash cost.
- Total storm event crashes per season (within a 1 mile proximity up and downstream of the prospective camera site).

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, and details of what each of these relates to are provided at their respective entry points on the toolkit website. 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 manufacturers, literature and the project TAC. In some cases, limited cost information was also provided by practitioners via the internet survey 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. The user is

presented with an option to convert their results to a Word or HTML format during this step.

## 4.6. Toolkit Enhancements

During the course of this phase of the project, the existing toolkit received updates and enhancements. These were the result of feedback received from users following the initial development of the toolkit during the first project phase. The key improvement made to the toolkit is the capability to create a Word or HTML version of the project report that is final step of the toolkit. This option allows the user to create a version of the project report that can have text and tables cut and paste as needed by the user. At this time, the toolkit does not have the direct capability to save files in a .pdf format. However, the Word or HTML formatted reports generated by the user can be directly printed to a .pdf if the user has that capability on the machine they are accessing the toolkit on. During this phase of the project, the Content Management System was also updated to use the latest libraries. This was done to consistently handle DOM (Document Object Model) readiness, particularly in Internet Explorer.

A final enhancement made to the toolkit was providing the ability for users to save their worksheets and revisit their scenarios in the future. To accomplish this, a new login system was implemented that allows users to save worksheets. It utilizes built-in user management and data management capabilities in Joomla! and Fabrik. The initial toolkit saved the worksheets behind the scenes, so an update was made so that a logged in user would be associated with their forms. A new screen was developed to provide the user with a means to access the forms they previously saved.

## 4.7. 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.
- A negative cost-benefit ratio will occur when the alternative cost (baseline condition) in the initial costs calculator is greater than the proposed equipment cost. An example is in the case of Hopper versus Tailgate spreaders, where the item being examined

may cost more than its alternative that would otherwise be purchased. This occurs when a Hopper is being compared to a Tailgate spreader as a baseline condition. Tailgate spreaders are inherently more expensive that Hopper spreaders which will results in a negative initial cost. This does not imply that the benefit-cost ratio generated by the hopper spreader is not positive; rather, it indicates that hopper spreaders have an advantage of a lower purchase cost, in addition to contributing to a reduction in crashes.

## 4.8. 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., Tow Plows, slurries). This disparity of quantified values is a shortcoming and needs to be addressed by future research projects which study a respective toolkit item in detail. 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. 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 present issues. Specifically, versions of Internet Explorer may not allow entry of data once the user reaches step 4 (benefits entry). This stems from the browser's default setting to "Compatibility" mode. Unfortunately, there is no programming mechanism that allows the toolkit website to address this issue without user intervention. ***In order to prevent any issues with the toolkit while using Internet Explorer, the user must make the following changes to the browser settings:***

- Open the toolkit website in Internet Explorer
- Open the "Tools" menu and check whether "Compatibility Tools" is selected. If it is selected, it should be unselected.
- Next, go to the "Tools" menu and select "Compatibility View Settings". Check to make sure clearroads.org (and/or cdhdigitaldesign.com) is not listed. If the website is listed, select it for removal from the list.

Following these steps, the toolkit website should work without issues in Internet Explorer.

In addition to browser settings, the user may also need to change settings in Microsoft Word to ensure that hidden data associated with the tables generated by the toolkit does not display prior to printing. Specifically, the user may need to turn off the Show/Hide function in Word, which is used to display special characters (spaces, paragraph breaks, etc.). This function may be turned off using "Ctrl-Shft-8" or deselecting the paragraph icon in the Home menu. Regardless of whether the user has the special characters feature turned on or off in Word, ***the final reports and tables generated by the toolkit will print without the additional characters and tables being displayed.***

## 4.9. 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 and updating the toolkit, this additional tracking could 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 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 expanded and enhanced a web-based tool to assist winter maintenance managers in computing benefit-cost ratios. Such information can 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. While the focus of the toolkit is on quantified, tangible benefits, the intangible benefits associated with each toolkit item are also provided for user reference.

The project consisted of a completing operational and usability enhancements to the toolkit itself, as well as the addition of ten new toolkit items for analysis. Initial efforts focused on determining the new items that would be added to the toolkit. This was done via an online survey of Clear Roads members and the winter maintenance community. Based on the top ten items selected by survey respondents, a literature review and state-of-the-practice was conducted to determine what research, reports and other relevant information were available pertaining to the new toolkit items. The focus of this review was on the costs and benefits and any existing benefit-cost ratios associated with these new items.

Once available information was collected, the development of the analysis approaches for each new toolkit item was completed. These analysis methodologies were initially developed in Excel, with the respective approach developed for each item then translated into the website format The website, which was previously developed with open source tools to minimize the cost of development while maximizing functionality, was updated to include the new toolkit items.

Following completion of the new toolkit items, each underwent testing and validation to verify that it was functioning correctly and producing reliable, accurate benefit-cost ratios on different internet browsers (Internet Explorer, Firefox, Chrome, etc.). Discrepancies were corrected within the toolkit as identified during this process. Following these tests, the toolkit was released to the project panel for further testing to identify any potential issues the researchers may have missed and to obtain suggested improvements. Concurrent with this testing, training materials, primarily a User Manual, were updated. These training materials were developed to walk the user through the toolkit step by step for each of the twenty toolkit items.

## 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 often a clear lack of documented information, particularly in literature, that spells out quantified values for the costs and benefits of different winter maintenance materials, equipment and operations. 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. Overall, as additional and less commonly used items are considered for inclusion in the toolkit, this will become a greater concern.

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 remains 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 can present challenges. For example, the costs of equipment, maintenance required and so forth greatly differ between these items. However, in order to facilitate website usability, a common approach must continue to be employed.

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 toolkit which has been expanded represents an approach to winter maintenance benefit-cost analysis that can be built and improved upon. As the costs and benefits of different winter maintenance items are better tracked and recorded in the future, improvements should be made to the toolkit. These improvements should include the revision of cost and benefit data inputs provided with current toolkit items. Also, as new quantified values become available, particularly benefits, these should be incorporated into the existing analysis procedures of the toolkit. This can be done directly by the user, assuming they are aware of these values, when the encounter the appropriate data entry location within the toolkit.

The expanded toolkit website should continue to be disseminated to Clear Roads members for them to employ both in a learning and analysis capacity. In a learning capacity, users are encouraged to evaluate and employ the ten new items that have been added, 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 should consider training users in groups, particularly if benefit-cost analysis is desired at a localized level (ex. sheds, garages, etc.). 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.

Finally, continued expansion of the toolkit in the future should be considered. This would include the addition of currently used materials, equipment and operations that are of interest to practitioners, as well as any new materials, technologies, etc. that are developed in the future.

# 7. APPENDIX A: PRACTITIONER SURVEY

## Introduction

This survey is being undertaken by the Western Transportation Institute, Montana State University, and is sponsored by the Clear Roads Pooled Fund, to obtain information about your preferences for items to be included in an upcoming expansion of the winter maintenance cost-benefit analysis toolkit. This work is expanding and refining the previously developed toolkit that performs cost-benefit analysis for winter maintenance materials, equipment and operations.

The objective of this survey is to prioritize and identify the top ten winter maintenance materials, equipment and operations that agencies would like to see added to the existing toolkit. The toolkit presently includes the following items: 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. In addition to prioritization, this survey also seeks any information you may have regarding evaluations, quantified cost or benefit data, or other information of interest to this work.

If you would like to participate, please take a few minutes and answer the questions below. The survey is expected to take less than 10 minutes to complete. You may provide this survey to others in your agency / organization as well. Participation is voluntary, and you can choose to not answer any question that you do not want to answer, and you can stop at any time.

Your contact information will only be used by the researchers for the purposes of this study. The researchers will not contact you for any other reason and your contact information will not be released or shared for any other reason. For questions about the research project, contact Xianming Shi at 406-994-6486 or xianming_s@coe.montana.edu. For questions regarding your rights as a human subject, contact Mark Quinn, IRB Chair, 406-994-4707 or mquinn@montana.edu.

1. Please enter your contact information:

| | |
|---|---|
| Name | |
| Agency (Region)/Title | |
| Mailing Address | |
| City | |
| State | |
| Zip Code | |
| Email address | |
| Phone Number | |

2. Please check your top 10 items in the following list which you would like to see added to the expanded toolkit. Please only check 10 items. Note, if there is an item(s) not included in this list which you would like to see added, please indicate this on the "Other" line.

- ☐ Comparing flexible blades to traditional blades
- ☐ Plow guards
- ☐ Pre-wetting at the spreader
- ☐ Slurries
- ☐ Spreader calibration
- ☐ Tow plows
- ☐ Open vs. closed loop spreader controls
- ☐ Laser guides
- ☐ Abrasives (sand/aggregates in different types or weights/sizes)
- ☐ Remote cameras for monitoring remote sites locations
- ☐ Contracted truck (private or municipal) versus a state-owned truck
- ☐ Tailgate vs. hopper spreaders

Other (please specify)

3. Have you or your agency performed any cost-benefit, cost effectiveness or general assessment studies for any of the previously listed items? Please select all that apply.

- ☐ Comparing flexible blades to traditional blades
- ☐ Plow guards
- ☐ Pre-wetting at the spreader
- ☐ Slurries
- ☐ Spreader calibration
- ☐ Tow plows
- ☐ Open vs. closed loop spreader controls
- ☐ Laser guides
- ☐ Abrasives (sand/aggregates in different types or weights/sizes)
- ☐ Remote cameras for monitoring remote sites locations
- ☐ Contracted truck (private or municipal) versus a state-owned truck
- ☐ Tailgate vs. hopper spreaders

Other (please specify)

4. Would you be able to share any cost-benefit, cost effectiveness or general assessment information that you may have available for inclusion in the toolkit? If so, please provide it here or email documentation/information to xianming_s@coe.montana.edu.

5. Do you have any additional thoughts or comments that you believe would be useful to the project team?

THANK YOU FOR YOUR TIME AND PARTICIPATION IN THIS IMPORTANT SURVEY!

# 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. 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 salt slurries is that an agency is presently using a standard spreader to apply salt. This assumption was made using the logic that if a salt slurry is of interest, an agency is likely already using granular salt.

The toolkit assumes that the use of contracted plows instead of state/agency owned vehicles will allow for a portion of the vehicle fleet to be retired. It is also assumed that these vehicles will be resold or salvaged for an average price. No assumptions are made regarding the potential labor impacts of contracted plowing, such as a transition from operating plows to managing contractors, as such information was not well defined.

Prewetting assumes that granular materials are already being used in deicing operations and that if a prewetting spreader is being purchased new, it is being purchased in the place of a traditional spreader. In this case, since some type of spreader would be purchased regardless, the cost of the baseline spreader should be deducted (by the toolkit) from the cost of a prewetting spreader. Note that this does not apply if an existing spreader is being retrofitted with a prewetting system.

Flexible blades assume that a traditional blade insert (including carbide) is presently being used. It is also assumed that a flexible blade, by better conforming to the pavement surface, will produce a barer pavement. In doing so, a reduction in storm-related crashes can be achieved, producing a benefit to motorists.

Tow Plows are expected to supplement the existing plow fleet and be purchased in place of a traditional plow equipped with an engine. In essence, they provide an additional piece of equipment without the need for an engine, operator, etc. The primary benefits of tow plows are reduced fuel and labor costs, as well as improved safety through a faster plowing and treatment of four lane roadways (two plows covering more lane miles than one).

Tailgate and hopper spreaders are both assumed to produce reductions in crashes through their application of treatment materials in an efficient manner. However, when evaluating these items, the selection of a tailgate spreader for comparison against the alternative of a hopper spreader will likely result in a negative benefit-cost ratio. This is not indicative of the tailgate spreader being an improper piece of equipment to use; rather, it is the result of the overall lower purchase cost of the hopper spreader, which offsets the quantified benefits of the tailgate spreader in the resulting calculations.

Open and closed loop spreader controls are generally assumed to function in a similar manner and produce the same results in terms of material use reductions compared to the use of a manual controller. The result is that material savings are expected to be obtained through their use, although a comparison between open and closed loop systems in the toolkit, in theory, should produce a 0.0 benefit cost ratio, as each system is considered equal (although in reality, they are not). This is the result of the absence of literature establishing the differences in material use produced by each respective controller type versus one another.

The use of laser guides by agencies has shown significant reductions in damage to roadside features (ex. mail boxes, etc.). Consequently, this directly translates into financial savings in terms of repair costs and damage claims. It is assumed that an agency has a record of the number of such accidents that occur each year and also has or can estimate an average cost figure for such damages as an input for the toolkit.

There is no specific work that has documented the use of remote cameras for monitoring in a strictly winter maintenance sense. While such cameras are typically part of an RWIS site, their individual contributions to improved safety, more efficient winter maintenance, and so forth have not been established. As a result, the toolkit assumes that the use of a remote camera in a specific location may produce a reduction in crashes along a highway segment one mile up and downstream of the camera site itself. This crash reduction is expected to be the result of timelier monitoring and observation of conditions at the site and a corresponding improvement to maintenance dispatching along the highway segment.

Spreader calibration assumes an average time to calibrate each spreader is known. In reality, different spreaders (even of the same type/model) may require different times to complete calibration owing to outside factors such as the specific vehicle the spreader is installed on, the number of staff available to assist in calibrations at any time, etc. However, the toolkit seeks to use an average calibration time, incorporating all staff hours used as one lump sum figure (ex. 2 personnel requiring 2 hours to calibrate is entered in the toolkit as 4 person hours).

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:

> Material Savings = annual material cost * (equipped vehicles/total vehicles) * 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.

# 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 is 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 $1/4^{th}$. 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 is 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).

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