Quantifying the Economic Value of Snow and Ice Operational Success

Final Report

CLEAR ROADS

research for winter highway maintenance

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16. Abstract

Public works agencies at state and municipal levels invest a large amount of money in winter maintenance operations to keep roads clear and safe for vehicles during the winter season. The report will focus on the development of a Clear Roads Benefit-Cost Tool that agencies can use to quantify the economic value of their snow and ice operations including investing in emerging technologies and innovative practices. The tool provides a realistic cost and benefit to the operations and allows for justification and planning for an appropriate annual budget.

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Executive Summary

The purpose of this research is to create a methodology and a tool that help agencies measure the economic value of their snow and ice operations, including investments in new technologies and practices. The tool developed will support better decision-making by providing realistic cost-benefit insights and aiding in budget planning and justification.

This research began with literature review to help gain an understanding of current practices and the state of these practices related to conducting analysis of winter maintenance operations. This created a reference for components of the tool, such as what the standardized input values or crash reduction value are. The research team reviewed multiple documents recommended by the Clear Roads project subcommittee as well as additional relevant literature gathered by the project team. Some of these related pieces of literature include prior Clear Roads publications, presentations and proceedings, and articles and papers in professional and trade journals.

After the literature review, the team conducted a survey to determine the needs from a tool for cost-benefits of winter operations, provide insights into gaps from the literature review, and practices of agencies. The survey was created to gather inputs from agencies to determine additional information and understandings that may be used in the creation of the tool. Based on these survey results, the functions and the outputs the tool were developed to best suit the needs of agencies.

The data inputs and methodology of the tool were then determined. This step helped show the inputs and outputs of the tool as well as the methodology of how the tool provides the outputs related to a benefit-cost analysis of winter maintenance operations for agencies.

The tool allows agencies to input their values and analyzes cost-benefit information that are unique to their operations. It allows agencies to better plan their budgets and measure the effectiveness of their winter maintenance operations. A user guide was developed to provide information on how to use the tool.

This final report summarized this research project, including literature review, survey of needs, gaps and practices, determining data inputs and methodology, and the tool development and documentation. The final report is intended to serve as a reference guide for this tool in terms of why this tool was made, how it was made, how it works, and what benefits it provides.

1. Introduction

Transportation agencies continuously collect and analyze vast amounts of data to support decision-making and operational efficiency. However, it can be difficult to measure the benefits of winter maintenance operations in terms of monetary value and see how the benefits compare to the costs. To address these challenges, a tool was created for streamlining data analysis and generating a benefit-cost ratio based on the data from each individual agency.

Winter maintenance operations are a major expenditure for transportation agencies, particularly in regions that experience frequent snow and ice events. These operations require significant resources, including labor, equipment, and materials such as salt and brine, to ensure road safety and reduce congestion. The costs associated with these activities can fluctuate due to factors such as weather severity, material usage, fuel expenses, and labor costs. Understanding these costs and how they impact the annual budget year to year is crucial for agencies aiming to optimize their budgets, improve efficiency, and justify expenditures.

To support data-driven decision-making, this research focuses on the steps taken to develop a tool that calculates the costs of winter maintenance operations and evaluates the benefits they provide. By using multiple data sources such as material usage, equipment, labor hours, and weather conditions, as inputs, the tool enables agencies to quantify costs, identify inefficiencies, and compare various operational strategies. Additionally, it provides insights into how cost-efficient winter maintenance operations are year to year based on different weather conditions.

Given the variability in winter maintenance practices across agencies, the types of data collected, and how it is collected can vary significantly. Furthermore, the overall costs vary significantly based on weather conditions, the size of the area being maintained during the winter, the type and amount of equipment used, what data services are used, etc. Flexibility was built into the tool so that it can use various input types and account for all costs and sizes agencies wish to analyze.

This research aims to provide agencies with an easy-to-use and versatile tool to enhance financial planning, improve operational efficiency, and test investing in emerging technologies and innovative practices.

1.1 Background

This project focuses on creating a tool that can help agencies quantify the economic value of their winter operations procedures. Agencies spend large portions of their annual budgets on keeping roads clear, but the direct benefits are not always easily measured. By leveraging this tool, agencies will be able to see the direct monetary benefit of keeping roads clear, compare winter maintenance budgets between years, with all the data being directly tailored to each agency separately. Agencies will also be able to attain a much higher level of insight through benefit-cost analysis and adjust their budget as needed.

The purpose of this report is to explain and document the process of how this tool was developed. The information that was attained from the literature reviews and the surveys to different agencies were instrumental in the development of the tool. Through review of these pieces of information, the data inputs and methodology of the tool were determined, allowing for the development and documentation of the tool.

1.2 Tool Development Methodology

The research team utilized the following methodology to complete the project as described below.

1.2.1 Literature Review

The research team completed a review of relevant literature and project documents to gain a better understanding of current practices for winter maintenance operations as well as how the data are attained and analyzed. The literature that was reviewed included documents such as prior Clear Roads publications, presentations and proceedings, and articles and papers in professional and trade journals. Through these reviews, a better understanding of agencies' benefit cost analyses, how values or benefits of winter maintenance operations are quantified, and what the typical standard inputs values can be understood. A summary of the literature review by the research team is contained in Section 2 of the report.

1.2.2 Survey of Needs, Gaps and Practices

A survey was sent out to agencies to understand any data gaps that are relevant to the development of the tool from the literature review. The survey was aimed at gaining additional insight into relevant data that can be implemented in the tool. This includes things like finding out what the relevant data inputs are as well as what the desired outputs of the tool should be. The survey asked questions to various agencies on their needs and standard practices so that the tool may fill in the gaps of conducting analysis for them. A summary of the survey and results can be found in Section 3 of the report.

1.2.3 Data Inputs and Methodology

From the survey and literature review, the data inputs and methodology of the tool were determined. Key variables are used as inputs for the tool to determine costs of each agency's winter maintenance operations and the benefits they provide in terms of both traffic safety and mobility. Using these variables the methodology is developed and goes over how the tool reaches the desired outputs. The data inputs and methodology section is contained in Section 4 of the report.

1.2.4 Tool Development and Documentation

The tool is developed based on all the information gathered in the previous steps. By using the input variables that consist of information available from all agencies, the tool can output a benefit-cost ratio that is tailored to each agency. It can be used to compare the cost efficiency of winter maintenance operations between years or even adjust budgets for future applications of emerging technologies.

2. Literature Review

The literature review was designed to explore the current practices for determining the cost and return on investment (ROI) or benefits within winter maintenance operations. The primary objective of this literature review was to analyze and assess the prevailing practices of transportation agencies, with a particular emphasis on identifying the most up-to-date, innovative, and effective approaches to determining benefits of winter maintenance operations along with confirming all potential cost variables. Relevant literature and experience with non-winter maintenance operational cost-benefit analyses such as transit operations were investigated. This section of the report summarizes the literature review and synthesizes key findings, current practices, trends, and issues.

2.1 AWSSI Enhancement in Support of Winter Road Maintenance (Midwestern Regional Climate Center - University of Illinois, 2019)

The document presents a comprehensive review of a project with the objective of improving winter road maintenance through the enhancement of the Accumulated Winter Season Severity Index (AWSSI). The Midwestern Regional Climate Center at the University of Illinois led the program, which was sponsored by Clear Roads and Aurora pooled fund studies. The project's purpose was to improve winter maintenance decision-making by expanding AWSSI coverage, including adding new locations, which would provide more detailed and reliable data for road maintenance authorities to optimize their operations throughout the winter season. It also helps to understand and plan for seasonal severity, resulting in more effective and efficient winter road management.

Four tasks were established to help the project achieve its goals. Task 1 introduced at least one new AWSSI location in each of the 35 Clear Roads states, resulting in 51 additional stations that improved the index's coverage and utility. Task 2 added the option to overlay past seasons on the current-year AWSSI time-series displays, allowing users to compare present conditions to previous data. Task 3 created a feature that projected the severity for the rest of the winter season using past data, providing insights for planning and decision-making. Furthermore, the study looked into the relationship between AWSSI (and an adjusted measure of AWSSI referred to as RAWSSI) and road maintenance operations data such as personnel hours, equipment hours, and material usage. The results show a significant correlation, especially with labor hours. However, the correlation varied by state, indicating that local factors such as geography and climate have an important effect. The document suggests supplying extra AWSSI parameters to state Departments of Transportation (DOT) to assist them in correlating the index with their specific road maintenance characteristics. This method recognizes the differences in operational factors among states and districts (Midwestern Regional Climate Center, Unviersity of Illinois, 2019), and showcases how the winter season has impacted different states and regions throughout the US in March of 2024.

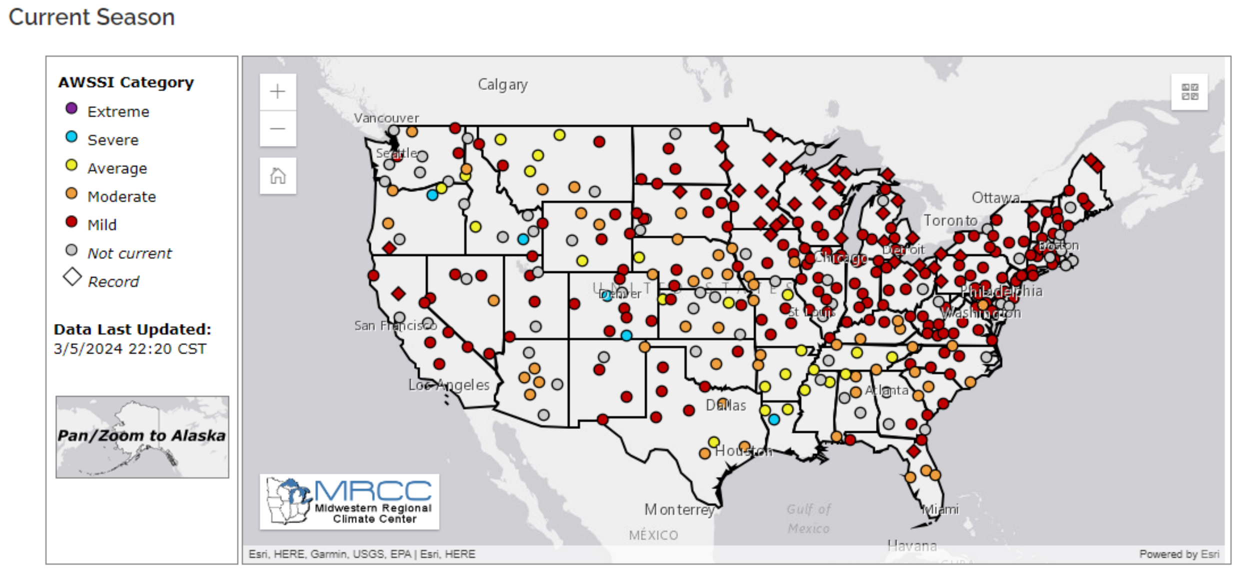

Figure 1. AWSSI Map of Winter Season Severity by Category. (The Midwestern Regional Climate Center, 2024)

By comparing current conditions with historical data in various domains, this report can assist the research team in establishing a more reliable foundation for determining economic metrics associated with winter severity and in creating a tool to quantify the economic value of winter maintenance operations.

2.2 Road Weather Information Systems (RWIS) Life-Cycle Cost Analysis – Aurora Project (Lee, Crow, Taavola, & Johnson, 2020)

The report discussed a comprehensive analysis of Road Weather Information Systems (RWIS) Life-Cycle Cost Analysis (LCCA), focusing on the methodologies for calculating life-cycle costs and benefits of RWIS, including their deployment, operation, and maintenance. The study was structured to guide public agencies in making informed decisions about RWIS investments, considering the rapid technological advancements and the need for timely repairs and replacements. The methodology outlined in the study involved several key steps. First, it required determining the RWIS deployment strategy, which included identifying necessary components, infrastructure, communications, and power sources. Next, the method involved collecting cost and lifespan data for individual RWIS components or the entire system. This data collection can be supplemented with information from other agencies or previous studies to fill the existing gaps.

The analysis outlined the necessity of quantifying both costs and benefits associated with RWIS. RWIS costs were categorized in two main types: “Capital Costs” and “Operations and Maintenance Cost”. Capital costs included expenses related to equipment and installation, while operations and maintenance costs encompassed ongoing operational expenses, maintenance, rehabilitation, communications, and potential replacement costs. Furthermore, the study provided a structured approach to perform LCCA for RWIS. It outlined steps such as estimating benefits and savings from RWIS (like winter maintenance savings, crash reduction, and mobility improvements) and calculating the expected life-cycle cost and Net Present Worth.

Additionally, the report included a simulated case study to demonstrate the application of the LCCA methodology in a practical scenario. This case study is using average values for adding one proposed new

RWIS site. As shown in tables below in Table 1, the annualized cost for the case study RWIS site was calculated to be $21,038,63. Next, each benefit category was quantified based on the expected impact of the RWIS, incorporating factors like reduced material usage, decreased labor costs, and lower accident rates. The monetary values assigned to these benefits were derived from established standards or calculated based on the specific context of the RWIS deployment. As a result, the total direct benefits excluding the social cost and mobility savings were quantified to be $75,312.00 per year. The total benefits were calculated to be as considerable as approximately $5 million dollars annually as shown in Table 2 with the combined savings from User Delay Cost (UDC) and social savings, which includes things such as medical costs, property damage, and legal fees.

Table 1. Annualized Cost for the Case Study RWIS Site. (Lee, Crow, Taavola, & Johnson, 2020)

RWIS cost elements	Average	Life span	Annualized capital cost
Individual components capital costs (installed)*			
• RPU	$6,053	10	$861.81
• Telecommunications equipment to transmit data (modem)	$840	10	$119.60
• Tower support structure	$12,424	20	$1,172.74
• Enclosure - cabinet	$8,472	20	$799.70
• IP surveillance camera (CCTV)	$4,742	7	$819.51
• Sensors			
○ Pavement condition sensor	$11,431	8	$1,768.63
○ Water level sensor	$870	4	$245.35
○ Air temperature/Relative humidity sensor	$1,590	9	$223.70
○ Wind direction and speed sensor	$2,274	9	$319.93
○ Precipitation sensor	$3,194	10	$454.75
○ Barometric pressure sensor	$571	10	$81.30
○ Visibility sensor	$7,195	8	$1,113.22
○ Presence of precipitation sensor	$3,854	8	$596.30
○ Traffic sensor	$6,540	9	$920.11
○ Ultrasonic snow depth sensor	$1,029	9	$144.77
○ Subsurface sensor advance	$6,539	8	$1,011.73
○ Surface temperature sensor advance	$7,242	8	$1,120.50
Operational costs			
• Telecommunication service (monthly per RWIS station)	$31		$372
• Subscription-based software service (yearly)	$95,333		$6,000
Maintenance costs (per RWIS station per year)	$2,893		$2,893
Total annualized cost			**$21,038.63**

Table 2. Case Study Benefit Summary. (Lee, Crow, Taavola, & Johnson, 2020)

Benefits	Savings
Direct benefits	
Patrol savings	$75,312.00
Material savings	$17,415.00
Indirect benefits	
Social savings	$1,442,328.00
Mobility - UDC savings	$3,394,666.67
Mobility - emissions savings	$73,282
Total benefits	$5,003,003.77

Lastly, the study combined the cost and benefits analysis to compute the Benefit-Cost ratios for the proposed RWIS site. These ratios were provided in Table 3, providing a quantitative measure of cost-effectiveness of the RWIS investment to help stakeholders understand the financial return in relation to the expanded resources.

Table 3. Case Study B/C Ratios. (Lee, Crow, Taavola, & Johnson, 2020)

Variable	B/C ratio
Direct benefits/annualized cost	4.41
Total benefits/annualized cost	237.8

The hypothetical cost-benefit analysis scenario demonstration in this report provides a good foundation and methodology for conducting the quantification of economic value analysis of winter maintenance operations.

2.3 Methods for Estimating the Benefits of Winter Maintenance Operations (Ye, Veneziano, Shi, & Fay, 2012)

Zhirui Ye, David Veneziano, Xianming Shi, and Laura Fay from the Western Transportation Institute established a method to quantify crash reductions, travel time savings, and fuel savings in monetary value to demonstrate the economic value of winter maintenance operations. Using 2001-06 winter season data from the Minnesota Department of Transportation (DOT) as a case study and following the method, the researchers estimated the quantified benefits of winter highway maintenance by the Minnesota DOT to be $227,003,713 per winter season. Figure 2 illustrates the overall framework for estimating statewide benefits. A summary of the methodology for estimating these benefits is listed below:

- Safety Benefit Estimation: A Negative Binomial model was developed to predict how many crashes were expected under different winter maintenance scenarios. Financial savings from crash reductions for the Minnesota winter season data from 2001-2006 were estimated at $167,683,800.
- Travel Time Savings Estimation: Differences in travel speeds over road under different winter maintenance scenarios were used to estimate travel time savings. Financial savings of $10,915,699 were estimated based on 828 route segments analyzed.
- Fuel Reduction Estimation: This estimation was based on the logic that vehicle fuel efficiency (in MPG) decreases under poorer road conditions. The differences between levels of fuel usage were used to estimate the financial savings of $41,057,063 for the 2005-06 winter season.

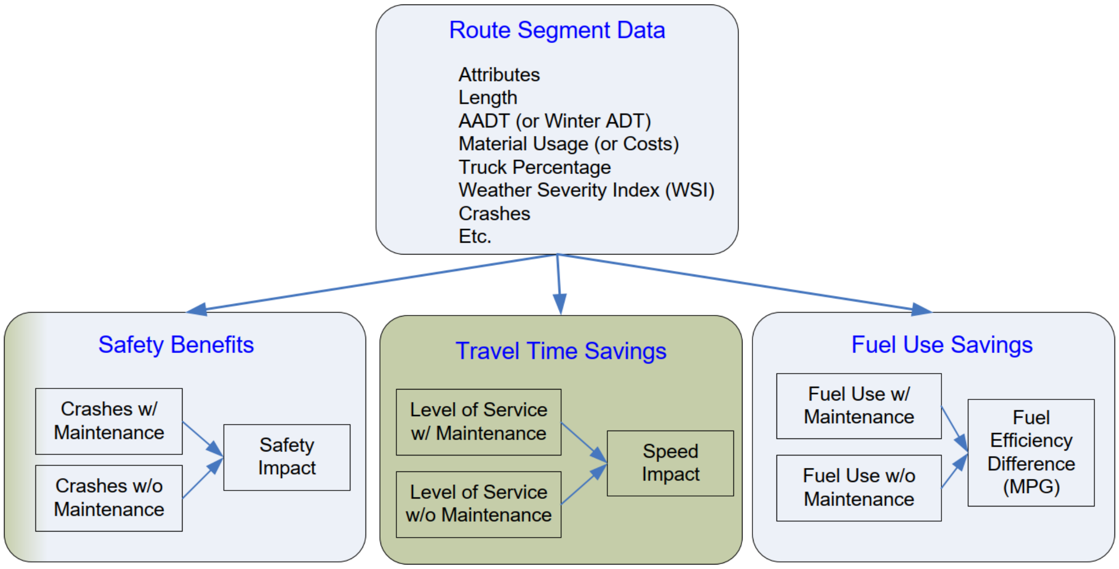

Figure 2. Overall Framework for Estimating Statewide Benefits. (Ye, Veneziano, Shi, & Fay, 2012)

Authors noted that the methodology used for the 2001-2006 Minnesota case study could be adopted by other states or local agencies, though the assumptions may need to be modified to reflect specific situations. The methodology was presented in a step-by-step manner to facilitate potential conversion to a software or web-based tool to ease the burden of estimating winter maintenance benefits and also potentially establish a consistent manner across states in which benefits can be estimated.

This report can help the research team determine potential formulas to include in an estimation tool for quantifying the economic benefits of winter maintenance operations.

2.4 Annual Survey of State Winter Maintenance Data (Clear Roads, 2024)

The Clear Roads pooled fund group has supported a multi-year project to systematically gather, compile and analyze a range of data from state DOTs related to their winter operations, including cost data for winter maintenance operations. The site is available at: https://www.clearroads.org/winter-maintenance-survey/.

State DOTs within the program have provided cost information on labor, equipment, and materials for each winter season dating back to July 1, 2014. Clear Roads plans to continue conducting this survey in the future, compiling multiple seasons' worth of data. Survey results for upcoming winters will be added to this page once each year's data analysis is completed. The most current season of data available is for the winter of 2023-2024 season. Figure 3 presents a view of the Excel spreadsheet that can be downloaded from the website. Data from different seasons can be viewed on the map in different colors as shown.

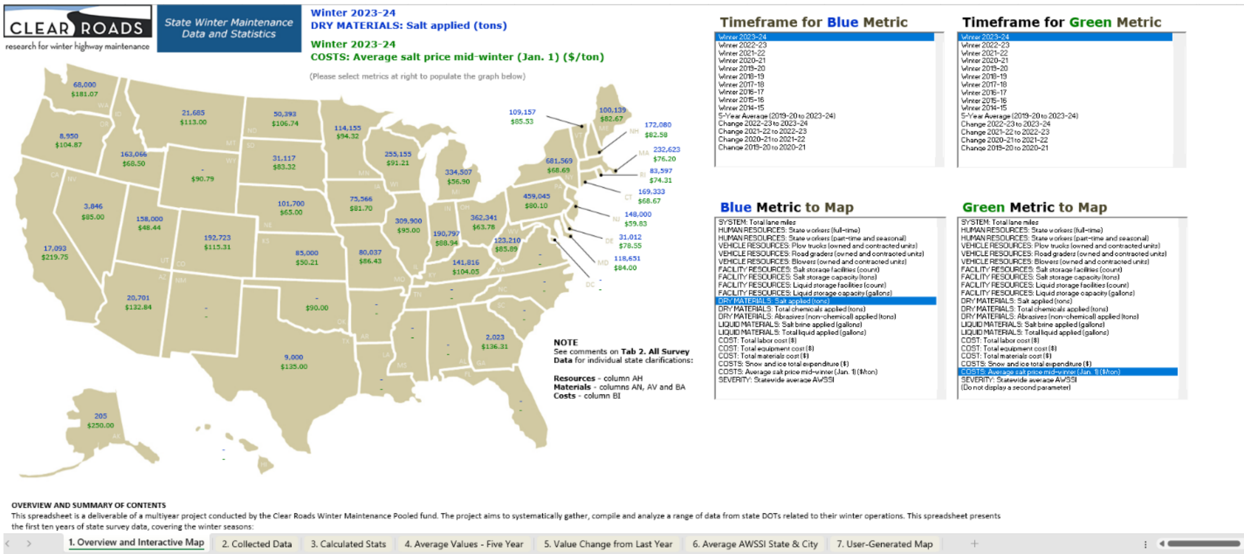

Figure 3. Summary View on State Winter Maintenance Data and Statistics. (Clear Roads, 2024)

This website can help the research team as a resource for average costs over prior winter maintenance seasons in looking at quantifying the economic value of winter maintenance operations.

2.5 Economic Benefits of Winter Road Operations (Veneziano, Shi, & Fay, 2018)

This study focused on stressing out the necessity of conducting a thorough benefit-cost analysis to comprehend the financial value of the benefits relative to the costs. Winter maintenance benefits were defined into two categories: First, quantifiable benefits were estimated, which include reduction in accident rates and associated costs, improved mobility and travel time, savings on vehicle operating costs due to better road conditions, and environmental benefits through reduced salt usage and decreased emissions. Second, qualitative benefits were estimated, which are not as easily translated into numerical terms and include improvements such as enhanced safety perception among the public, increased reliability of road networks during winter months, and improved quality of life due to more efficient winter travel.

The study also investigated different methodologies for estimating winter maintenance benefits. For example, authors explained how "Stochastic Simulation" is employed to quantify reduced delay times by providing a case study in which normal variates are used to represent vehicle speeds under various levels of service. The use of "Regression Tree Models" was also pointed out to provide insights into how different factors like service level and storm intensity may affect maintenance requirements and costs. "Economic Model" was another method of analysis that was presented in the study. The model calculates benefits by comparing costs across different levels of service, providing a comprehensive understanding of how different maintenance strategies impact overall costs and benefits.

Additionally, the study referenced reports and data showing the direct costs of winter maintenance, highlighting the significant portion of state highway agencies' budgets dedicated to these activities (around 20% on average, equating to direct costs of $2.3 billion and indirect costs of $5 billion annually). Furthermore, it discussed the societal and economic impacts of winter maintenance, pointing to studies that show the substantial benefits in terms of reduced accidents, improved mobility, and economic productivity. It noted specific findings, such as a study in Washington state that found a 12-fold increase in accidents in January compared to July, and another study indicating a 1300% increase in accidents during severe winter weather in Iowa.

Overall, this study can help the research team by providing a variety of cost-benefit analyses and models, in addition to real-world implication of these models to help quantify the economic value of winter maintenance operations.

2.6 Utilization of AVL/GPS Technology: Case Studies (Lee & Nelson, 2018)

This report described the use of automated vehicle location (AVL) and global positioning systems (GPS) by transportation agencies to monitor vehicle locations and operational status of equipment for winter road maintenance operations. The AVL/GPS system is to provide automatic vehicle location tracking for dispatchers and maintenance supervisors. In addition, AVL/GPS systems can provide vehicle maintenance technicians with valuable information about vehicle diagnosis. AVL/GPS systems can also be integrated with existing vehicle components used for snowplow operations such as spreader controllers and plow blades to provide reports to maintenance supervisors on material applied and plow usage by snowplow operators.

Six detailed case studies with state Departments of Transportation (DOTs) (Utah, Washington State, Michigan, Wisconsin, Nebraska, and Colorado) were conducted for this study. These case studies involved in-depth conversations with DOT staff involved in AVL/GPS system planning, procurement, implementation, management, and operations. The key results and lessons learned from the case studies were outlined in this final report. The case studies can be used as a guide to help state DOTs implement and use different AVL/GPS applications based on their unique geographic characteristics, organizational settings, winter maintenance requirements, and technical capabilities. Organizations can leverage the lessons learned from the case studies for launching, accelerating, replacing, and upgrading AVL/GPS for their winter maintenance operations.

One of the main benefits Michigan DOT (MDOT) has gained with the AVL/GPS system is the ability to track snowplow vehicles' speed and location. In this way, MDOT can review how effective their roadway maintenance activities are and identify segments/areas that need improvement for future operations. MDOT also uses the system data to determine what speed is optimal for spreading salt, brine, sand and other de-icing chemicals to reduce plow cycle times.

Wisconsin DOT had the advantage of having an AVL/GPS system when routes were reconfigured. This allowed Wisconsin DOT to increase the total lane-miles each truck was responsible for maintaining based on an optimization project. As a result, they were able to save about $85,000 per route annually. Brown County saved $1.2M in 2018 in equipment costs, as route optimization effectively absorbed 165 new lane miles and eliminated the need to expand the fleet. Dane County was able to remove four trucks from its fleet after a second round of optimization. Material usage and fuel consumption were reduced with the integration of the AVL/GPS system.

This study can help the research team determine how the GPS/AVL systems can reduce winter maintenance operations costs through an increase in the efficiency of material applications.

2.7 Benefit-Cost Assessment of Automatic Vehicle Location (AVL) in Highway Maintenance (Meyers E. &., 2003)

Eric Meyer and Ishtiaque Ahmed from the University of Kansas reviewed the benefit-cost of AVL systems implemented for highway maintenance at the request of Kansas Department of Transportation (KDOT) in 2000. Winter maintenance operations were a part of this study, but the authors included other highway maintenance operations within the analysis.

This study started with a survey of highway maintenance AVL users, which provided base parameters for the benefit-cost analysis. Two risk perspectives were reviewed to provide a lower limit to very high limit of results. The low risk used all conservative assumptions, representing the minimum benefits limit; while the high risk used fewer conservative assumptions to represent the upper benefit limits one may realize. Overall, the benefits for any given user should fall with the range developed in this analysis.

The data gathered from the survey was used to determine the benefit-cost ratio. The cost assessment reviewed investment costs and operations and maintenance costs. Some of the benefits not related to winter maintenance activities were observed, including:

- More timely responses to emergencies;
- Reduced legal costs from tort claims allegedly involving KDOT maintenance vehicles;
- Reduced time with routine paperwork;
- Enhanced locational accuracy of various inventories and map segments;
- Near real-time traveling information;
- Improved efficiency and effectiveness of roadside maintenance; and
- Reduced fleet maintenance cost due to improved fleet management.

A 20-year life cycle was reviewed in this analysis. The overall benefit-cost estimates from this research are:

- Savings in paperwork – moderate estimate of 15% time savings, resulting in $67,908 to $101,862 per year;
- Savings from more efficient fleet management – between 5-20% savings resulting in $398,864 to $1,595,455 in savings. For painting trucks, the savings would be between $17,336 to $69,344.

This report also reviewed savings from reduction of crashes; however, it was not directly related to winter maintenance operations. This report can help the research team estimate savings from the use of GPS/AVL systems in terms of paperwork and in fleet management.

2.8 Economic Impact of Winter Road Maintenance on Road Users (Hanbali, 1994)

Rashad Hanbali developed a methodology to evaluate the effectiveness of winter maintenance operations through comparing known financial benefits and costs gathered from road maintenance agencies. The overall conclusion from the report was that winter maintenance operations resulted in an average direct savings to road users of 45 and 20 cents per vehicle kilometer of travel on two-lane highways and multilane freeways, respectively.

Direct costs that can be measured were found to be labor, equipment, materials, and administration, while direct benefits to winter maintenance operations include vehicle operating cost reduction, travel time reduction, and reduction of vehicle crashes. This study referenced prior research that indicated travel speed reductions during winter weather events were 25 percent and 15 percent of the normal travel speeds on two-lane highways and multilane freeways, respectively. Formulas were presented for calculating vehicle operating cost reductions and travel time cost impacts within the overall methodology.

Several different conclusions were also presented regarding the value of winter road maintenance operations. In terms of safety, it was concluded that winter maintenance operations reduce traffic accident costs by 88 percent and 85 percent for two-lane highways and multilane freeways, respectively. In addition, the average traffic accident severity was reduced by 10 percent and 30 percent for two-lane highways and multilane freeways, respectively.

This report can help the research team determine potential formulas to include in an estimation tool for quantifying the economic benefits of winter maintenance operations.

2.9 Evaluating Public Transit Benefits and Costs – Best Practices Guidebook (Litman, 2024)

Public transit provides various mobility services to the general public, including buses, trains, ferries, shared taxi and their variations. It can play important and unique roles in an efficient and equitable transportation system by providing affordable basic mobility for non-drivers, resource-efficient travel on busy corridors, and a catalyst for more efficient development. It can have diverse impacts (benefits and costs), including many that are indirect and external. Some result from the existence of the service, others from transit use, some from reduced automobile travel, and others from transit's ability to affect land use development patterns, as summarized in Table 4. Not all transit services have all these impacts, but most have several.

Table 4. Public Transport Benefits and Cost. (Litman, 2024)

	Improved Transit Service	Increased Transit Travel	Reduced Automobile Travel	Transit-Oriented Development
Metric	Service Quality (speed, comfort, safety, etc.)	Transit Ridership (passenger-miles or mode share)	Mode Shifts or Automobile Travel Reductions	Portion of Development With TOD Design Features
Potential Benefits	• Improved convenience and comfort for existing users. • Equity benefits (since existing users tend to be disadvantaged). • Option value (the value of having an option for possible future use). • Improved operating efficiency (if service speed increases). • Improved security (reduced crime risk)	• Mobility benefits to new users. • Increased fare revenue. • Increased public fitness and health (by increasing walking and bicycling trips). • Increased security as more non-criminals ride transit and wait at stops and stations.	• Reduced traffic congestion. • Road and parking facility cost savings. • Consumer savings. • Reduced chauffeuring burdens. • Increased traffic safety. • Energy conservation. • Air and noise pollution reductions.	• Additional vehicle travel reductions ("leverage effects"). • Improved accessibility, particularly for non-drivers. • Community cohesion and reduced crime risk. • More efficient development (reduced infrastructure costs). • Farmland and habitat preservation.
Potential Costs	• Higher capital and operating costs and subsidies. • Land and road space. • Traffic congestion and accident risk imposed by transit vehicles.	• Transit vehicle crowding.	• Reduced automobile business activity.	• Various problems associated with more compact development.

Public transport can have various types of benefits and costs, many of which tend to be overlooked or undervalued in conventional transportation economic evaluation.

Conventional transport economic evaluation tends to overlook and undervalue many transit benefits such as basic mobility, social equity goals, vehicle ownership and parking cost savings, or more efficient land development. Accessibility-based analysis, which measures the number of destinations that people can reach within a given time period, tends to increase the value of high-quality public transit.

Public transit can also have significant costs, including facility and operating expenses, and various external costs. Many of these costs are fixed so transit services tend to have low marginal costs and experience scale economies (unit costs decline with increased use). These factors should be considered when evaluating public transit benefits and costs:

- Public transit can provide various types of impacts. A comprehensive evaluation should consider all significant benefits and costs.
- Many transit services (those that operate at times and places with low demand) exist mainly to provide basic mobility for non-drivers. Although relatively costly per trip, they are often cheaper than alternatives such as taxis and chauffeuring, or inadequate mobility for non-drivers.
- High-quality (relatively fast, convenient, comfortable, and integrated) transit can attract discretionary travelers who would otherwise drive, which reduces traffic problems including congestion, parking costs, accidents, and pollution emissions.
- High-quality transit can stimulate transit-oriented development, in compact, multi-modal neighborhoods where residents tend to own fewer vehicles, drive less, and rely more on

alternative modes than in more automobile-oriented communities. This can leverage additional travel reductions and benefits (besides just the travel shifted to transit).

- Transit improvements tend to provide greater estimated benefits if evaluated using accessibility-based indicators, such as the number of jobs or services that can be reached, rather than mobility-based indicators such as travel time savings.
- Traffic congestion tends to maintain equilibrium: it increases until delays discourage additional peak-period vehicle trips. High-quality, grade-separated transit can reduce congestion costs by reducing the point of equilibrium, offering travelers an alternative to driving, and supporting compact development which reduces travel distances.
- Highway expansion tends to induce additional vehicle travel which increases external costs such as downstream congestion, parking demand, traffic risk, and pollution emissions. These impacts should be considered when comparing roadway expansions with transit improvements.
- Transit travel time unit costs vary significantly depending on travel conditions and user preferences. Many travelers prefer high-quality transit even if it takes longer than driving because they can work or rest.
- These impacts and benefits tend to increase if transit improvements are implemented with support strategies such as walking and cycling improvements, more compact development, transportation demand management programs, and efficient road and parking pricing.
- Since active transport (walking and cycling) and public transit are complements, transit travel tends to increase public fitness and health.
- Public transit services have three features that justify public support and underpricing: they help achieve social equity objectives, they experience scale economies, and they can reduce various external costs including traffic congestion, accident risk, and pollution emissions.
- Current demographic and economic trends (aging population, rising fuel prices, urbanization, changing consumer preferences, increasing health and environmental concerns) are increasing demand for transit and transit-oriented development, and therefore their benefits.

This study can help show how to quantify indirect variables within transportation-related operations.

2.10 Additional Studies

- Sustainable Winter Road Operations (Shi & Fu, 2018) is a collection of several papers on topics related to the impacts of winter weather on the roadway transportation system. One of the papers presented in the collection documents is a framework for a life-cycle sustainability assessment (LCSA) that accounts for multiple factors. This included a summary listing of direct costs that is similar to direct costs referenced in other literature in this review, as well as indirect costs and social and environmental impacts that are more difficult to quantify (Cui, Xie, & Shi, 2018).

- The Development of a Surface Transportation Impact Factor for Winter Severity Indices (Thomas, Bennett, Hassan, Adu-Gyamfi, & Edara, 2022) report aims to develop a comprehensive Winter Severity Index (WSI) that not only considers the meteorological aspects of winter but also incorporates the impacts on road safety, mobility, and maintenance costs. This new WSI tool is designed to provide a broader understanding of the impacts of winter weather events, enabling better comparison of winter weather management and performance across Missouri's diverse regions.

Missouri experiences a wide range of winter weather conditions due to its geographic location, which influences traffic patterns, population distribution, and road maintenance needs. The study emphasized the necessity of capturing the impacts of winter weather events more comprehensively. The WSI developed in this research includes factors like crash costs, delay costs, and maintenance costs associated with winter weather events. Additionally, the monetary value of using WSI was estimated by quantifying the impact of winter weather events in terms of the three main cost variables mentioned above. Below is how each variable was estimated:

1. **Maintenance Costs**: These costs are the tangible expenses that MoDOT incurs to respond to and manage winter weather events. The study obtained maintenance cost data from multiple MoDOT maintenance facilities for each winter event. These costs included expenses such as equipment use, labor, materials like salt and sand, and other operational costs related to snow and ice removal.

2. **Crash Costs**: The study estimated the safety impact of winter events by examining the change in the number of crashes during winter weather events compared to a baseline (clear weather days). The change in crash numbers was then monetized using comprehensive crash unit costs provided by the Federal Highway Administration (FHWA) or derived from other relevant sources. The crash costs included economic impacts, quality-adjusted life years (QALY), and other comprehensive costs associated with different severities of crashes (fatal, disabling injury, evident injury, possible injury, and property damage only).

3. **Delay Costs**: The mobility impact was estimated by calculating the total delay caused by winter weather events and monetizing this delay using the value of time. The study used baseline travel times for road segments and compared these with travel times during winter events to calculate the delay. The total delay was then multiplied by the traffic volume and the value of time (based on USDOT guidance or other relevant sources) to estimate the delay costs.

By integrating these costs into the WSI, the study provided a monetary valuation of winter weather impacts on the transportation network. This allowed MoDOT to understand the broader economic implications of winter weather and the benefits of effective winter weather management strategies.

Several studies have looked into the benefit-to-cost ratio (BCR) of the RWIS system considering its safety benefits; however, certain biases are associated with the adopted techniques. This study (Davesh, Wu, & Kwon, 2021) addresses this issue by implementing a before-and-after study using the Empirical Bayes approach for a case study of two RWIS stations in Iowa, U.S. In addition, this study develops safety performance functions and yearly calibration factors using large scale spatial data and a set of reference locations to quantify the sole effect of an RWIS station. To this end, a detailed economic analysis is conducted to quantify the cost-effectiveness of RWIS. Results show that after the implementation of the two RWIS stations, 41.91% and 26.15% of inclement weather collisions have been reduced. The BCR for these stations is 39.97 and 9.83, respectively, indicating RWIS is an economically viable countermeasure and hence the transportation agencies can be more confident while allocating funds for its implementation.

Quantifying the Impact that New Capital Projects Will Have on Roadway Snow and Ice Control Operations (Sullivan, Dowds, Novak, Scott, & Ragsdale, 2017) report focuses on developing an automated method to quantify the expected impact of new capital projects on roadway snow and ice control (RSIC) operations. The research aimed at two main types of capital projects: additions of new roadway capacity and new roadway configurations. The methodological approach involved quantifying the impact of these projects on total vehicle-hours of travel (VHTs) and equipment needs for the RSIC fleet. The methodology included extending an existing RSIC allocation and routing tool into an integrated RSIC model that could plan efficient routes for RSIC fleets while minimizing total operating hours and fuel usage.

The findings revealed that new suburban roadways significantly increase the RSIC burden, requiring additional vehicle-minutes of travel and potentially necessitating additional fleet trucks per mile of new roadway. The research created a Microsoft Excel-based decision support tool to provide quick estimates of the monetary impact of various major highway project types on RSIC operations. The "User Data" sheet in the tool contains economic costs and units for various resources such as fuel, salt, abrasives, and equipment types, including trucks and sidewalk plows. It also includes operational frequency and rates, like the average number of snowplow dispatch events per year and average salt usage by project type. The tool also includes a "Decision Support Tool" that allows users to input project types and region types to calculate additional annual costs associated with new or modified roadways concerning winter maintenance, in addition to calculating additional costs for fuel, salt, effort, equipment and service time, summing up to provide an annual additional cost. Lastly, the case study results sheet presents the burden increase for different types of projects under low salt and high salt storm conditions. For instance, adding a new roadway of one lane in either direction in a suburban area results in an increase of 168 vehicle-minute per pass for a low-salt storm and 125 for a high-salt storm.

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3. Survey of Needs, Gaps, and Practices

This section provides a summary of the responses received from the survey by public agencies for this project. The survey was designed to gather basic, high-level information regarding how each agency would benefit from an economic tool that would measure the value of winter maintenance operations.

3.1 Introduction

This task focused on developing and conducting an online survey to gather information from Clear Roads member states and non-Clear Roads states, and municipalities. The purpose of the survey was to gather information on how states track the cost of winter maintenance operations. The survey helped gain an understanding of which agencies or organizations track costs, which variables are the most common to be tracked and what capabilities would be useful for the tool. The survey also collected information on agencies' current procedures and most common variables. The surveys were distributed through the following methods:

- Clear Roads member state DOTs, and
- International agencies through the Norwegian Public Roads Administration and other Nordic countries through the Nordic Road Association (NVF).

A total of 28 surveys were received from 25 agencies and have been summarized in this section. Table 5 presents a listing of the agencies that responded to the survey.

Table 5. Transportation Agency Survey Respondents

Survey Respondents			
Texas DOT	Matthew Heinze	Kiewit Meridiam Partners	Phillip Anderle
Minnesota DOT	Tom Peters	City of Columbus, Dept of Public Service	Scott Lucas
Ministere des Transports et de la Mobilité Durable du Quebec	Pierre-Guy Brassard	Directorate of Roads and Highways	Ondřej Eichler

Survey Respondents			
North Dakota DOT	Barry Kinnischtzke	Rijkswaterstaat Netherlands	Rini Donker
North Dakota DOT	Brad Darr	Ville de Pointe-Claire	Erik Rolland
Wyoming DOT	Chris Romo	Kansas DOT	Robert Allen Fuller
Montana DOT	Jason Allen	Norwegian Public Roads Administration	Bård Nonstad
Montana DOT	Doug McBroom	Vermont Agency of Transportation	Todd C Law
Town of Middlebury, Vermont	Emmalee Cherington	New Hampshire DOT	David Gray
Kansas DOT	Clay Adams	Illinois DOT	Keith Donovan
Kansas DOT	Clay Adams	Massachusetts DOT	Mark Goldstein
Utah DOT	Jessica Andrews	Iowa DOT	Craig Bargfrede
City of Farmington Hills, Minnesota	Bryan Pickworth	City of Bozeman, Montana	John Van Delinder
Alaska DOT&PF	Daniel Schacher	City of Columbus, Ohio	Scott Tourville

3.2 Summary of Survey Responses

The survey for transportation agencies consisted of 27 questions.

Question 1. Does your agency have a mission statement and/or legislative language governing your agency's roadway snow and ice mitigation program.

Yes	No
16	12

Question 2. Does your agency have a standard method for determining the costs of winter operations?

Yes	No
23	5

Question 3. Does your agency have a standard method for determining the benefits or Return On Investment (ROI) of winter operations?

Yes	No
23	5

Question 4. What challenges do you experience when developing your budget for snow and ice operations? (select all that apply)

Answer Choices	Responses
Quality of Data or Lack of Data	8
Time / staffing and/or financial resources	7
Hard to predict needs within variable weather patterns	25
Increase cost of material / labor (inflation)	18
Other	8

Question 5. What challenges do you have in determining your benefits for snow and ice operations? (select all that apply)

Answer Choices	Responses
Not Applicable - your agency does not calculate benefits	7
Quality of Data or Lack of Data	13
Time / staffing and/or financial resources	9
Hard to predict/capture impact to society	17
Other (please specify)	6

Question 6. Select which of the following data elements you currently include or would like to include in your operational cost calculations. (select all that apply)

Answer Choices	Responses
Material Cost	25
Fuel	23
Full-Time Labor Costs	24
Plows (Including Blades)	23
Trucks, Motor Graders, Loaders	23
Seasonal Labor Costs	21

Answer Choices	Responses
Equipment Maintenance Costs	18
Contractor Labor Costs	18
Salt Spreaders	14
Roadside investments (snow fence, living snow fence, etc.)	14
Facilities and material storage cost	12
AVL Capital Cost	12
AVL Subscription Costs	11
Third Party Data (Weather, Traffic, Etc.)	12
Planning and administrative cost	11
Training Costs	12
RWIS Capital Cost	9
MDSS	9
Mobility Delay Cost (User Delay Cost; Passenger Vehicles and Commercial)	9
Snow Hauling and Disposal	8
Public outreach (including public facing websites)	6
Route-optimization tools	5
Other (please specify)	4

Question 7. The cost variables you selected in question 6 are below. Please rank the top 5 most impactful to your operations.

Answer Choices	Average Score
Full-Time Labor Costs	4.27
Material Cost	3.66
Trucks, Motor Graders, Loaders	2.41
Equipment Maintenance Costs	1.83
Plows (Including Blades)	1.71
Salt Spreaders	1.45
Facilities and material storage cost	1.32
Fuel	1.58
Snow Hauling and Disposal	0.00
Route-optimization tools	1.22

Answer Choices	Average Score
Seasonal Labor Costs	1.48
Mobility Delay Cost (User Delay Cost; Passenger Vehicles and Commercial)	1.35
AVL Capital Cost	1.03
Contractor Labor Costs	1.48
MDSS	1.03
RWIS Capital Cost	0.00
AVL Subscription Costs	1.03
[Insert text from Other]	1.13
Planning and administrative cost	0.00
Third Party Data (Weather, Traffic, Etc.)	1.16
Training Costs	0.00
Public outreach (including public facing websites)	1.03
Roadside investments (snow fence, living snow fence, etc.)	1.06

Question 8. From the cost variables you selected in question 7, which variable takes up the largest portion of your budget?

Answer Choices	Responses
Material Cost	3
Salt Spreaders	1
Facilities and material storage cost	0
Snow Hauling and Disposal	0
Plows (Including Blades)	1
Trucks, Motor Graders, Loaders	0
AVL Capital Cost	0
RWIS Capital Cost	0
MDSS	0
Route-optimization tools	0
Equipment Maintenance Costs	2
AVL Subscription Costs	0
Fuel	0
Full-Time Labor Costs	16

Answer Choices	Responses
Seasonal Labor Costs	0
Contractor Labor Costs	1
Training Costs	0
Mobility Delay Cost (User Delay Cost; Passenger Vehicles and Commercial)	1
Third Party Data (Weather, Traffic, Etc.)	0
Public outreach (including public facing websites)	0
Planning and administrative cost	0
Roadside investments (snow fence, living snow fence, etc.)	0
[Insert text from Other]	1
Additional comments / explanation of your choice	0

Question 9. From the list of cost variables in question 6, what cost components are hardest to estimate and/or most variable? (select all that apply)

Answer Choices	Responses
Material Cost	11
Fuel	6
Equipment Maintenance Costs	5
Full-Time Labor Costs	5
Contractor Labor Costs	4
Mobility Delay Cost (User Delay Cost; Passenger Vehicles and Commercial)	4
Seasonal Labor Costs	2
Roadside investments (snow fence, living snow fence, etc.)	2
Facilities and material storage cost	1
Snow Hauling and Disposal	1
Trucks, Motor Graders, Loaders	1
AVL Capital Cost	1
Route-optimization tools	1
Public outreach (including public facing websites)	1
[Insert text from Other]	1

Answer Choices	Responses
Salt Spreaders	0
Plows (Including Blades)	0
RWIS Capital Cost	0
MDSS	0
AVL Subscription Costs	0
Training Costs	0
Third Party Data (Weather, Traffic, Etc.)	0
Planning and administrative cost	0
Additional comments / explanation of your choices	7

Question 10. Select which of the following data elements you currently include or would like to include in your calculation of benefit or ROI impact to winter operations: (select all that apply)

Answer Choices	Responses
Safety – reduction of weather related crashes	19
Congestion/travel time	14
Reliability of travel time	13
Freight movement of goods	9
Other (please specify)	7

Question 11. If you selected any of the benefit data elements in question 10, can you briefly explain how you quantify the benefits

Agency	Freight movement of goods	Safety – reduction of weather related crashes	Congestion/travel time	Reliability of travel time	Other (please specify)
Texas Department Transportation	Truck not having to stop or slow down due to conditions.	These are currently tracked via a TC system			
Minnesota Department of Transportation					Follow us dot fhwa methods for safety and travel time.
Ministere des Transports et de la Mobilité Durable du Québec		Crash data monitoring			Road salt reduction / spreading rate per km

Agency	Freight movement of goods	Safety – reduction of weather related crashes	Congestion/travel time	Reliability of travel time	Other (please specify)
NDDOT			Performance Measures	Performance Measures	
WYDOT	do not currently	do not currently	do not currently	do not currently	
Montana	Would get us a cost/delay to talk to decision makers	We track this but not well.	For winter related events		
NDDOT					
Town of Middlebury					
Kansas DOT					
UDOT	would like to include in future so business impact could be measured	already included, based off of accident cost	already included, based off of user cost	would like to include, based off of user cost	
Directorate of Roads and Highways					
Rijkswaterstaat Netherlands					
Ville de Pointe-Claire		number of crashes per time period, vary by gravity of incident	average travel time on main arteries		
Kansas DOT	Not quantified.	Crashes		Time to normal speeds.	
Norwegian Public Roads Administration	We do not include them today, but we wish to do so				
Vermont Agency of Transportation					
NHDOT				Can we provide the public with means of traveling at the speeds we post on our message boards	
IL DOT		we currently dont but may like to.			

Agency	Freight movement of goods	Safety – reduction of weather related crashes	Congestion/travel time	Reliability of travel time	Other (please specify)
Massachusetts Dept. of Transportation	We have never calculated any of these benefits as an agency (to my knowledge). This is where we need much help from this project.				
City of Farmington Hills, MI		Work in progress, need ideas or solutions	Talk with county to see if there camera system can the into an AI system possibly	Depending on timing of event	
Iowa DOT					This is something we have explored but not put into practice yet.
Alaska DOT&PF		Reductions in fatal and sever crashes during winter weather			
Montana Department of Transportation					
Kansas DOT		Crash Records	dont know	dont know	
City of Bozeman MT			We don't quantify but would like to.		
Kiewit Meridiam Partners		Tracking of weather related accidents			
City of Columbus, Ohio		dont use, but would compare crash numbers during event compared to numbers when roads are normal	dont use, but would compare travel times during event and outside event	dont use, not sure how would calculate	
City of Columbus, Depart. of Public Service					We are trying to regain an acceptable amount of friction on a roadway in a reasonal time for the lowest cost possible.

Question 12. Have you tested new technologies or innovative best practices to reduce winter operations costs or increase benefits? (Examples: targeted pretreating/prewetting, or ground speed controls for material spreaders)

Yes	No
24	2

Question 13. Does your agency set aside a portion of the annual budget for investigating new technologies?

Yes	No
10	16

Question 14. Please describe how your agency is determined to fund the testing/implementing of new technologies. If not applicable, please type N/A

Agency	Open-Ended Response
Texas Department Transportation	The Research Technology Innovation division handles all of the up-and-coming tech. Districts and other divisions can also do research, however it is somewhat limited and typically in partnership with RTI.
Minnesota Department of Transportation	Established research program that looks for problems/needs and run it through a selection process; ad hoc, peer to peer, discuss and decide to seek out funding from senior leadership through established Resource Investment Council.
Ministere des Transports et de la Mobilité Durable du Québec	ad hoc decisions
NDDOT	N/A
WYDOT	case by case
Montana	N/A
NDDOT	
Town of Middlebury	

Agency	Open-Ended Response
Kansas DOT	
UDOT	Trial runs, research projects, experiments
Directorate of Roads and Highways	N/A
Rijkswaterstaat Netherlands	
Ville de Pointe-Claire	N/A
Kansas DOT	N/A
Norwegian Public Roads Administration	N/A
Vermont Agency of Transportation	We use Clear Roads research for new technologies and have used research moneys from FHWA in the past for things like route optimization.
NHDOT	
IL DOT	
Massachusetts Dept. of Transportation	Research topics are proposed by would-be Champions and those who oversee the SPR (State Planning and Research - I think) grants choose the proposals they deem worthy.
City of Farmington Hills, MI	Ask management and try to stay progressive with trialing resource's
Iowa DOT	We have a process which starts with our research committee specifically looking at winter operations projects. We use operational funding to cover these expenses.
Alaska DOT&PF	Project specific.
Montana Department of Transportation	Not sure
Kansas DOT	N/A
City of Bozeman MT	We budget it.
Kiewit Meridiam Partners	N/A
City of Columbus, Ohio	If I can justify the expense and show there may be value, I usually get the money.
City of Columbus, Depart. of Public Service	N/A

Question 15. Does your agency have a standard annual escalation/inflation rate to winter operations costs? (considering contracted equipment rates)

Yes	**No**
4	21

Question 16. If budget wasn't an issue, what aspect of your operations would you invest additional money?

Agency	Open-Ended Response
Texas Department Transportation	Labor, facilities, and equipment
Minnesota Department of Transportation	Liquid expansion, storage capacity, equipment and staffing,
Ministere des Transports et de la Mobilité Durable du Québec	Training / knowledge transfer
NDDOT	Equipment and facilities to provide more liquid capabilities.
WYDOT	management says asphalt patching or more maintenance overlays
Montana	Winter Materials, Facilities and Equipment
NDDOT	The NDDOT needs to invest in more brine making and storage.
Town of Middlebury	
Kansas DOT	Training Retention of experienced staff
UDOT	More trucks, more drivers, more mechanics
Directorate of Roads and Highways	better reporting and planning software
Rijkswaterstaat Netherlands	
Ville de Pointe-Claire	new vehicles and equipment
Kansas DOT	Equipment
Norwegian Public Roads Administration	Developing new equipment, testing new methods and material. RWIS and follow up system.
Vermont Agency of Transportation	purchase of tow plows, as hiring full time staff is still an issue in some areas and temporary/seasonal employees are not filling the void, nor are our efforts to hire contractors to operate our equipment for winter operations.

Agency	Open-Ended Response
NHDOT	More liquid application tools and more RWIS stations
IL DOT	Full Time/Temporary Employees.
Massachusetts Dept. of Transportation	Mobile RWIS on all salt spreaders. I believe the potential salt savings justify the cost.
City of Farmington Hills, MI	Training and trying new technologies
Iowa DOT	Increase full-time staffing and new equipment.
Alaska DOT&PF	Compensation for employees. Safety Gear. Upgrade to buildings that support our operations.
Montana Department of Transportation	Snow plow trucks
Kansas DOT	Labor Salary dollars
City of Bozeman MT	Route optimization and training new operators.
Kiewit Meridiam Partners	New plow bit technology and equipment to utilize liquid de-icers more.
City of Columbus, Ohio	staffing and trucks
City of Columbus, Depart. of Public Service	Technology, equipment, and people

Question 17. What are some data gaps that currently exist for your agency when conducting a realistic benefit-cost analysis or ROI?

Agency	Open-Ended Response
Texas Department Transportation	
Minnesota Department of Transportation	Determining how much of the system wide performance is due to snow and ice operations, Travel time
Ministere des Transports et de la Mobilité Durable du Québec	Quality of material composition data Hours of operation
NDDOT	AVL would be helpful in providing much of the data needed for the costs. It is very difficult to determine a benefit value that is realized by the travelling public.
WYDOT	unsure
Montana	Delay time, safety
NDDOT	N/A
Town of Middlebury	

Agency	Open-Ended Response
Kansas DOT	
UDOT	Assuming a consistent salt distribution rate instead of having a more precise measurement.
Directorate of Roads and Highways	
Rijkswaterstaat Netherlands	
Ville de Pointe-Claire	no service baseline to measure against
Kansas DOT	Ways of measuring benefits.
Norwegian Public Roads Administration	A good road condition model for different roads and climate, and information on the accident rate under different winter condition.
Vermont Agency of Transportation	personnel to analyze data and determine what analysis should be conducted.
NHDOT	Lack of ability to capture a way status of road surface conditions around the State due to lack of RWIS stations on all areas of the State
IL DOT	N/A
Massachusetts Dept. of Transportation	We capture most costs well, but not the benefits. The value of this research effort is it will allow us to estimate a reasonable agency winter operations budget, and then hopefully quantify the benefits, which should substantially exceed costs.
City of Farmington Hills, MI	Need to tie in our AVL with operations and management software
Iowa DOT	Having access to all of the data points that we would need to conduct a realistic ROI.
Alaska DOT&PF	Accurate costing
Montana Department of Transportation	
Kansas DOT	
City of Bozeman MT	Variables that affect plow route completion time.
Kiewit Meridiam Partners	Accident reports are latent.
City of Columbus, Ohio	we don’t really have any data to use beyond what people remember and some general stats-cost of OT, inches of snow, and amount of material used.
City of Columbus, Depart. of Public Service	The ability to easily pull cost data from our asset management system.

Question 18. What would be your agency's desired outputs/functions from a benefit-cost tool for quantifying the economic value? (Consider these outputs in terms of annualized cost or overall capital cost of snow and ice operations)

Agency	Open-Ended Response
Texas Department Transportation	
Minnesota Department of Transportation	Being able to test different operation scenarios to determine best practices. Blowing snow cost benefit tool is an example of targeted evaluation method: https://snowcontroltools.umn.edu/cost-benefit-tool
Ministere des Transports et de la Mobilité Durable du Québec	To be able to compare many options to choose the best / cheaper. Decision support function
NDDOT	
WYDOT	unsure
Montana	the benefits of Snow and Ice removal compared to the costs
NDDOT	
Town of Middlebury	
Kansas DOT	
UDOT	In addition to what we already have, we would like to have the impact of freight travel and how that affects businesses
Directorate of Roads and Highways	
Rijkswaterstaat Netherlands	
Ville de Pointe-Claire	average level of service delivered to the population vs normalized cost where the normalized cost would be a function of the cost that year compared to expected cost for a winter of that severity
Kansas DOT	
Norwegian Public Roads Administration	It will be easier to get enough money for winter maintenance
Vermont Agency of Transportation	I feel that benefit-cost would be around the mobility of the traveling public and performance measures relating to road conditions/ mobility.

Agency	Open-Ended Response
NHDOT	We would want to be able to show that investing in new equipment, materials and technology allows us to keep the roads safer and cleaner in a shorter time with less cost.
IL DOT	
Massachusetts Dept. of Transportation	Apples to Apples. For a dollar spent on winter operations, what is the benefit returned, in dollars.
City of Farmington Hills, MI	To have some rough #'s at the end of the winter season…snow and Ice is all melted and gone but other than safety and mobility we need to quantify the economics etc.
Iowa DOT	
Alaska DOT&PF	Cost vs LOS targets. Would increasing or decreasing LOS impact budget vs mobility.
Montana Department of Transportation	
Kansas DOT	
City of Bozeman MT	Not following this question.
Kiewit Meridiam Partners	NA
City of Columbus, Ohio	some way to quantify benefits would honestly be a huge win, as well as a way to set a target performance metric.
City of Columbus, Depart. of Public Service	Regaining of grip on the road in a reasonable time for the lowest cost possible.

Question 19. Do you monitor, manage, or quantify environmental impacts from your operations? (i.e. low salt or sand routes near certain environmentally sensitive sites; monitoring and selecting less corrosive chemical materials or coat bridge decks to protect.)

Yes	**No**
11	15

Question 20. How is risk considered or included in cost of your operations?

Agency	Open-Ended Response
Texas Department Transportation	
Minnesota Department of Transportation	We can draw on all resources to reduce risk and will pull from other sources to mitigate risk.
Ministere des Transports et de la Mobilité Durable du Québec	Risk sharing in contracts for fuel cost and salt quantity
NDDOT	It is assumed every winter will be different, but it typically averages out over time. That is why we typically use 5 year average to determine a snow and ice control budget.
WYDOT	
Montana	not
NDDOT	
Town of Middlebury	
Kansas DOT	
UDOT	We assume a minimum of 25 storms statewide that will require a response.
Directorate of Roads and Highways	N/A
Rijkswaterstaat Netherlands	
Ville de Pointe-Claire	impacts how we prioritize routes
Kansas DOT	Not considered directly.
Norwegian Public Roads Administration	
Vermont Agency of Transportation	We try to balance risk with environmental and budgetary considerations.
NHDOT	
IL DOT	
Massachusetts Dept. of Transportation	I can't say that it is, or isn't considered, but we are conducting operations during inclement conditions to mitigate the average motorist's risk to operate. We're also trying to reduce the risk that poor roadway conditions lead to a disruption that closes road(s) and mobility grinds to a halt.
City of Farmington Hills, MI	Not sure we can do that now
Iowa DOT	
Alaska DOT&PF	Not considered

Agency	Open-Ended Response
Montana Department of Transportation	The goal is always reduce risk to the traveling public
Kansas DOT	
City of Bozeman MT	Isn't.
Kiewit Meridiam Partners	We are required by contract to maintain bare and wet roads 24x7. The amount of chlorides needed to try and accomplish this are a risk concern for the environment but we have not performed testing yet.
City of Columbus, Ohio	it’s not
City of Columbus, Depart. of Public Service	We make the roadways passable so they are safe.

Question 21. How many hours of refresher training do you provide to your winter maintenance staff/operators per season?

Answer Choices	Responses
N/A No refresher training is provided	1
<5hrs	7
5-10hrs	10
10-20 hrs	7
>30hrs	1

Question 22. How many hours of new staff/operator training do you provide to your winter maintenance staff/operators per season?

Answer Choices	Responses
<5hrs	0
5-10hrs	3
10-20 hrs	10
20-30 hrs	1
>30hrs	10

Question 23. Please summarize your perceived value and/or benefits of training including any metrics you may use to quantify the benefits of training staff.

Agency	Open-Ended Response
Texas Department Transportation	High value on education to better utilize the available resources.
Minnesota Department of Transportation	Safer Operators, optimize materials, liability reductions, qualified staff, safety to the public, reduced costs
Ministere des Transports et de la Mobilité Durable du Québec	Training is one of the key of success for winter maintenance operation. We work to improve our training program and to develop tools to monitor that aspect
NDDOT	
WYDOT	less damage to equipment
Montana	We do not use any
NDDOT	No metrics but recognize value.
Town of Middlebury	
Kansas DOT	Training and experience are essential to an effective and efficient winter operation
UDOT	Incorporating the use of simulators for training has reduced accidents ten fold.
Directorate of Roads and Highways	
Rijkswaterstaat Netherlands	
Ville de Pointe-Claire	reduction in accidents, improved quality, speed and cost of operations
Kansas DOT	No metrics, but we believe we have less accidents.
Norwegian Public Roads Administration	The contractors are responsible for the training of their staff. We provide the text books.
Vermont Agency of Transportation	We don't have metrics, but training our employees is paramount to ensuring they understand our level of service and expectations so that they can adjust as needed on the road to provide for safe and efficient movement of people and goods.

Agency	Open-Ended Response
NHDOT	We see less accidents and better treatment of our roads the more training our staff has on the materials they are applying and timing of plowing/treatments
IL DOT	
Massachusetts Dept. of Transportation	Not just staff: we hold tailgate trainings where I get to speak with almost 1,000 contractors/drivers with whom we work. Our message has 3 points: Safety, Operations, Environmental. It is an important opportunity we get annually to reiterate how important it is that we maintain salt usage efficiency. I always say our goal is to establish and maintain safe roadway conditions while using as little salt as possible to do so.
City of Farmington Hills, MI	Any tools that we can try or pilot to use would be exciting
Iowa DOT	Training is a very important part of our overall Winter Operations program. All field staff members take part in the training program and it is viewed as a continuous learning environment regardless of years or service.
Alaska DOT&PF	Not quantified
Montana Department of Transportation	I believe it is of high value in reducing material costs/ equipment damage/ and overall safety, but it is very difficult to quantify
Kansas DOT	
City of Bozeman MT	We see short term value to train just to get through the winter. It is so expensive to live here that most workers move on after one year. Our average experience for our crews are <1 year.
Kiewit Meridiam Partners	Very important
City of Columbus, Ohio	reduction in accidents, more efficient staff, more efficient operations
City of Columbus, Depart. of Public Service	We train our staff to safely operate the equipment, to use the correct amount of deicers, to make roads passable.

Question 24. May we contact you with follow-up questions?

Yes	No
25	1

4. Data Inputs and Methodology

4.1 Objective

The goal of this research project was to develop a tool that agencies can use to quantify the economic value of their snow and ice operations including investing in emerging technologies and innovative practices. As outlined in the technical scope of this project, one of the activities in Task 4 was to determine the variables or inputs that should be used with the tool for the desired outputs. Along with information on these inputs, this task included the development of the methodology that will be used within the economic tool. This tool allows agencies to make better decisions by providing a realistic cost and benefit to the operations and allow for justification and planning for an appropriate annual budget.

This section is to identify the variables desired for quantifying the economic value of snow and ice operational success. Direct variables include road network characteristics, cost information, and variables needed for determining benefits.

4.2 Input Variables

4.2.1 Road Network Characteristics

The variables to consider related to the road network in determining the costs of winter maintenance include:

- Weather Data
- Network Data

Weather Distribution and Durations:

Weather data pertaining to winter maintenance can be summarized by the table below. The event type can be defined by each agency by severity based on their own weather characteristics and expected winter maintenance. The most relevant data measurement is the total hours of winter events there are. The total hours of winter events will be calculated based on the number of events and the average span of events per year. These hours will be applied to each of the networks when calculating the benefits along with the percent speed reduced and percent of each event type. Users are also able to utilize their accumulated winter season severity index (AWSSI). The AWSSI score can be entered along with the state, and average hourly rate for winter maintenance workers.

Event Type	Percent Per Season	Percent speed reduced when not treated
• Light/Mild • Moderate • Heavy • Icy Storm	Percent	Percent

Number of Events Per Year	Average Span per Event (Hr)
Count	Value

Or

State	AWSSI	Average Hourly Rate for Winter Maintenance Workers ($)	Calculated Total Event Hours for the Whole State	Calculated Total Days of Events for the Whole State
State	Score	Hours	Calculated Hours – No Input	Calculated Days – No Input

<u>Network and Operation Data:</u>

Network and Operation Data will include a network area description that can be as large or as small as needed. Annual Average Daily Traffic (AADT) data can be broken down into different volume bins, % heavy vehicles, speed, lane-miles, as well as center-line miles.

Network Area Description	AADT	% Commercial Vehicles	Treated Road Average Vehicle Speed (mph)	Lane-miles	Center-line miles
• Network label (X county – low priority) • Network label (Y county – high priority)	• <5,000 • 5,000-7,500 • 7,501-10,000 • 10,001 – 12,500 • 12,501 – 15,500 • >15,500	Percentage	MPH	Mile	Mile

4.2.2 Costs Variables

The variables to consider in determining the costs of winter maintenance include:

- Direct Cost Estimate for the Season
  (Derived from AWSSI)

OR

- Labor (Internal to Agency)
- Labor (Private Contractor)
- Fuel
- Deicing Material

AND

- Capital Equipment and Maintenance
- Discount Rate
- Software/Data Subscriptions
- Training
- Infrastructure and Environmental Maintenance
- Vehicle, Equipment, and Material Storage
- Environmental Cost
- Other

Direct Cost Estimate for the Season:

The cost of labor (private and agency), fuel, and deicing material, make up the direct annual cost of winter maintenance operations. End users can add these variables manually or these can be derived from the AWSSI. The following table can be used to provide an estimation of annual direct costs for the whole state based on the state and AWSSI, instead of filling out the Labor (Internal to Agency), Labor (Private Contractor), Fuel, and Deicing Material tables.

These costs are estimated by using linear regression to predict direct cost estimates based on previous years data, relative to each state. Further details on this process can be found in the Benefit-Cost Calculation Methodology section under the Annual Direct Cost subsection.

State	AWSSI	Calculated Direct Annual Cost for Whole State
State	Score	Calculated Cost – No Input

Or

Labor (Internal to Agency):

Winter maintenance operations are very labor intensive and require qualified and informed individuals for successful execution. Cost of labor not only includes the time plowing the snow but also the cost of managing staff, equipment, resource allocation, management of data, and other types of labor involved in winter maintenance. The table below breaks down the labor costs by employee type, hour, and average labor hourly rate. Average annual labor costs can be derived from the information included in the table. If the annual cost of labor is already known, then just that column can be filled in and All Labor can be selected in the first column.

Type of Employee	Total Hours per Type of Employee Per Year	Average Cost per Hour	Annual Cost
• Full-Time - Manager - Associate - Assistant • Seasonal • All Labor	Count	Cost	Cost

And

<u>Labor (Private Contractor):</u>

In many cases private contractors have their own contracts with agencies that determine the way in which they are paid for their services. Rather than payment being on an hourly basis, sometimes contractors are paid in a lump sum for performing specific tasks or simply being available. Private contract labor costs can be derived using the variables listed in the table below.

Private Contractor (Contract Type)	Annual Cost
• Fixed-Price Contract • Time and Materials Contract • Performance-Based Contract • Retainer Fees	Cost

And

<u>Fuel:</u>

Winter maintenance vehicles require fuel to operate and clear out roads during storm events. The type and amount of fuel used, and its average price determines the fuel cost per year. If the annual cost of fuel is already known, then just that column can be filled in and All Fuel can be selected in the first column.

Type of Fuel	Annual Gallons of Fuel Used	Average Cost per Gallon ($)	Annual Cost
• Gasoline • Diesel • Other Fuel Type • All Fuel	Count	Cost	Cost

And

Deicing Material:

Salt, chemicals, and abrasives are essential in keeping the roads clear after plowing away the snow. Each of the deicing products has its own price and amount needed based on the characteristics of winter events. Data needed to determine the costs of deicing materials are broken down in the table below. If the annual cost of deicing materials is already known, then just that column can be filled in and All Material can be selected in the first column.

Material	Annual Amount of Material Used	Cost per unit - Unit Cost ($/unit)	Annual Cost
• Solid Salt (NaCl) • Salt brine (liquid NaCl) • Inhibited salt brine • Magnesium Chloride (MgCl2) • Abrasives • Calcium Chloride (CaCl2) • Blended Products • Sodium Chloride Brine or Blend • Calcium chloride brine or blend • Magnesium chloride brine or blend • Potassium acetate brine or blend • Enhanced brines • All Material	• Solid Salt – Tons per Year • Brine – Gallons per year • Sand/Abrasives - Cubic Yards of Sand/Abrasives	• Cost of solid salt per ton • Cost of Brine per gallon • Cost of Sand/Abrasives per cubic yard	Cost

Capital Equipment and Maintenance:

For each piece of capital equipment, there are associated costs for purchasing them, as well as each having their own life expectancy, and maintenance costs. The annualized costs of current equipment will be determined when the total costs are calculated using the capital cost and salvage value. These pieces of capital equipment include not only winter maintenance vehicles, but also RWIS stations, weather stations, spreaders, plows, AVL devices, and other equipment or devices that support snow and ice control operations. The following information will be collected as variables for the tool.

Type of Equipment	Current Amount of Equipment	Amount of Equipment to be Purchased this Year	Capital Cost - Unit Cost ($/unit)	Maintenance Cost Per Unit ($)	Life Expectancy (Years)	Salvage Value
• Snow and Ice Removal Trucks - Tandem Axle - Single Axle - Tow plow • Spreader Systems - Prewetting systems - Slurry generators - Controllers • Plows - Wing plow - Front plow - Belly plow - Sensors - Controllers • Other - Road Grader - Loader - Blower • Weather Stations/ RWIS • AVL/GPS	Count	Count	Cost	Cost	Year (or Value)	Dollar value for salvage

Discount Rate:

The discount rate is used to annualize the cost of the initial investment made on winter maintenance equipment. This variable will be used when calculating the overall costs and benefits associated with winter maintenance.

Discount Rate
Percentage

Software/Data Subscriptions:

Various software and database tools are used during winter maintenance and can potentially have a yearly subscription cost, or a cost related to the storage of data based on size and usage. This table breaks them down into the type of subscription as well as how much it costs to have these software/data subscriptions per year.

Subscription Type	Subscription Cost per Year
• Data Subscription • Software Subscription • RWIS • Weather Provider	Cost

Training:

Training is essential to get new hires up to standard as well as to provide refreshers or teach new skills and procedures to current staff. Training costs can be broken down by type of training conducted per year.

Type of Training	Cost per year
• New Hire • Start of Season Required Training • Start of Season Optional Training • Additional Other Training	Cost

Infrastructure and Environmental Maintenance:

Winter and road maintenance has many indirect costs such as infrastructure maintenance. These types of infrastructure maintenance include things such as maintaining roads due to salt and chemicals causing corrosion, leading to more frequent repairs. Environmental maintenance includes repairing the damage caused by the runoff of the salt and chemicals used in treating roads.

Infrastructure Maintenance Type	Maintenance Cost per year
• Roadway Maintenance • Environmental Maintenance (bridge flushing, etc.)	Cost

Storage:

Vehicles and the materials used for winter maintenance need to be stored until they are ready for use. This storage comes with its own associated costs which are broken down in the table below.

Storage Type	Storage Cost per year
• Material Storage • Vehicle Storage	Cost

Environmental Cost:

The cost of defending against the environmental impact of using salt in winter maintenance operations can vary greatly depending on the agency and their respective budget. The table below allows the user to input the amount of salt being used as well as the cost per ton, to accurately gauge the cost.

Type of Deicing Material	Amount of Deicing Materials	Estimated Impact to Environment per Year ($/Unit)
• Tons of rock salt • Gallons of brine (1 gallon = 2.6 lb salt)	Count	Cost

Other:

There are many associated costs involved with winter maintenance operations, and some may not be fully captured within the categories listed above. Agencies are encouraged to capture and document the costs that are not included in the categories above to provide comprehensive cost information for evaluating the overall costs associated with winter maintenance operations.

Other Cost Variables	Cost per year
• Insurance and Liability Coverage • Utilities and Operational Overhead	Cost

4.2.3 Benefits Variables:

According to the survey results, the variables that agencies would want to include to calculate benefits were mainly

- Safety – reduction of weather-related crashes
- Commercial Freight and Passenger Vehicle Delay

Safety:

One of the important benefits of winter maintenance is the prevention of crashes. Snow and ice significantly alter road surfaces, often without warning, creating slippery and unpredictable driving conditions. With prompt and efficient snow removal, these crashes can be mitigated. Factors such as improved safety on roadways do not translate directly to dollars, so their impacts must be estimated. These estimates are calculated with the following variables:

- Number of crashes for each severity
- Estimated percentage of vehicles exposed to icy/wet roads before and after treatment
- User Delay Costs
- Pavement Factors (Default values provided)
- Crash Severity Costs (Default values provided)

The default values for pavement factors are provided from SHRP report for "Development of Anti Icing Technology", 1994. Cost estimates for crash severities are provided by the FHWA "Highway Safety Benefit Cost Analysis Guide", 2018.

Number of Each Crash Severity

Number of Fatal	Number of Injury (A)	Number of Injury (B)	Number of Injury (C)	Number of Property Damage Only (PDO) (O)
Count	Count	Count	Count	Count

Percentage of Vehicles Exposed to Icy or Wet Roads

The percentage of vehicles exposed to icy roads which includes both snow and ice, as well as the percentage of vehicles exposed to wet roads before treatment will need to be provided. Additionally, the same percentages will need to be provided for after treatment.

This will require the end user to make these assumptions based on their experience. The user should consider the driving condition if they were to not treat the roadway and type of snow and ice they experience. The percentage of vehicles exposed to ice/wet roads metric can be estimated roughly by DOTs. Typically, the road networks that are being inputted are assumed to be covered with snow and/or ice. In most cases an estimate of 90% to 100% can be used for before treatment, and the same percentage can be used for wet roads after treatment.

Vehicles Exposed to Icy Roads (Untreated)	Vehicles Exposed to Wet Roads (Untreated)	Vehicles Exposed to Icy Roads (Treated)	Vehicles Exposed to Wet Roads (Treated)
Percentage	Percentage	Percentage	Percentage

Default Pavement Factors

Default pavement factors are based off the SHRP report for "Development of Anti Icing Technology", 1994. These factors were calculated by multiplying the percentage of fatal, injury, and property damage only accidents by the accident rate per million vehicle-miles on ice and snow-covered pavements and wet pavements respectively.

Fatal on Wet Pavement Factor	Injury On Wet Pavement Factor	PDO on Wet Pavement Factor	Fatal on Ice Pavement Factor	Injury on Ice Pavement Factor	PDO on Ice Pavement Factor
0.074	1	1.2	0.15	2.1	2.4

Source: https://www.trb.org/publications/shrp/SHRP-H-385.pdf

Default Crash Severity Costs

The following crash costs are provided by the FHWA "Highway Safety Benefit-Cost Analysis Guide", 2018. This value considers medical expenses, vehicle insurance, legal implications, and inflation.

Cost Fatal	Cost Injury (A)	Cost Injury (B)	Cost Injury (C)	Cost PDO (O)
$11,637,947	$674,353	$204,143	$129,001	$12,108

Source: https://safety.fhwa.dot.gov/hsip/docs/fhwasa18001.pdf

Commercial Freight and Passenger Vehicle Delay Cost:

Another important benefit of winter maintenance is the reduction in commercial freight and passenger vehicle delay. By keeping the roads clear of snow and ice, drivers can drive faster while still maintaining safe speeds. Benefits associated with reduction in vehicle delays can be estimated using the vehicle delay costs and road network information.

Vehicle delay costs are a key component in determining the benefits that are provided through winter maintenance operations. Vehicle delay cost is a value that provides a monetary representation of the time lost by individuals and businesses. For this case, the vehicle delay cost will be used to determine the economic value that is provided by winter maintenance. This is calculated by determining the value of time for passenger and commercial vehicles respectively. User delay can be estimated based on average travel speed from various sources such as field observations, traffic sensors, or probe data.

Vehicle Delay Cost (Passenger)	Vehicle Delay Cost (Commercial)
Cost/hr.	Cost/hr.

Source: https://ops.fhwa.dot.gov/wz/resources/publications/fhwahop12005/sec2.htm

4.3 Benefit - Cost Calculation Methodology

Using the variables outlined above, the following is the methodology and logic of the tool for quantifying the benefits and costs associated with snow and ice control operations. The components of the methodology include:

- Initial Capital Investment on Equipment
- Annual Direct Costs
- Annual Indirect Costs
- Annualized Costs
- Annual Cash Flow – TOTAL Costs
- Cost Per Lane Mile
- Safety Benefits
- Commercial Freight and Passenger Vehicle Delay Benefits
- Annual Cash Flow – TOTAL Benefits
- Benefit Cost Ratio

4.3.1 Initial Capital Investment on Equipment

The initial capital investment on equipment can be calculated based on the amount of equipment purchased multiplied by the unit cost. This value is used to calculate annualized costs.

$$Initial\ Investment\ Per\ Equipment = Count_{Equipment\ Type} * Unit\ Cost$$

$$Total\ Initial\ Investment = \sum Count_{Equipment\ Type} * Unit\ Cost$$

4.3.2 Annual Direct Costs

The annual direct costs include costs of labor, deicing materials, fuel, and equipment that needed to be purchased the same year for winter maintenance needs. The costs may vary, depending on the number, severity, and duration of winter events per year.

$$\begin{aligned} &Annual\ Direct\ Costs \\ &\quad = Annual\ Labor\ Costs + Annual\ Fuel\ Costs + Annual\ Deicing\ Material\ Costs \\ &\quad + \sum Count_{New\ Equipment\ Type} * Unit\ Cost \end{aligned}$$

Or

$$Annual\ Direct\ Costs = \ Estimated\ Annual\ Direct\ Costs\ Based\ on\ AWSSI$$
$$Annual\ Direct\ Costs\ (Y) = (m * AWSSI) + b$$

By using the AWSSI, an estimation can be provided through linear regression. By using built in linear regression tools within Excel, the slope and intercept have been calculated for each state based on the direct costs data, that have been collected from state DOT's. The slope intercept formula can be used to calculate the "y" (direct annual costs) by using the already calculated "m" (slope) and "b" (intercept), and by providing "m" (AWSSI). The tool will already apply the correct slope and intercept coefficients based on the state selected. Availability of data varies between states, so some may not be able to calculate estimates.

4.3.3 Annual Indirect Costs

The annual indirect costs include costs of training, software and data subscriptions, equipment maintenance, infrastructure and environmental maintenance, environmental, and storage. Indirect costs typically remain consistent and do not depend on the number of events.

$$\begin{aligned} &Annual\ Indirect\ Costs \\ &\quad = Annual\ Training\ Costs + Annual\ Software/Data\ Subscription\ Costs \\ &\quad + Annual\ Equipment\ Maintenance\ Costs \\ &\quad + Annual\ Infrastructure\ and\ Environmental\ Maintenance\ Costs \\ &\quad + Annual\ Storage\ Costs + Enivroment\ Cost + Annual\ Other\ Costs \end{aligned}$$

4.3.4 Annualized Asset Costs

Annualized costs are determined for assets intended for multi-year use, like vehicles for winter maintenance.

$$PV\ Salvage\ Per\ Equipment = \frac{Salvage\ Value}{1 - (1 + i)^{-n}}$$

$$\begin{aligned} &Total\ Annualized\ Costs \\ &\quad = \sum \frac{(Initial\ Investment\ Per\ Equipment - PV\ Salvage\ Per\ Equipment) * i}{1 - (1 + i)^{-n}} \end{aligned}$$

Where:

- i = discount rate
- n = lifespan of equipment
- PV = Present Value

4.3.5 Annual Cash Flow – TOTAL Costs

Annual cash flow provides the sum of the annual costs and is used to calculate the benefit to cost ratio.

$$Annual\ Cash\ Flow_{Costs} = Annual\ Direct\ Costs + Annual\ Indirect\ Costs + Total\ Annualized\ Costs$$

4.3.6 Cost Per Lane Mile

A lane mile is a measure of the total length as well as the number of lanes on a roadway. The cost per lane mile provides a value that shows how much each mile of road costs to treat based on the annual cash flow of winter maintenance costs.

$$Cost\ Per\ Lane\ Mile = \frac{Annual\ Cash\ Flow_{Costs}}{Lane\ Miles}$$

4.3.7 Safety Benefits

The monetary value provided by reducing the number of crashes due to untreated icy roads is calculated below. First, the total cost of each crash severity is calculated based on the number of crashes for when the roads are treated vs untreated. The percentage of vehicles exposed to ice/wet roads metric can be estimated roughly by DOT's based on experience. Untreated roads are assumed to be icy, and treated roads are wet. While both have potential for crashes, the icy conditions have a higher probability for a crash to occur. As such, input examples for untreated conditions could be set to a 90% icy and 10% wet (equaling 100%); while treated roadways would be closer to the inverse of 10% icy with 90% wet. The savings are then calculated by subtracting the costs of the crashes on treated roads vs costs of the crashes on untreated roads.

Untreated (UT):

$$AADT_{Ice\ (UT)} = AADT * Center\ line\ miles * Days_{\ Events} * \%_{Vehicles\ Exposed\ to\ Ice\ (UT)}$$

$$AADT_{Wet\ (UT)} = AADT * Center\ line\ miles * Days_{\ Events} * \%_{Vehicles\ Exposed\ to\ Wet\ (UT)}$$

$$Count_{\ Expected\ Crash\ Severity\ (UT)} = ((AADT_{\ Ice\ (UT)} * Factor_{Ice\ Pavement\ Severity}) + (AADT_{\ Wet\ (UT)} * \ Factor_{Wet\ Pavement\ Severity})) * 10^{-6}$$

$$Cost_{Crash\ Severity\ (UT)} = Count_{User\ Input\ Crash\ Severity} * Cost_{Crash\ Severity}$$

Treated (T):

$$AADT_{Ice\ (T)} = AADT * Center\ line\ miles * Days_{\ Events} * \%_{Vehicles\ Exposed\ to\ Ice\ (T)}$$

$$AADT_{\ Wet\ (T)} = AADT * Center\ line\ miles * Days_{\ Events} * \%_{Vehicles\ Exposed\ to\ Wet\ (T)}$$

$$Count_{\,Expected\ Crash\ Severity\ (T)} = ((AADT_{\,Ice\ (T)} * Factor_{Ice\ Pavement\ Severity}) + (AADT_{\,Wet\ (T)} * \ Factor_{Wet\ Pavement\ Severity})) * 10^{-6}$$

$$\%\ Reduction = \frac{Count_{\,Expected\ Crash\ Severity\ (UT)} - Count_{\,Expected\ Crash\ Severity\ (T)}}{Count_{\,Expected\ Crash\ Severity\ (UT)}}$$

$$Cost_{Crash\ Severity\ (T)} = Count_{User\ Input\ Crash\ Severity} * Cost_{Crash\ Severity} * \%\ Reduction$$

Source: https://www.trb.org/publications/shrp/SHRP-H-385.pdf

Savings

$$Safety\ Benefit\ Cost_{Crash\ Severity\ Savings} = Cost_{Crash\ Severity\ (UT)} - Cost_{Crash\ Severity\ (T)}$$

$$Safety\ Benefit\ Cost_{Total\ Savings} = \sum Safety\ Benefit\ Cost_{Crash\ Severity\ Savings}$$

4.3.8 Commercial Freight and Passenger Vehicle Delay Benefits

The monetary value of reducing delay with winter maintenance operations is provided below. First the total hours of events which is estimated to be how long vehicles would be spending on either icy or wet roads is calculated. This is either done by providing the average span of events and the number of events with an option of listing its event type to determine the percent of hours each event type receives, or by providing the AWSSI and average hourly rate of workers. When the AWSSI is provided, an estimate will be calculated through linear regression by calculating the slope and intercept coefficients for each state to estimate the annual number of workers and labor costs based on previous data provided by DOTs. For a conservative estimation, the labor hours are divided by two as the time snowplow operator spent on the road is not entirely on treating roads. AAHT, VMT, and vehicle delay are calculated to get the total savings from vehicle delay costs. Data availability varies by state, and therefore, some states may not be able to calculate the estimates. In this case to calculate estimates, state data must be added to the table on the State Data tab and the macros “CalculateEstimatedExpenditures,” and “CalculateLaborCostAndWorkers” must be rerun for estimates to be made available for states with no data.

$$Total\ Hours\ of\ Events = \sum Average\ Span\ of\ Event * Number\ of\ Events$$

Or

$$Total\ Number\ of\ Workers\ (Y) = \ (m * AWSSI) + b$$

$$Total\ Cost\ of\ Labor\ (Y) = \ (m * AWSSI) + b$$

$$Total\ Hours\ of\ Events = \frac{Total\ Cost\ of\ Labor}{Total\ Number\ of\ Workers} * \frac{1}{Average\ Hourly\ Rate} * \frac{1}{2}$$

$$Average\ Annual\ Hourly\ Traffic_{Passenger} = \frac{AADT}{24} * \left(1 - \frac{\%_{Commercial}}{100}\right)$$

$$Average\ Annual\ Hourly\ Traffic_{Commercial} = \frac{AADT}{24} * \left(\frac{\%_{Commercial}}{100}\right)$$

$$VMT_{Passenger} = Average\ Annual\ Hourly\ Traffic_{Passenger} * Centerline\ Miles$$

$$VMT_{Commercial} = Average\ Annual\ Hourly\ Traffic_{Commercial} * Centerline\ Miles$$

$$Speed_{(UT)} = Speed_{(T)} * \ (1 - \ Speed\ Percent_{(Event\ Type)}\ )$$

$$\Delta Vehicle\ Delay_{Passenger} = \frac{VMT_{Passenger}}{Speed_{(UT)}} - \frac{VMT_{Passenger}}{Speed_{(T)}}$$

$$\Delta Vehicle\ Delay_{Commercial} = \frac{VMT_{Commercial}}{Speed_{(UT)}} - \frac{VMT_{Commercial}}{Speed_{(T)}}$$

$$\begin{aligned} &User\ Delay\ Cost\ Savings\ Per\ Hour_{(Event\ Type)} \\ &\quad = \big(\Delta Vehicle\ Delay_{Passenger} * Vehicle\ Delay\ Cost_{Passenger} * (Total\ Hours\ of\ Events \\ &\quad * Percent_{(Event\ Type)})\big) + (\Delta Vehicle\ Delay_{Commercial} * Vehicle\ Delay\ Cost_{Commercial} \\ &\quad * \big(Total\ Hours\ of\ Events * Percent_{(Event\ Type)}\big)) \end{aligned}$$

$$User\ Delay\ Cost\ Savings\ Per\ Hour_{Total} = \sum User\ Delay\ Cost\ Savings\ Per\ Hour_{(Event\ Type)}$$

4.3.9 Annual Cash Flow – TOTAL Benefits

$$Annual\ Cash\ Flow_{Benefits} = Safety\ Benefit\ Cost_{\ Total\ Savings} + User\ Delay\ Cost_{Total\ Savings}$$

4.3.10 Benefit to Cost Ratio

$$BCR = \frac{Annual\ Cash\ Flow_{Benefits}}{Annual\ Cash\ Flow_{Costs}}$$

4.4 Step-by-Step Methodology for a Hypothetical Scenario

4.4.1 User Input Example

Weather

Event Type	Percent Per Season	Percent speed reduced when not treated
Light/Mild	50	20%
Moderate	25	50%
Heavy	13	70%
Icy Storm	12	80%

Number of Events Per Season	Average span of event (hr.)
5	10

Network

Network Area Description	AADT	% Commercial Vehicles	Treated Road Vehicle Speed	Lane-miles	Center-line miles
Network (County X)	10000	5%	45	1,250	500

Capital Equipment

Type of Equipment	Current Amount of Equipment	Amount of Equipment to be Purchased this Year	Capital Cost - Unit Cost ($/unit)	Life Expectancy (Years)	Salvage Value
Single Axle	3	1	$180,000	10 years	$36,000
Tandem Axle	2	0	$220,000	10 years	$44,000

Equipment Maintenance

Type of Equipment	Current Amount of Equipment	Maintenance Cost per Year per Unit
Single Axle	3	$5000
Tandem Axle	2	$5000

Discount Rate

Discount Rate
5%

Software/Data Subscription

Subscription Type	Subscription Cost per Year
AVL Data	$10,000
Data Storage	$15,000

Labor (Internal to Agency)

If annual costs are already known, then it can be used as an input in the Annual Cost column without providing breakdown costs by employee type.

Type of Employee	Total Hours Per Type of Employee Per Year	Average Cost Per Hour	Annual Cost
Full-Time Associate	500	$150	= 500 x $150 = $75,000
Seasonal	150	$120	= 150 x $120 = $18,000

Labor (Private Contractor)

Private Contractor (Contract Type)	Annual Cost
Fixed-Price Contract	$30,000

Fuel

If annual costs are already known, then it can be used as an input in the Annual Cost column without providing breakdown costs by fuel type.

Type of Fuel	Average Gallons of Fuel Per Event	Average Cost per Gallon	Annual Cost
Diesel	167	$3.59	

Product (Deicing Material)

If annual costs are already known, then it can be used as an input in the Annual Cost column without providing breakdown costs by material type.

Material	Amount of Material per Event	Cost per unit - Unit Cost ($/unit)	Annual Cost
Solid Salt (NaCl) for anti-icing and deicing	500 Tons of Solid Salt	$100/ton of Solid Salt	
Salt brine (liquid NaCl)	30,000 gallons of Salt brine	$0.50/a gallon of Salt brine	

Training

Type of Training	Cost per year
Start of Season Required Training	$10,000
Additional Training	$5,000

Infrastructure and Environmental Maintenance

Infrastructure Maintenance Type	Maintenance Cost per year
Roadway Maintenance	$10,000

Storage

Storage Type	Maintenance Cost per year
Material and Vehicle Storage	$5,000

Environmental Cost

Type and Amount of Deicing Materials	Estimated Impact to Environment
• 500 tons of rock salt • 30,000 gallons of brine (1 gallon = 2.6 lb salt) = 39 tons	$2.00 per ton

Other

Other Cost Variables	Cost per year
Insurance and Liability Coverage	$100,000
Utilities and Operational Overhead	$150,000

Number of Each Crash Severity

These values can be pulled from crash data sets that each DOT has based on their severity.

Number of Fatal	Number of Injury (A)	Number of Injury (B)	Number of Injury (C)	Number of PDO (O)
1	5	10	23	60

Percentage of Vehicles Exposed to Icy or Wet Roads

These values represent a case where the benefits of winter maintenance versus no winter maintenance can be measured.

Vehicles Exposed to Icy Roads (Untreated)	Vehicles Exposed to Wet Roads (Untreated)	Vehicles Exposed to Icy Roads (Treated)	Vehicles Exposed to Wet Roads (Treated)
90%	10%	10%	90%

Vehicle Delay Costs

Vehicle Delay Cost (Passenger)	Vehicle Delay Cost (Commercial)
$20/hr.	$40/hr.

4.4.2 Calculations

Initial Capital Investment on Equipment

$$Initial\ Investment\ Single\ Axle = 3 * 180{,}000 = \$540{,}000$$
$$Initial\ Investment\ Tandem\ Axle = 2 * 220{,}000 = \$440{,}000$$

where,

$180,000 per Single Axle

$220,000 per Tandem Axle

Annual Direct Costs

$$Annual\ Direct\ Costs = \$93{,}000 + \$30{,}000 + \$3{,}000 + \$325{,}000 + \$180{,}000 = \$631{,}000$$

where,

$93,000 = Full-Time Associate + Seasonal Employee

$30,000 = Fixed-Price Contract

$3,000 = Diesel

$325,000 = Solid Salt + Salt Brine

$180,000 = New Single Axle (because one is being purchased this season – need for overall budget)

Annual Indirect Costs

$$Annual\ Indirect\ Costs = \$25{,}000 + \$25{,}000 + \$15{,}000 + \$10{,}000 + \$5{,}000 + \$1{,}078 + \$250{,}000 = \$331{,}078$$

where,

$25,000 = Single Axle Equipment Maintenance Costs

$25,000 = AVL Data + Data Storage

$15,000 = Start of Season Required Training + Additional Training

$10,000 = Roadway Maintenance

$5,000 = Material Vehicle Storage

$1,078 = Rock Salt + Brine (Environmental Cost)

$250,000 = Insurance and Liability Coverage + Utilities and Operational Overhead

Annualized Asset Costs

$$PV\ Salvage\ Single\ Axle = \frac{\$108{,}000}{1-(1+0.05)^{-10}} = \$279{,}730$$

$$PV\ Salvage\ Tandem\ Axle = \frac{\$88{,}000}{1-(1+0.05)^{-10}} = \$227{,}928$$

$$Total\ Annualized\ cost = \frac{(\$540{,}000 - \$279{,}730) * 0.05}{1 - (1 + 0.05)^{-10}} + \frac{(\$440{,}000 - \$227{,}928) * 0.05}{1 - (1 + 0.05)^{-10}}$$
$$= \$61{,}170$$

where,

$540,000 = Total Single Axle Cost

$108,000 = Total Salvage Value for Single Axles

$440,000 = Total Tandem Axle Cost

$88,000 = Total Salvage Value for Tandem Axles

0.05 = Discount Rate

10 = Lifespan of Equipment

Total Annual Cost

$$Annual\ Cash\ Flow_{Costs} = \$631{,}000 + \$331{,}078 + \$61{,}170 = \$1{,}023{,}248$$

where,

$631,000 = Annual Direct Costs

$331,078 = Annual Indirect Costs

$61,170 = Annualized Asset Costs

Cost Per Lane Mile

$$Cost\ Per\ Lane\ Mile = \frac{\$1{,}023{,}248}{1{,}250} = \$818.60\ per\ lane\ mile$$

where,

$1,023,248 = Annual Cash Flow (Costs)

1,250 = Lane-Miles

Safety Benefits Savings

Determining road users exposed to wet or icy conditions if treatment has occurred or if roads were left untreated

$$Total\ Hours\ of\ Events = 5 * 10\ = 50$$

where,

5 = Number of Events

10 = Average Span of Events

$$Days\ of\ Events = 50/24 = 2$$

where,

50 = Total Hours of Events

$AADT_{Ice\ S1} = 10000 * 500 * 2 * 0.9 = 9{,}000{,}000$ *[90% of vehicles exposed to icy surfaces if no treatment occurs]*

$AADT_{Wet\ S1} = 10000 * 500 * 2 * 0.1 = 1{,}000{,}000$ *[The remaining 10% of vehicles exposed to wet surface if no treatment occurs]*

$AADT_{Ice\ S2} = 10000 * 500 * 2 * 0.1 = 1{,}000{,}000$ *[With treatment, only 10% exposed to icy surfaces]*

$AADT_{Wet\ S2} = 10000 * 500 * 2 * 0.9 = 9{,}000{,}000$ *[The remaining 90% are exposed to wet surfaces with treatment]*

where,

10000 = AADT

500 = Center line miles

2 = Days of Events

Percent of Vehicles Exposed to wet or icy surfaces under each scenario (treated or not treated)

S_1 = untreated & S_2 = treated

Using the formulas for $Count_{\ Expected\ Crash\ Severity\ UT/T}$ and % Reduction the results are shown below.

	Fatal	Injury(A,B,C)	PDO(O)
Expected Crashes (Untreated)	**1.42**	19.90	22.80
Expected Crashes (Treated)	**0.82**	11.10	13.20
% Reduction	**43%**	44%	42%

Example Expected Crashes (Untreated) for Fatal Calculation:

$$Count_{\ Expected\ Crash\ Severity\ (UT)} = ((AADT_{\ Ice\ (UT)} * Factor_{Ice\ Pavement\ Severity}) + (AADT_{\ Wet\ (UT)} * \ Factor_{Wet\ Pavement\ Severity})) * 10^{-6}$$

$$\mathbf{1.42} = ((9{,}000{,}000 * 0.15) + (1{,}000{,}000 * 0.074)) * 10^{-6}$$

where,

9,000,000 = AADT Ice (Untreated)

0.15 = Factor Ice Pavement (Fatal)

1,000,000 = AADT Wet (Untreated)

0.074 = Factor Wet Pavement (Fatal)

Resulting in **1.42** = Expected Crashes (Untreated)

Example Expected Crashes (Treated) for Fatal Calculation:

$$Count_{\,Expected\ Crash\ Severity\ (T)} = ((AADT_{\,Ice\ (T)} * Factor_{Ice\ Pavement\ Severity}) + (AADT_{Wet\ (T)} * \ Factor_{Wet\ Pavement\ Severity})) * 10^{-6}$$

$$\mathbf{0.82} = ((1{,}000{,}000 * 0.15) + (9{,}000{,}000 * 0.074)) * 10^{-6}$$

where,

1,000,000 = AADT Ice (Treated)

0.15 = Factor Ice Pavement (Fatal)

9,000,000 = AADT Wet (Treated)

0.074 = Factor Wet Pavement (Fatal)

Resulting in **0.82** = Expected Crashes (Treated)

Example % Reduction for Fatal Calculation:

$$\%\ Reduction = \frac{Count_{\,Expected\ Crash\ Severity\ (UT)} - Count_{\,Expected\ Crash\ Severity\ (T)}}{Count_{\,Expected\ Crash\ Severity\ (UT)}}$$

$$\mathbf{43}\% \ = 0.4270 = \frac{1.42 - 0.82}{1.42}$$

where,

1.42 = Expected Crashes (Untreated)

0.82 = Expected Crashes (Treated)

Resulting in 0.4270 = **43%** = Reduction/100

Repeat for the other crash types (Injury and PDO)

Using the formulas for $Cost_{Crash\ Severity\ UT/T}$ and $Safety\ Benefit\ Cost_{Crash\ Severity\ Savings}$ the results are shown below.

	Fatal	Injury (A)	Injury(B)	Injury (C)	PDO (O)
User Input Crashes	1	5	10	23	60
Cost (Untreated)	$11,637,947.00	**$3,371,765.00**	$2,041,430.00	$2,967,023.00	$726,480.00
Cost (Treated)	$5,004,317.21	**$1,483,576.60**	$898,229.20	$1,305,490.12	$305,121.60
Savings	$6,633,629.79	**$1,888,188.40**	$1,143,200.80	$1,661,532.88	$421,358.40

Example Cost (Untreated) for Injury (A) Calculation:

$$Cost_{Crash\ Severity\ (UT)} = Count_{User\ Input\ Crash\ Severity} * Cost_{Crash\ Severity}$$
$$\mathbf{\$3{,}371{,}765} = 5 * \$674{,}353$$

where,

5 = User Input Crashes

674,353 = Cost Injury (A)

Resulting in **$3,371,765** = Cost (Untreated)

Example Cost (Treated) for Injury (A) Calculation:

$$Cost_{Crash\ Severity\ (T)} = Count_{User\ Input\ Crash\ Severity} * Cost_{Crash\ Severity} * \%\ Reduction$$

$$\mathbf{\$1,483,576.60} = 5 * \$674{,}353 * 0.44$$

where,

5 = User Input Crashes

$674,353 = Cost Injury (A)

44/100 = 0.44 = % Reduction to decimal

Resulting in $1,483,576.60 = Cost (Treated)

Example Savings for Injury (A) Calculation:

$$Safety\ Benefit\ Cost_{Crash\ Severity\ Savings} = Cost_{Crash\ Severity\ (UT)} - Cost_{Crash\ Severity\ (T)}$$
$$\mathbf{\$1,888,188.40} = \mathbf{\$3,371,765} - \mathbf{\$1,483,576.60}$$

where,

$1,483,576.60 = Cost under treated conditions

$3,371,765 = Cost under untreated conditions

Resulting in **$1,888,188.40** = Savings Injury (A)

Repeat for the other crash types

$$\begin{aligned} Safety\ Benefit\ Cost_{Total\ Savings} \\ &= \$6{,}633{,}629.79 + \$1{,}888{,}188.40 + \$1{,}143{,}200.80 + \$1{,}661{,}532.88 + \$421{,}358.40 \\ &= \$11{,}747{,}910.27 \end{aligned}$$

where,

$6,633,629.79= Fatal Savings

$1,888,188.40= Injury (A) Savings

$1,143,200.80= Injury (B) Savings

$1,661,532.88= Injury (C) Savings

$421,358.40= PDO (O)

Vehicle Delay Costs Savings

$$Total\ Hours\ of\ Events = 5 * 10\ = 50$$

where,

5 = Number of Events

10 = Average Span of Events

$$Average\ Annual\ Hourly\ Traffic_{Passenger} = \frac{10000}{24} * \left(1 - \frac{5}{100}\right) = 396$$

where,

10000 = AADT

5 = % Commercial Vehicles

$$Average\ Annual\ Hourly\ Traffic_{Commercial} = \frac{10000}{24} * \left(\frac{5}{100}\right) = 21$$

where,

10000 = AADT

5 = % Commercial Vehicles

$$VMT_{Passenger} = 396 * 500 = 197{,}917$$

where,

396 = AAHT Passenger

500 = Centerline Miles

$$VMT_{Commercial} = 500 * 500 = 10{,}417$$

where,

500 = AAHT Commercial

500 = Centerline Miles

$$Speed_{(UT)} = 45 * \left(1 - \frac{20}{100}\right) = 36$$

where,

45 = Speed mph (Treated)

20 = Percent Speed Reduced (Light/Mild)

$$\Delta User\ Delay_{Passenger} = \frac{197{,}917}{36} - \frac{197{,}917}{45} = 1{,}100$$

where,

197,917 = VMT Passenger

36 = Speed mph (Untreated)

45 = Speed mph (Treated)

$$\Delta User\ Delay_{Commercial} = \frac{10{,}417}{36} - \frac{10{,}417}{45} = 58$$

where,

10,417 = VMT Commercial

$$User\ Delay\ Cost\ Savings\ Per\ Hour_{(Light,Mild)} = \left(1{,}100 * 20 * (50 * \frac{50}{100})\right) + \left(58 * 40 * (50 * \frac{50}{100})\right) = \$607{,}642$$

where,

20 = Vehicle Delay Cost (Passenger)

50 = Total Hours of Events

40 = Vehicle Delay Cost Commercial

50 = Percentage Per Season (Light/Mild)

Repeating this process for all event types, yields:

$$User\ Delay\ Cost\ Savings\ Per\ Hour_{Total} = 607{,}642 + 1{,}215{,}283 + 1{,}474{,}544 + 2{,}333{,}344 = \$5{,}630{,}813$$

Total Benefits Savings

$$Annual\ Cash\ Flow_{Benefits} = \$11{,}764{,}427 + \$5{,}630{,}813 = \$17{,}395{,}240$$

where,

$11,764,427 = Safety Benefit Cost Total Savings

$5,630,813 = User Delay Cost Total Savings

Benefit to Cost Ratio

$$BCR = \frac{\$17{,}395{,}240}{\$1{,}023{,}248} = 17.00\ or\ 1{,}700\%$$

4.5 Results Summary

- Budget Projection: $631,000
- Annual Cash Flow Costs: $1,023,248
- Cost Per Lane Mile: $818.60
- Annual Cash Flow Benefits: $17,395,240
- BCR: 17.00

5. Tool Development and Documentation

5.1 Purpose

The purpose of the tool development and documentation is to present how to use the Clear Roads Benefit-Cost Tool (Tool) and the areas to manage in the future to maintain the Tool's functionality. This Tool was built in Excel's Visual Basic Application (VBA) and contains a data entry form that can store user input, make calculations, and load previously entered data. The tool also contains a summary page that allows previously entered data to be compared and a direct cost analysis page that graphs key direct costs year by year for visualization purposes. The main purpose of this tool is to calculate the costs and benefits of winter maintenance operations based on user input. This section will first walk through how to use the tool, the different modules within the tool, what each relevant sheet contains and any hidden sheets within the tool.

5.2 Overview

This tool acts as a data entry form, database, and calculator for winter maintenance operations. The tool contains various tables for various categories that will be used in the calculations for the cost and benefit for winter maintenance operations. The user will enter their specific information into each table category and use the submit button to store that info into its respective database sheet and table. The tool then can conduct a cost benefit analysis and provide relevant information to the user based on the submitted data. On the **Summary Page**, different calculations can be compared, and on the **Direct Cost Analysis** page direct cost information can be graphed year-to-year.

The workbook sheets are:

1.) **Instructions** (Yellow) - Information on how to use the tool and how to update or delete inputs.

2.) **Data Entry Form** (Green) - User inputs values for various categories and calculates results.

3.) **Summary Page** (Purple) - Compare results between different scenarios.

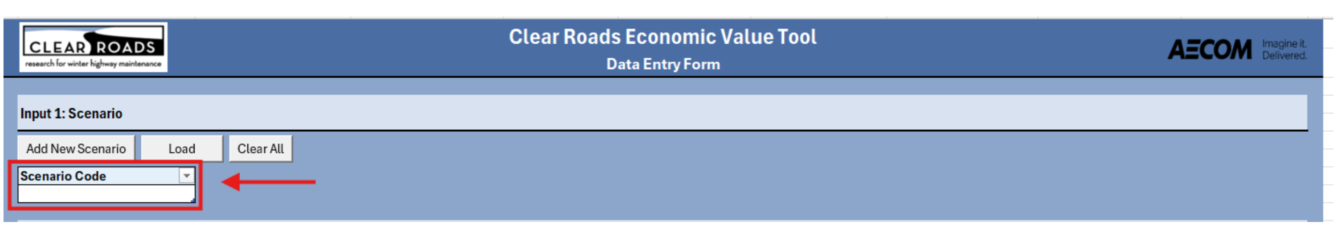
4.) **Direct Cost Analysis** (Light Blue) - Provide inputs related to direct costs to view the maximum, minimum, and visualize yearly trends.

5.) **Database Tables** (Red) – There is a sheet for each data input category. They are stored in separate sheets and can be modified as needed and are all linked by the scenario code.

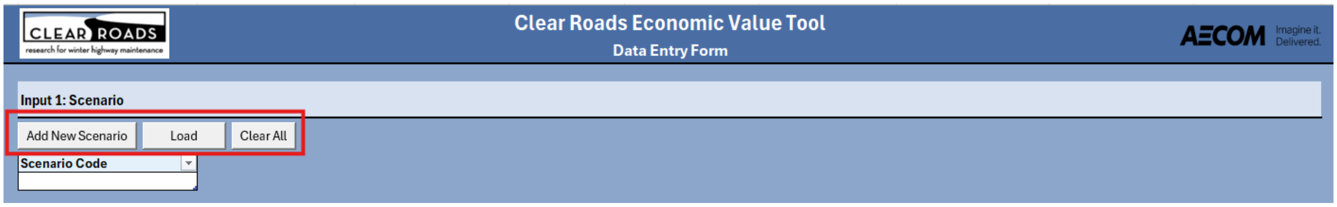
Upon opening the workbook, **be sure to enable Macros** to run the tool.

5.3 Add Data with Data Entry Form

Step 1: Add Scenario Code



On the second page of the excel file you will find the **Data Entry Form**. This form is where you will input all relevant information that pertains to your specific winter maintenance operations. The first input you will need to complete is called ***Input 1: Scenario***, where you will need to fill in the scenario code. This scenario code will act as a unique identifier to link all the data in a category, allowing for the final results to be calculated.

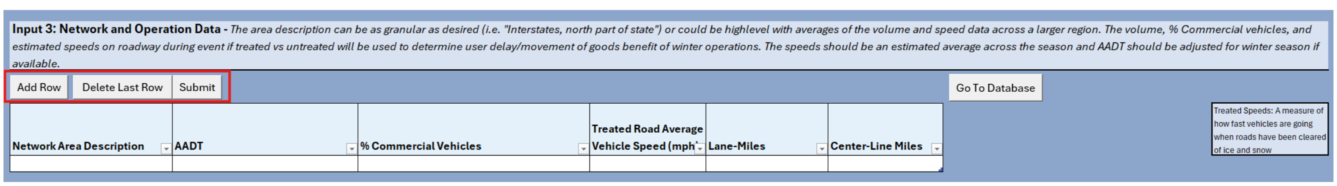


The ***Add New Scenario*** button, saves the scenario code that is currently entered into the drop-down list. Now, whenever scenario code is selected, all previously saved scenario codes can be seen and selected from instead of manually entered.

The ***Load*** button, fills in all tables with the information that was submitted with the scenario code that is currently entered. This is a quick way to view all the data that has been inputted for a scenario code, as well as what is going into the calculations. Lastly the ***Clear All*** button will clear all the tables on the data entry form and reduce the row sizes to one.

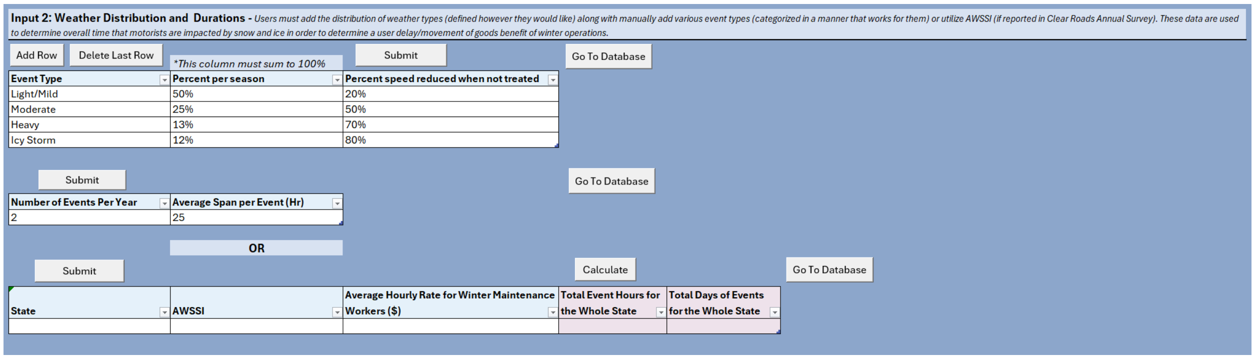
Step 2: Inputs

Network and Operation Data Input:



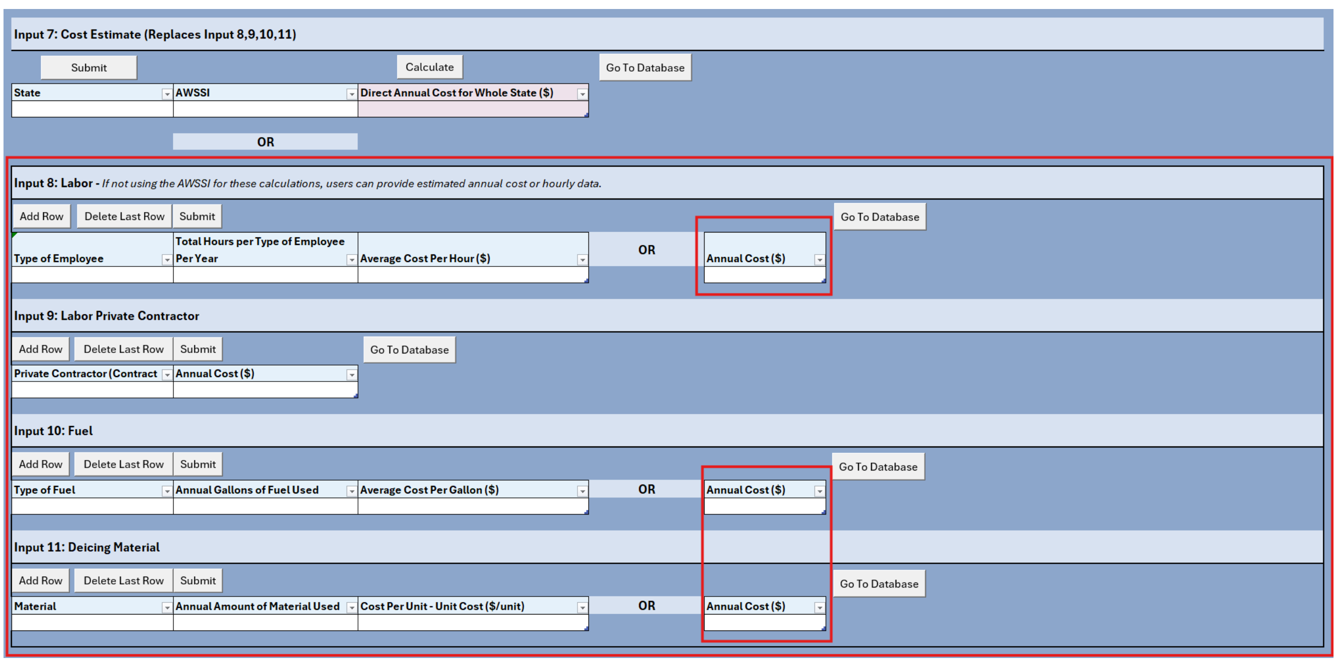
The Add Row button adds an additional row to allow for multiple inputs before submitting. The Delete Last Row button deletes the last row in the table to a minimum of one. Some inputs will not allow the user to add additional rows. This is because when calculating the results of the cost benefit analysis there can only be one input for that category per scenario at a time. The Submit button saves the data currently entered into the table into the respective database sheet and database table, with the currently entered Scenario Code.

Weather Data Inputs (2):



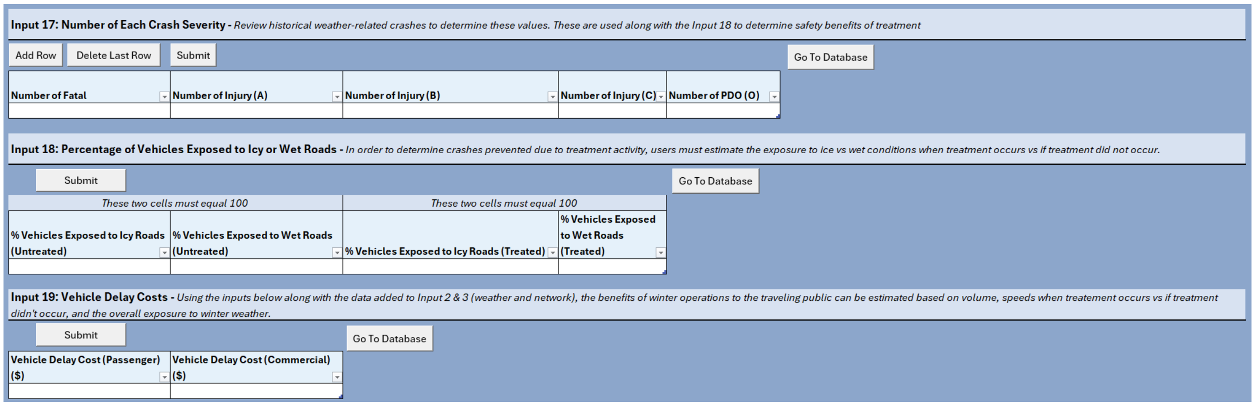
In Input 2: Weather, there is an OR option. The user has a choice to either manually enter in the estimated number of winter events and the average span of those winter events or allow the tool to estimate the total event hours for a specific state based on the AWSSI and average hourly rate for winter maintenance workers using the calculated button. If the estimated total event hours are submitted for a scenario code it will use that value in calculations even if values have been submitted for the other table, since this estimates annual event hours for the whole state. Only one estimated annual event hours for the state can be submitted per scenario code. However, the percentages for each event type above the two tables must be filled in.

Direct Cost Inputs (7, 8, 9, 10, & 11):



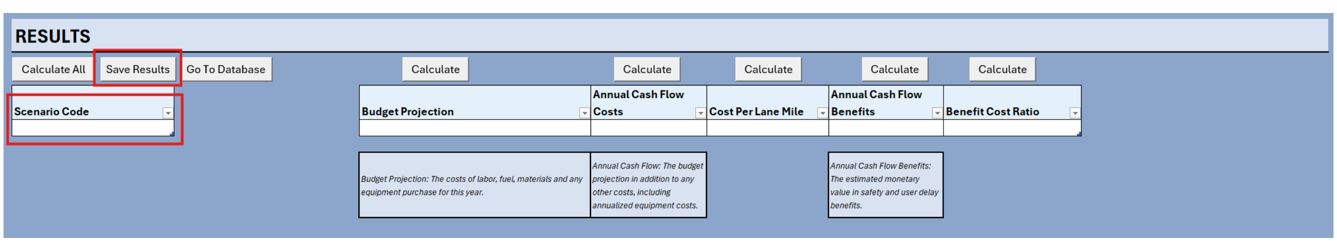
The user may choose to use **Input 7** to estimate the direct annual costs for the whole state for the year, based on the state and AWSSI, or manually input direct cost information for **Input 8, 9, 10, and 11**. If the user chooses to manually input direct cost information, then the Annual Cost can be inputted directly in the right most table instead of using the leftmost table or if this is not known it can be calculated based on specific information related to the amount and cost in the leftmost table. There can only be one estimate for direct annual costs per scenario code, and if the user chooses to manually input direct costs in the Annual Cost table, then it will override any values that would have been calculated in the leftmost table.

Benefit Inputs (17, 18, & 19):



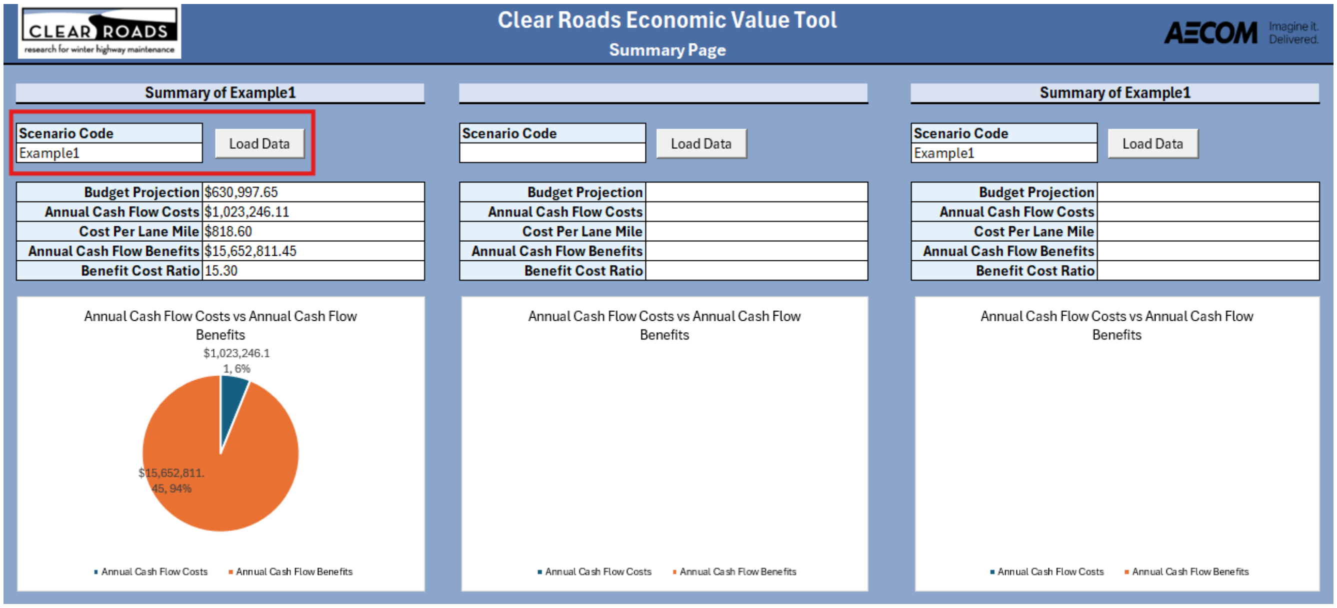
Inputs 17,18 and 19 are used to estimate the safety and delay benefits by utilizing user inputs related to the numbers of crashes based on each severity type, the percentage of vehicles exposed to icy or wet roads, and vehicle delay costs for both passenger and commercial vehicles respectively. The number of crashes will act as a starting point for measuring the safety benefits of winter operation procedures. These crash numbers can be found by reviewing database records for weather related crashes and finding the category it has been labeled as. The categories are fatal (K), suspected serious/disabling injury (A), suspected minor/evident Injury (B), possible injury (C), and property damage only/no apparent injury (O). The percentage of vehicles exposed to icy or wet roads will act as an estimate to determine the number of vehicles that will be affected by these conditions before and after treatment. For example, if the road network that is inputted is almost entirely icy before treatment, then a high percentage can be estimated for icy roads before treatment and a low percentage can be estimated for wet roads before treatment. After treatment the opposite would be true. Lastly, the vehicle delay cost will help provide a monetary estimate of the benefits of winter operation procedures in terms of vehicle delay. These costs will be unique to each jurisdiction as economic and traffic variables play a role in determining the delay cost for both passenger and commercial vehicles.

Step 3: Calculate Results



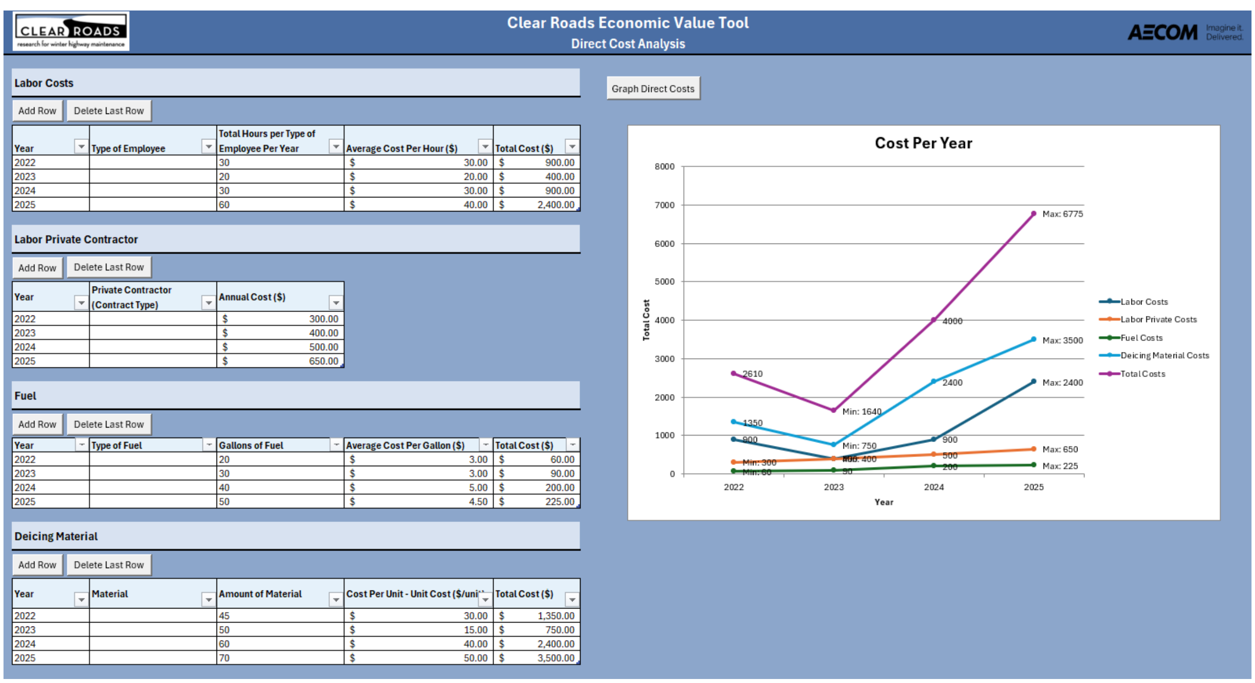
After all the data entry form has been filled out and submitted with a scenario code. The results of the cost benefit of analysis can be calculated and outputted to the table shown above. First a scenario code must be typed into the table which contains a dropdown of previously saved scenario codes. Then the ***Calculate All*** or separate ***Calculate*** buttons may be used to calculate different parts of the cost benefit analysis. These results can then be saved to the Results sheet by using the ***Save Results*** button.

5.4 Summary Page



The **Summary Page** allows the user to compare saved results of up to 3 scenario codes. By inputting a scenario code and pressing the ***Load Data*** button, the saved results will be formatted into the table shown and create a pie chart showing the benefit to costs.

5.5 Direct Cost Analysis Page

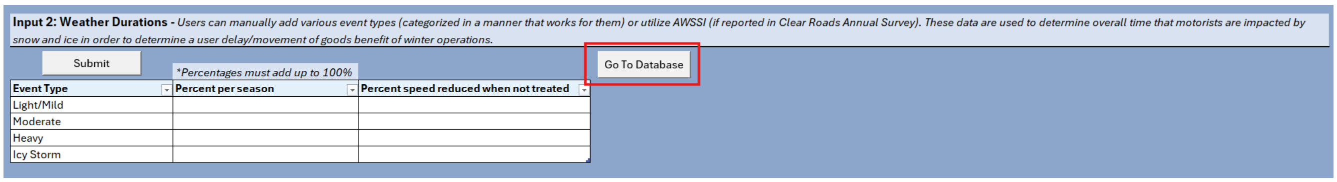


The **Direct Cost Analysis Page** allows the user to input direct costs in tables like the data entry form. Rows can be added and deleted but will require a year input at the beginning of each row. The ***Graph Direct***

Costs button will create a line graph for each of the categories in separate colors with the year as the X-axis and the Total Cost as the Y-axis. The minimum and maximum will also be labeled on the graph.

5.6 Remove/Modify Submitted Data

Whenever the ***Submit*** button is used, any data with a matching scenario code will be overwritten with the current data that is being submitted. This allows the user to edit data for each scenario code by first using the ***Load*** button to bring in previously entered data, make edits to it, and submit it once again.



To remove data entirely without overwriting it, use the ***Go To Database*** button and this will bring the user to the database sheet for the specific table the button is next to. Here the user can right click any row and delete it from the table entirely or modify the table.

5.7 Tool Maintenance

This section goes through the backend of the tool for future maintenance.

Modules in Tool:

Modules	Subs	Description	Sheets Utilizing Command
Module 1	Sub GoToSheet(SheetName)()	Brings the user to the database sheet for a table. This macro is repeated through the data entry form.	Data Entry Form
Module 1	LoadScenarioData()	Loads previously submitted data onto the data entry form from the various database sheets based on the scenario code that is currently inputted.	Data Entry Form
Module 1	AddRowToTable(tableName As String)	Helper function for LoadScenarioData()	Data Entry Form
Module 1	DeleteLastRowFromTable(tableName As String)	Helper function for LoadScenarioData()	Data Entry Form
Module 1	AddScenarioCodeToDropdown()	Saves the current input scenario code to the dropdown list.	Data Entry Form
Module 1	ClearAllTables()	Clears all data input in the tables on the Data Entry Sheet and reduces row sizes to one.	Data Entry Form
Module 1	Submit(***TableName***)TableData()	Submits the data currently entered into the specific category table on the data entry form, to the correct database sheet table. This macro is repeated throughout the data entry form.	Data Entry Form

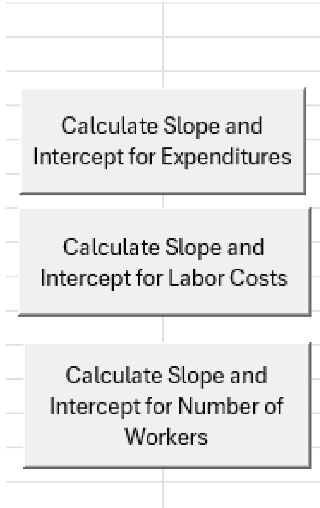
Module 1	AddRowTo(***TableName***)Table()	Adds row to specified table. This macro is repeated throughout the data entry form and the direct cost analysis sheets.	Data Entry Form, Direct Cost Analysis
Module 1	DeleteLastRowFromDelayTable( )	Deletes the last row from the specified table down to a minimum of one. This macro is repeated throughout the data entry form and the direct cost analysis sheets.	Data Entry Form, Direct Cost Analysis
Module 2	CalculateAll()	Performs the following macros: CalculateBudgetProjection() CalculateAnnualCashFlowCosts(), CalculateCostPerLaneMile(), CalculateAnnualCashFlowBenefits() CalculateBenefitCostRatio().	Data Entry Form
Module 2	CalculateBudgetProjection()	Calculates the direct costs based on matching scenario code data.	Data Entry Form
Module 2	CalculateAnnualCashFlowCosts	Calculates total annual costs based on matching scenario code data.	Data Entry Form
Module 2	CalculateCostPerLaneMile()	Calculates the cost per lane mile based on matching scenario code data.	Data Entry Form
Module 2	CalculateAnnualCashFlowBenefits()	Calculates annual cash flow of benefits based on matching scenario code data.	Data Entry Form
Module 2	CalculateBenefitCostRatio	Calculates the benefit to cost ratio based on the total annual costs and the annual cash flow benefits.	Data Entry Form
Module 2	SaveResults()	Saves the results in the results table to the results sheet and table with the inputted scenario code.	Data Entry Form
Module 3	CalculateExpenditures	Performs linear regression on the StateDataTable to calculate the slope and intercept for each state based on AWSSI and Expenditures.	State Data
Module 3	CalculateLaborCosts()	Performs linear regression on the StateDataTable to calculate the slope and intercept for each state based on AWSSI and Labor Costs.	State Data
Module 3	CalculateWorkers	Performs linear regression on the StateDataTable to calculate the slope and intercept for each state based on AWSSI and number of workers.	State Data
Module 5	CalculateEstimatedExpenditures ()	Calculates the annual direct costs for the whole state with user inputted AWSSI using the slope intercept formula and the matching state slope and intercept for expenditures.	Data Entry Form
Module 5	CalculateLaborCostAndWorkers ()	Calculates the total event hours for the whole state with user inputted AWSSI and average hourly rate using the slope intercept formula and the matching state slope and intercept for number of workers and labor costs.	Data Entry Form
Module 4	CreateCostPerYearGraph()	Plots Cost Per Year graph based on user input in each category for direct costs.	Direct Cost Analysis
Module 4	Sub LabelMinMax(series As series, data As Object)	Helper function for CreateCostPerYearGraph() to label the min and max on the graph.	Direct Cost Analysis

Module 4	CopyScenarioResults()	Loads the saved results based on the input scenario code into the correct cells. This macro is repeated in the Summary Page.	Summary Page

5.8 Updating Data For Estimations

State	Year	AWSSI	Expenditures	Labor Cost	Workers	Labor (In House)	Labor (Private)
Alabama	2022	34					
Alaska	2022	2,527		$ 13,633,838	553	480	73
Arizona	2022	416	$ 13,799,159	$ 4,326,025	520	520	0
Arkansas	2022	94			0		
California	2022	421	$ 170,344,209	$ 77,450,659	2545	1,945	600
Colorado	2022	780	$ 113,339,226	$ 35,275,715	1488	1,408	80
Connecticut	2022	368	$ 16,979,218	$ 9,217,971	1380	1,380	0
Delaware	2022	86	$ 602,684	$ 211,707	452	404	48
District of Columbia	2022	47			0		
Florida	2022	6			0		
Georgia	2022	23	$ 10,737,042	$ 3,393,463	1922	1,922	0
Hawaii	2022				0		
Idaho	2022	1,006	$ 30,022,351	$ 5,760,787	571	551	20
Illinois	2022	327	$ 78,651,767	$ 22,502,567	3116	1,690	1,426
Indiana	2022	290	$ 35,726,079	$ 4,125,549	1858	1,753	105
Iowa	2022	653			1494	1,069	425
Kansas	2022	388	$ 14,582,000	$ 5,868,000	1130	1,100	30
Kentucky	2022	119	$ 45,968,551	$ 10,252,827	1800	1,800	0
Louisiana	2022	24			0		
Maine	2022	1,408	$ 47,800,000	$ 17,800,000	745	745	0
Maryland	2022	88	$ 35,755,531	$ 11,401,341	780	750	30
Massachusetts	2022	244	$ 92,571,000	$ 9,380,000	1200	400	800
Michigan	2022	1,080	$ 108,969,258		519	410	109
Minnesota	2022	1,646	$ 173,953,000	$ 59,777,671	1756	1,663	93
Mississippi	2022	49			0		
Missouri	2022	224	$ 31,747,628	$ 11,330,492	2597	2,180	417
Montana	2022	1,368	$ 35,347,362	$ 12,881,984	729	565	164
Nebraska	2022	726	$ 37,420,000	$ 12,004,000	833	783	50
Nevada	2022	801	$ 22,055,582	$ 7,703,521	434	431	3
New Hampshire	2022	916	$ 54,044,136	$ 20,417,422	680	680	0

On the **State Data** sheet there is a table that contains data related to reported data on a state's direct cost expenditures that comprises labor, materials, and fuel. It also contains how many workers that were hired by the state both in-house and private, organized by year from 2014 to 2023. When calculating annual direct costs and annual winter event hours the estimations may not be available for states without reported data or may be more accurate for some states due to a higher volume of reported data.



State	Slope	Intercept
Alabama	60043.70328	207592.5276
Arizona	29755.08477	1448996.121
Arkansas (Negative Slope)	-8225.033113	16211679.07
California	406461.2216	0
Colorado	197634.6588	0
Connecticut	35182.31643	11558128.57
Delaware	65647.99635	0
Georgia	93552.12389	6743641.664
Idaho	22824.97256	4383171.595
Illinois	83975.73718	44309906.22
Indiana	30263.11846	23536668.79
Iowa	19411.94923	21210644.52
Kansas	44966.16365	387254.4408
Kentucky	145480.2165	22287819.7
Maine	4525.832448	32436227.41
Maryland	373703.3178	8666139.438
Massachusetts	100438.6118	51333123.02
Michigan	25713.56137	72329505.79
Minnesota	71321.1531	21374452.23
Missouri	122972.8124	7510280.647
Montana	14256.90842	11965457.72
Nebraska	45903.78133	2773240.519
Nevada	26897.67141	1084779.661
New Hampshire	3657.827512	43220221.85
New Jersey	336850.0774	0
New Mexico	196363.6364	0
New York (Negative Slope)	-94514.44797	437959228.7
North Dakota	13809.99597	3044160.037
Ohio	107525.5911	58960082.37
Oregon	24020.22805	22475489.07
Pennsylvania	169914.3872	178338908.5
Rhode Island	2114.638237	10254739.08
South Carolina	30895.04945	1548538.471
South Dakota	23613.78457	0
Tennessee	56563.15054	14580691.79
Texas	389318.5847	0
Utah	20969.20301	15560860.28
Vermont	20072.94586	10923936.86
Virginia	1654843.976	0
Washington	34548.15769	36332935.67
West Virginia	133519.518	0
Wisconsin	49391.53774	37763033.74
Wyoming	22752.63923	5084072.024

State	Slope (Labor Costs)	Intercept (Labor Costs)
Alabama	27697.8206	0
Alaska (Negative Slope)	-48312.67895	135719977.7
Arizona	10039.43905	196081.2436
California	177978.9652	0
Colorado	59113.29953	0
Connecticut	20891.01958	4490639.444
Delaware	14862.10966	0
Georgia	12994.15428	2816096.618
Idaho	4566.077087	632411.3603
Illinois	26666.66484	13251001.26
Indiana	10760.42487	326851.5219
Iowa	4514.688911	10554508.2
Kansas	15205.32548	968355.3258
Kentucky	40225.96438	4790008.229
Maine	452.9962885	13348897.1
Maryland	77546.58996	6690477.649
Massachusetts	9534.996779	6145696.636
Minnesota	15230.91559	13473076.08
Missouri	64082.66586	113642.392
Montana	7016.320663	2367182.547
Nebraska	18084.68966	0
Nevada	10376.55886	0
New Hampshire	124.2956775	15713402.05
New Jersey	58646.61654	0
New York (Negative Slope)	-84735.64929	268295748
North Dakota	5811.820013	1431118.963
Ohio	2680.606715	26704648.94
Oregon	8255.297948	9554665.474
Pennsylvania	57560.67681	83855644.24
Rhode Island (Negative Slope)	-740.4978528	1544751.796
South Carolina	15100.53077	521845.841
South Dakota	6051.3156	0
Tennessee	17510.62313	4529467.305
Texas	215986.5326	0
Utah (Negative Slope)	-7913.673072	12828751.59
Vermont	1482.763221	10093109.72
Virginia	38312.12122	19142081.33
Washington	10850.20631	15349351.07
West Virginia	41302.46969	2579661.674
Wisconsin	12940.33039	11142744.3
Wyoming	17349.69414	0

State	Slope (Workers)	Intercept (Workers)
Alabama	-12.16727861	1190.746538
Alaska	0.005834662	157.8823569
Arizona	0.173613051	442.6901596
Arkansas	3.881678666	0
California	0.316047664	3698.832199
Colorado	-1.483245433	2623.680225
Connectic	-0.231847532	1480.710305
Delaware	-1.177387412	583.767947
District of	0	0
Florida	0	0
Georgia	-7.196598944	1222.373904
Idaho	0.199743499	340.50751
Illinois	-2.588812421	4203.793709
Indiana	-1.678568559	2069.559679
Iowa	0.206707104	1376.862915
Kansas	-2.285934881	1936.259979
Kentucky	-1.293657782	1233.991237
Louisiana	2.818391767	19.93091822
Maine	0.091605766	773.5028353
Maryland	-3.63456893	1359.505815
Massachu	-0.449721728	1180.390575
Michigan	-0.046229287	500.4002652
Minnesota	2.08613356	0
Mississip	-0.498331814	51.25421522
Missouri	0.974283215	2736.563998
Montana	-0.016853494	744.7437564
Nebraska	0.014555081	962.8218757
Nevada	-0.356332349	527.3455124
New Ham	-0.003322932	675.4337268
New Jerse	0.254263789	303.125706
New Mexi	-3.629304962	1104.592504
New York	0.569782851	3075.154333
North Car	0	0
North Dak	-0.000423379	366.9926164
Ohio	0.530981069	2762.024526
Oklahoma	-2.472373837	536.9400411
Oregon	0.392567478	916.265499
Pennsylva	0.887343125	4398.183934
Rhode Isla	-0.015179606	158.2180722
South Car	-8.665773911	1606.199486
South Dak	0.018707771	395.7383864
Tennessee	5.885177085	0
Texas	21.47685731	2047.190804
Utah	0.842932731	209.2083265
Vermont	0.013163087	320.5886769
Virginia	0.450859969	746.4551569
Washingt	0.253030799	1217.669557
West Virgi	-0.045266868	4655.297742
Wisconsir	0	0
Wyoming	0.951558184	0

Using the ***Calculate Slope and Intercept*** buttons, the slopes and intercepts can be generated through linear regression and the data in the previously mentioned table. The current slopes and intercepts for the tool have already been generated. States with a negative slope and states with no data will not have predictive analytics available. However, if data is directly added to the table in the same format provided the ***Calculate Slope and Intercept*** can be used to generate a new set of slopes and intercepts. These buttons can also be used to generate a new set if data for more recent years are added as well.

5.9 Hidden Sheets

There are two hidden sheets within the tool. One contains the data used for linear regression called **State Data** which was previously mentioned. The other sheet called **Dropdowns** contains all the dropdowns used in the Tool. To unhide either of the tabs, simply right-click any of the tabs and click “Unhide…”, select the “Dropdown” or “State Data” tab from the panel, and press “OK”. The hidden list tab will appear at the very end of the sheet list. In the Dropdown tab, there are some values linked to some dropdown lists in the tool.

6. Conclusion

As presented in this report, the main research output is the tool itself, along with a tool manual and this report. The tool is meant to be flexible to meet the needs of a variety of agencies and available data. Some agencies may have resources to get granular data points, while others may just have higher level data points. The tool allows for both options. The tool’s default data may require updating, which is outlined in the manual, along with agencies adding their own default values. The tool offers a useful and practical way for agencies to estimate and understand the benefits and costs of their winter maintenance operations.

Appendix A – Survey Responses

Question 1. Does your agency have a mission statement and/or legislative language governing your agency's roadway snow and ice mitigation program.

Agency	Response	If yes, please provide a brief description
Texas Department Transportation	Yes	Connecting you with Texas
Minnesota Department of Transportation	No	We do not have a mission statement specific to snow and ice operations, but we follow MnDOT Strategic Directions outlined at: https://www.dot.state.mn.us/policy/operations/oe015-guidance.html...
Ministere des Transports et de la Mobilité Durable du Québec	Yes	General statement of the MTMD : Promote the sustainable mobility of people and goods through safe and accessible transportation systems that contribute to the development of Quebec
NDDOT	Yes	Safely move people and goods
WYDOT	Yes	Not specifically for snow and ice but overall "To provide a safe, high quality, and efficient transportation system".
Montana	No	
NDDOT	No	
Town of Middlebury	No	
Kansas DOT	No	
UDOT	Yes	We have a snow removal policy: https://drive.google.com/file/d/15KS3yAw6rwpJUkWRnR2TDTqqimD-dV1x/view We also have an admin policy regarding snow removal: https://adminrules.utah.gov/public/rule/R918-3/Current%20Rules?searchText=918-3
Directorate of Roads and Highways	Yes	
Rijkswaterstaat Netherlands	Yes	we have a legal responsibility to do everything we can to prevent slippery roads the mission roads are black in all conditions (not always possible)
Ville de Pointe-Claire	No	
Kansas DOT	No	
Norwegian Public Roads Administration	Yes	The government gives the NPRA instructions every year in a "order" letter. Describing the mission and goals for our activity.
Vermont Agency of Transportation	Yes	Snow and Ice Control plan that provides info on BMPs, application rates, levels of service, expectations.
NHDOT	No	
IL DOT	No	

Agency	Response	If yes, please provide a brief description
Massachusetts Dept. of Transportation	Yes	Chapter 81, Section 19 of the General Laws as amended by Chapter 187, Acts of 1933 authorizes and directs the Massachusetts Highway Department to keep such state highways or parts thereof as it may select, sufficiently clear of snow and ice to be reasonably safe for public travel; the Department engages in this activity to promote highway safety and mobility during winter weather.
City of Farmington Hills, MI	Yes	It's in our Lobby, I'll provide when I'm @ the DPW location if needed. We just went through the APWA Re-Accreditation process…. We had to post it…
Iowa DOT	Yes	We do not have a mission statement or legislative language but we use Instructional Memorandums or IM's to provide our field staff with general guidelines for Winter Operations.
Alaska DOT&PF	Yes	Mission Statement is year-round- "Keep Alaska moving...."
Montana Department of Transportation	Yes	The Montana Department of Transportation's mission is to serve the public by providing a transportation system and services that emphasizes quality, safety, cost-effectiveness, economic vitality and sensitivity to the environment.
Kansas DOT	No	
City of Bozeman MT	No	
Kiewit Meridiam Partners	No	
City of Columbus, Ohio	Yes	The purpose of the City of Columbus Snow and Ice Control Plan is to allocate trained personnel, proper equipment and adequate materials to provide Passable Roadways that allow for safe traveling conditions on roadways.
City of Columbus, Depart. of Public Service	Yes	The purpose of the City of Columbus Snow and Ice Control Plan is to allocate trained personnel, proper equipment and adequate materials to provide Passable Roadways that allow for safe traveling conditions on roadways.

<u>Question 2.</u> Does your agency have a standard method for determining the costs of winter operations?

Agency	Response	If yes, can you outline a high-level method used?
Texas Department Transportation	Yes	TxDOT captures cost via MMS to get actual cost of each event. At the end of the season a review of cost will be reviewed to project the next year's budget.
Minnesota Department of Transportation	Yes	MnDOT tracks labor, equipment and material costs for snow and ice operations and supporting activities down to the route level which are then reported at a District and Statewide level. Several of the factors which determine the costs of winter operations can be found in the following link. https://www.dot.state.mn.us/maintenance/winter-report.html

Agency	Response	If yes, can you outline a high-level method used?
Ministere des Transports et de la Mobilité Durable du Québec	Yes	Many methods are used : entrepreneur calculation method, detailed network characterization, past contracts value, inflation rate, salt use
NDDOT	Yes	5 year average of snow and ice control costs (mainly labor, equipment, and materials costs)
WYDOT	Yes	5yr avg
Montana	Yes	We have Winter Maintenance Activates that we track and calculate the costs
NDDOT	Yes	Cost Tracking Performance Measure utilizing 5 year average and tracking with Clear Roads Winter severity index
Town of Middlebury	Yes	salt use, labor hours, equipment costs
Kansas DOT	Yes	Annual costs of Labor, Equipment, materials, and contracts. Dollars and quantities
UDOT	Yes	Three year average, additional money for inflation and new lane miles on the system
Directorate of Roads and Highways	Yes	we monetize salt use on m2, also we plan our service in central system for our company so we can calculate our cost and also effect on environment near to roads
Rijkswaterstaat Netherlands	Yes	we take the average over the last ten years and take indexations etc. in to account
Ville de Pointe-Claire	No	
Kansas DOT	Yes	Labor, Equipment, Materials & Other are tracked and tabulated.
Norwegian Public Roads Administration	Yes	The model calculate the amount of road length and road objects who requires winter maintenance, and the number of actions depending on the winter climate and the AADT and price per action.
Vermont Agency of Transportation	Yes	winter severity versus winter costs.
NHDOT	Yes	We use the past 5 years of storm data and figure in the increased cost of labor and materials.
IL DOT	Yes	We create a weekly snow and ice report during winter months that compares current year costs to the average of the previous 3 years. This includes salt usage, man hours, fuel and equipment costs.
Massachusetts Dept. of Transportation	Yes	We have a Winter Operations (Snow & Ice) budget that addresses 3 needs: 1)Hired Equipment (85% of our winter roadway maintenance is performed by contractors); 2) Materials (Salt - mined/solar and liquid magnesium chloride as well as a few thousand tons of sand (very minor). Our standard winter operations annual cost report neglects the cost/depreciation of state-owned assets (or Vendor equipment since we're "renting" it).

Agency	Response	If yes, can you outline a high-level method used?
City of Farmington Hills, MI	Yes	Budget and accounting of labor hours , equipment use age, material usage etc.
Iowa DOT	Yes	We track all materials that are applied to the roadway during winter operations for the entire winter season. We then calculate the total material costs for each district and garage. We have the total of lane miles for each district and garage separated into high volume roadways down to low volume roadways to show the total amount of lane miles each garage is responsible for based on traffic volume. We then do a straight calculation of total material costs per lane mile for each garage.
Alaska DOT&PF	No	
Montana Department of Transportation	Yes	MDT uses a Maintenance Management System that we can pull data and information out of nearly live time
Kansas DOT	Yes	Actual costs after all labor, equipment, and materials are entered into the system.
City of Bozeman MT	No	
Kiewit Meridiam Partners	No	
City of Columbus, Ohio	Yes	We utilize a work order system which estimates costs
City of Columbus, Depart. of Public Service	No	

<u>Question 3.</u> Does your agency have a standard method for determining the benefits or Return On Investment (ROI) of winter operations?

Agency	Response	If yes, can you outline a high-level method used?
Texas Department Transportation	Yes	No is the response, however wanted to make a comment. Crashes are reviewed and a goal of returning to dry roadway is also used.
Minnesota Department of Transportation	No	
Ministere des Transports et de la Mobilité Durable du Québec	No	
NDDOT	Yes	Performance Measures: Speed recovery after winter storms and roads open to traffic
WYDOT	No	
Montana	No	

Agency	Response	If yes, can you outline a high-level method used?
NDDOT	Yes	We have a winter speed recovery performance measure and recently replicated MNDOTS Brine use/Salt use yearly performance measure.
Town of Middlebury	No	
Kansas DOT	No	
UDOT	Yes	We have a dashboard that breaks down cost per storm, avoided crash benefits, reduced delay benefits and total estimated dollar benefit.
Directorate of Roads and Highways	Yes	
Rijkswaterstaat Netherlands	Yes	we are a government agency (ministry of infrastructure and waterworks) and have the legal responsibility to provide safe roads so return on investment is not an issue
Ville de Pointe-Claire	No	
Kansas DOT	No	
Norwegian Public Roads Administration	No	
Vermont Agency of Transportation	Yes	Working on measures for return to normal travel speeds.
NHDOT	No	
IL DOT	No	
Massachusetts Dept. of Transportation	No	
City of Farmington Hills, MI	Yes	We have had the traffic engineer get our crash data in the past but not sure if we separated the weather stuff and winter season from all accidents… something to look into
Iowa DOT	No	
Alaska DOT&PF	No	
Montana Department of Transportation	No	
Kansas DOT	No	
City of Bozeman MT	No	
Kiewit Meridiam Partners	No	
City of Columbus, Ohio	No	
City of Columbus, Depart. of Public Service	No	

Question 4. What challenges do you experience when developing your budget for snow and ice operations? (select all that apply)

Agency	Quality of Data or Lack of Data	Time/staffing and/ or financial resources	Hard to predict needs within variable weather patterns	Increase cost of material/labor (inflation)	Other
Texas Department Transportation	Quality of Data or Lack of Data		Hard to predict needs within variable weather patterns	Increase cost of material / labor (inflation)	
Minnesota Department of Transportation		Time / staffing and/or financial resources	Hard to predict needs within variable weather patterns	Increase cost of material / labor (inflation)	We address unanticipated impacts to snow and ice budgets by transfers from other budget lines/sources, for extreme winters we have a Snow and Ice Budget Contingency process which allows us to access additional budget without specific legislative authorization, we budget based on a 5 year average to address variable winters, allowed to acquire other money SRC (State Road Construction) and capital funds. With the exception of the Snow and Ice Contingency accessing other sources impacts those programs which could present challenges in other areas.
Ministere des Transports et de la Mobilité Durable du Québec	Quality of Data or Lack of Data		Hard to predict needs within variable weather patterns	Increase cost of material / labor (inflation)	poor competition and lack of interest from the industry
NDDOT			Hard to predict needs within variable weather patterns	Increase cost of material / labor (inflation)	
WYDOT			Hard to predict needs within variable weather patterns	Increase cost of material / labor (inflation)	

Agency	Quality of Data or Lack of Data	Time/staffing and/or financial resources	Hard to predict needs within variable weather patterns	Increase cost of material/labor (inflation)	Other
Montana					Montana does not have a line-item winter Budget, we have an overall budget and winter activities come off the top
NDDOT				Increase cost of material / labor (inflation)	Timely data our financial system spits out totals on 16th of month.
Town of Middlebury		Time / staffing and/or financial resources	Hard to predict needs within variable weather patterns	Increase cost of material / labor (inflation)	
Kansas DOT			Hard to predict needs within variable weather patterns		
UDOT		Time / staffing and/or financial resources	Hard to predict needs within variable weather patterns	Increase cost of material / labor (inflation)	
Directorate of Roads and Highways	Quality of Data or Lack of Data		Hard to predict needs within variable weather patterns		
Rijkswaterstaat Netherlands					
Ville de Pointe-Claire	Quality of Data or Lack of Data		Hard to predict needs within variable weather patterns	Increase cost of material / labor (inflation)	
Kansas DOT			Hard to predict needs within variable weather patterns		
Norwegian Public Roads Administration	Quality of Data or Lack of Data		Hard to predict needs within variable weather patterns	Increase cost of material / labor (inflation)	

Agency	Quality of Data or Lack of Data	Time/staffing and/or financial resources	Hard to predict needs within variable weather patterns	Increase cost of material/labor (inflation)	Other
Vermont Agency of Transportation		Time / staffing and/or financial resources	Hard to predict needs within variable weather patterns	Increase cost of material / labor (inflation)	
NHDOT			Hard to predict needs within variable weather patterns	Increase cost of material / labor (inflation)	
IL DOT		Time / staffing and/or financial resources	Hard to predict needs within variable weather patterns	Increase cost of material / labor (inflation)	
Massachusetts Dept. of Transportation		Time / staffing and/or financial resources	Hard to predict needs within variable weather patterns		Staffing hits on it, but the 1,000+ contractors we work with need drivers to fill their seats, or valuable would-be equipment sits idle.
City of Farmington Hills, MI	Quality of Data or Lack of Data		Hard to predict needs within variable weather patterns		It's also hard to achieve a high level of service at all times depending on the timing of events etc.
Iowa DOT			Hard to predict needs within variable weather patterns	Increase cost of material / labor (inflation)	We utilize historic data from our GPS/AVL system and our Workday system to help guide budget decisions.
Alaska DOT&PF	Quality of Data or Lack of Data		Hard to predict needs within variable weather patterns	Increase cost of material / labor (inflation)	
Montana Department of Transportation			Hard to predict needs within variable weather patterns	Increase cost of material / labor (inflation)	
Kansas DOT			Hard to predict needs within variable weather patterns		

Agency	Quality of Data or Lack of Data	Time/staffing and/ or financial resources	Hard to predict needs within variable weather patterns	Increase cost of material/labor (inflation)	Other
City of Bozeman MT		Time / staffing and/or financial resources	Hard to predict needs within variable weather patterns		
Kiewit Meridiam Partners			Hard to predict needs within variable weather patterns		
City of Columbus, Ohio	Quality of Data or Lack of Data		Hard to predict needs within variable weather patterns	Increase cost of material / labor (inflation)	We are lucky that our council makes sure we have adequate funding; our only financial struggle is equipment budget.
City of Columbus, Depart. of Public Service			Hard to predict needs within variable weather patterns	Increase cost of material / labor (inflation)	

Question 5. What challenges do you have in determining your benefits for snow and ice operations? (select all that apply)

Agency	Quality of Data or Lack of Data	Time/staffing and/ or financial resources	Hard to predict needs within variable weather patterns	Increase cost of material/labor (inflation)	Other
Texas Department Transportation		Quality of Data or Lack of Data	Time / staffing and/or financial resources	Hard to predict/capture impact to society	Current project to get AVL in all plows to collect data to truck
Minnesota Department of Transportation		Quality of Data or Lack of Data		Hard to predict/capture impact to society	
Ministere des Transports et de la Mobilité Durable du Québec	Not Applicable - your agency does not calculate benefits				

Agency	Quality of Data or Lack of Data	Time/staffing and/ or financial resources	Hard to predict needs within variable weather patterns	Increase cost of material/labor (inflation)	Other
NDDOT				Hard to predict/capture impact to society	
WYDOT	Not Applicable - your agency does not calculate benefits				
Montana					
NDDOT		Quality of Data or Lack of Data		Hard to predict/capture impact to society	
Town of Middlebury		Quality of Data or Lack of Data		Hard to predict/capture impact to society	
Kansas DOT		Quality of Data or Lack of Data		Hard to predict/capture impact to society	
UDOT		Quality of Data or Lack of Data	Time / staffing and/or financial resources	Hard to predict/capture impact to society	personnel to perform analysis of benefits.
Directorate of Roads and Highways			Time / staffing and/or financial resources	Hard to predict/capture impact to society	
Rijkswaterstaat Netherlands	Not Applicable - your agency does not calculate benefits				

Agency	Quality of Data or Lack of Data	Time/staffing and/ or financial resources	Hard to predict needs within variable weather patterns	Increase cost of material/labor (inflation)	Other
Ville de Pointe-Claire		Quality of Data or Lack of Data		Hard to predict/capture impact to society	We know AECOM has access to "delay avoidance" and associated data. We believe the benefits of S&I ops actually outweigh the costs (or why would we be doing it?) I think this research and tool will underscore how valuable the benefits of our combined S&I Ops are by seeing them dwarf the costs that obtained them.
Kansas DOT				Hard to predict/capture impact to society	We do get mostly positive feedback on our pro active methods such as Anti icing etc.
Norwegian Public Roads Administration				Hard to predict/capture impact to society	
Vermont Agency of Transportation				Hard to predict/capture impact to society	
NHDOT	Not Applicable - your agency does not calculate benefits				
IL DOT	Not Applicable - your agency does not calculate benefits				
Massachusetts Dept. of Transportation			Time / staffing and/or financial resources	Hard to predict/capture impact to society	
City of Farmington Hills, MI					Contractual performance requirements
Iowa DOT		Quality of Data or Lack of Data	Time / staffing and/or financial resources	Hard to predict/capture impact to society	

Agency	Quality of Data or Lack of Data	Time/staffing and/ or financial resources	Hard to predict needs within variable weather patterns	Increase cost of material/labor (inflation)	Other
Alaska DOT&PF	Not Applicable - your agency does not calculate benefits				
Montana Department of Transportation		Quality of Data or Lack of Data	Time / staffing and/or financial resources	Hard to predict/capture impact to society	Current project to get AVL in all plows to collect data to truck
Kansas DOT		Quality of Data or Lack of Data		Hard to predict/capture impact to society	
City of Bozeman MT	Not Applicable - your agency does not calculate benefits				
Kiewit Meridiam Partners				Hard to predict/capture impact to society	
City of Columbus, Ohio	Not Applicable - your agency does not calculate benefits				
City of Columbus, Depart. of Public Service					

Question 6. Select which of the following data elements you currently include or would like to include in your operational cost calculations. (select all that apply)

Agency	Material Cost	Salt Spreaders	Facilities and material storage cost	Snow Hauling and Disposal	Plows (Including Blades)	Trucks, Motor Graders, Loaders	AVL Capital Cost	RWIS Capital Cost	MDSS	Route-optimization tools	Equipment Maintenance Costs	AVL Subscription Costs
Texas Department Transportation	Material Cost	Salt Spreaders	Facilities and material storage cost		Plows (Including Blades)	Trucks, Motor Graders, Loaders					Equipment Maintenance Costs	
Minnesota Department of Transportation	Material Cost	Salt Spreaders	Facilities and material storage cost	Snow Hauling and Disposal	Plows (Including Blades)	Trucks, Motor Graders, Loaders	AVL Capital Cost	RWIS Capital Cost	MDSS	Route-optimization tools	Equipment Maintenance Costs	AVL Subscription Costs
Ministere des Transports et de la Mobilité Durable du Québec	Material Cost	Salt Spreaders	Facilities and material storage cost		Plows (Including Blades)	Trucks, Motor Graders, Loaders					Equipment Maintenance Costs	AVL Subscription Costs
NDDOT	Material Cost		Facilities and material storage cost	Snow Hauling and Disposal	Plows (Including Blades)	Trucks, Motor Graders, Loaders	AVL Capital Cost	RWIS Capital Cost	MDSS		Equipment Maintenance Costs	AVL Subscription Costs
WYDOT									MDSS			
Montana	Material Cost	Salt Spreaders		Snow Hauling and Disposal	Plows (Including Blades)	Trucks, Motor Graders, Loaders					Equipment Maintenance Costs	
NDDOT	Material Cost				Plows (Including Blades)	Trucks, Motor Graders, Loaders			MDSS			
Town of Middlebury	Material Cost	Salt Spreaders	Facilities and material storage cost		Plows (Including Blades)	Trucks, Motor Graders, Loaders	AVL Capital Cost				Equipment Maintenance Costs	
Kansas DOT	Material Cost	Salt Spreaders			Plows (Including Blades)	Trucks, Motor Graders, Loaders						
UDOT	Material Cost	Salt Spreaders	Facilities and material storage cost		Plows (Including Blades)	Trucks, Motor Graders, Loaders	AVL Capital Cost	RWIS Capital Cost			Equipment Maintenance Costs	AVL Subscription Costs
Directorate of Roads and Highways	Material Cost	Salt Spreaders			Plows (Including Blades)	Trucks, Motor Graders, Loaders				Route-optimization tools	Equipment Maintenance Costs	

Agency	Material Cost	Salt Spreaders	Facilities and material storage cost	Snow Hauling and Disposal	Plows (Including Blades)	Trucks, Motor Graders, Loaders	AVL Capital Cost	RWIS Capital Cost	MDSS	Route-optimization tools	Equipment Maintenance Costs	AVL Subscription Costs
Rijkswaterstaat Netherlands												
Ville de Pointe-Claire	Material Cost	Salt Spreaders	Facilities and material storage cost	Snow Hauling and Disposal	Plows (Including Blades)	Trucks, Motor Graders, Loaders					Equipment Maintenance Costs	
Kansas DOT	Material Cost				Plows (Including Blades)	Trucks, Motor Graders, Loaders					Equipment Maintenance Costs	
Norwegian Public Roads Administration												
Vermont Agency of Transportation	Material Cost				Plows (Including Blades)	Trucks, Motor Graders, Loaders						
NHDOT	Material Cost				Plows (Including Blades)	Trucks, Motor Graders, Loaders					Equipment Maintenance Costs	
IL DOT	Material Cost			Snow Hauling and Disposal	Plows (Including Blades)	Trucks, Motor Graders, Loaders						
Massachusetts Dept. of Transportation	Material Cost	Salt Spreaders	Facilities and material storage cost	Snow Hauling and Disposal	Plows (Including Blades)	Trucks, Motor Graders, Loaders	AVL Capital Cost	RWIS Capital Cost	MDSS		Equipment Maintenance Costs	AVL Subscription Costs
City of Farmington Hills, MI	Material Cost	Salt Spreaders	Facilities and material storage cost		Plows (Including Blades)	Trucks, Motor Graders, Loaders	AVL Capital Cost	RWIS Capital Cost	MDSS			AVL Subscription Costs
Iowa DOT	Material Cost	Salt Spreaders			Plows (Including Blades)	Trucks, Motor Graders, Loaders	AVL Capital Cost	RWIS Capital Cost			Equipment Maintenance Costs	AVL Subscription Costs
Alaska DOT&PF	Material Cost			Snow Hauling and Disposal	Plows (Including Blades)	Trucks, Motor Graders, Loaders	AVL Capital Cost	RWIS Capital Cost	MDSS		Equipment Maintenance Costs	
Montana Department of Transportation	Material Cost	Salt Spreaders	Facilities and material storage cost	Snow Hauling and Disposal	Plows (Including Blades)	Trucks, Motor Graders, Loaders	AVL Capital Cost	RWIS Capital Cost			Equipment Maintenance Costs	AVL Subscription Costs
Kansas DOT	Material Cost											

Agency	Material Cost	Salt Spreaders	Facilities and material storage cost	Snow Hauling and Disposal	Plows (Including Blades)	Trucks, Motor Graders, Loaders	AVL Capital Cost	RWIS Capital Cost	MDSS	Route-optimization tools	Equipment Maintenance Costs	AVL Subscription Costs
City of Bozeman MT	Material Cost									Route-optimization tools		AVL Subscription Costs
Kiewit Meridiam Partners	Material Cost	Salt Spreaders	Facilities and material storage cost		Plows (Including Blades)	Trucks, Motor Graders, Loaders	AVL Capital Cost		MDSS	Route-optimization tools	Equipment Maintenance Costs	AVL Subscription Costs
City of Columbus, Ohio	Material Cost		Facilities and material storage cost		Plows (Including Blades)	Trucks, Motor Graders, Loaders	AVL Capital Cost	RWIS Capital Cost	MDSS	Route-optimization tools	Equipment Maintenance Costs	AVL Subscription Costs
City of Columbus, Depart. of Public Service	Material Cost				Plows (Including Blades)	Trucks, Motor Graders, Loaders	AVL Capital Cost				Equipment Maintenance Costs	

Agency	Fuel	Full-Time Labor Costs	Seasonal Labor Costs	Contractor Labor Costs	Training Costs	Mobility Delay Cost (User Delay Cost; Passenger Vehicles and Commercial)	Third Party Data (Weather, Traffic, Etc.)	Public outreach (including public facing websites)	Planning and administrative cost	Roadside investments (snow fence, living snow fence, etc.)	Other (please specify)
Texas Department Transportation	Fuel	Full-Time Labor Costs		Contractor Labor Costs		Mobility Delay Cost (User Delay Cost; Passenger Vehicles and Commercial)	Third Party Data (Weather, Traffic, Etc.)	Public outreach (including public facing websites)			
Minnesota Department of Transportation	Fuel	Full-Time Labor Costs	Seasonal Labor Costs	Contractor Labor Costs	Training Costs		Third Party Data (Weather, Traffic, Etc.)	Public outreach (including public facing websites)	Planning and administrative cost	Roadside investments (snow fence, living snow fence, etc.)	
Ministere des Transports et de la Mobilité Durable du Québec	Fuel	Full-Time Labor Costs	Seasonal Labor Costs	Contractor Labor Costs					Planning and administrative cost	Roadside investments (snow fence, living snow fence, etc.)	road signs, snow blowing, climate change / extreme weather

Agency	Fuel	Full-Time Labor Costs	Seasonal Labor Costs	Contractor Labor Costs	Training Costs	Mobility Delay Cost (User Delay Cost; Passenger Vehicles and Commercial)	Third Party Data (Weather, Traffic, Etc.)	Public outreach (including public facing websites)	Planning and administrative cost	Roadside investments (snow fence, living snow fence, etc.)	Other (please specify)
NDDOT	Fuel	Full-Time Labor Costs	Seasonal Labor Costs	Contractor Labor Costs						Roadside investments (snow fence, living snow fence, etc.)	
WYDOT						Mobility Delay Cost (User Delay Cost; Passenger Vehicles and Commercial)	Third Party Data (Weather, Traffic, Etc.)			Roadside investments (snow fence, living snow fence, etc.)	
Montana	Fuel	Full-Time Labor Costs	Seasonal Labor Costs	Contractor Labor Costs	Training Costs					Roadside investments (snow fence, living snow fence, etc.)	
NDDOT	Fuel	Full-Time Labor Costs	Seasonal Labor Costs	Contractor Labor Costs							
Town of Middlebury	Fuel	Full-Time Labor Costs	Seasonal Labor Costs		Training Costs			Public outreach (including public facing websites)	Planning and administrative cost	Roadside investments (snow fence, living snow fence, etc.)	
Kansas DOT	Fuel	Full-Time Labor Costs	Seasonal Labor Costs	Contractor Labor Costs	Training Costs						
UDOT	Fuel	Full-Time Labor Costs	Seasonal Labor Costs	Contractor Labor Costs	Training Costs		Third Party Data (Weather, Traffic, Etc.)	Public outreach (including public facing websites)	Planning and administrative cost	Roadside investments (snow fence, living snow fence, etc.)	
Directorate of Roads and Highways	Fuel			Contractor Labor Costs			Third Party Data (Weather, Traffic, Etc.)		Planning and administrative cost		
Rijkswaterstaat Netherlands											

Agency	Fuel	Full-Time Labor Costs	Seasonal Labor Costs	Contractor Labor Costs	Training Costs	Mobility Delay Cost (User Delay Cost; Passenger Vehicles and Commercial)	Third Party Data (Weather, Traffic, Etc.)	Public outreach (including public facing websites)	Planning and administrative cost	Roadside investments (snow fence, living snow fence, etc.)	Other (please specify)
Ville de Pointe-Claire	Fuel	Full-Time Labor Costs	Seasonal Labor Costs	Contractor Labor Costs						Roadside investments (snow fence, living snow fence, etc.)	
Kansas DOT	Fuel	Full-Time Labor Costs	Seasonal Labor Costs								
Norwegian Public Roads Administration											Our models are not that detailed.
Vermont Agency of Transportation	Fuel	Full-Time Labor Costs	Seasonal Labor Costs	Contractor Labor Costs		Mobility Delay Cost (User Delay Cost; Passenger Vehicles and Commercial)	Third Party Data (Weather, Traffic, Etc.)		Planning and administrative cost		
NHDOT	Fuel	Full-Time Labor Costs	Seasonal Labor Costs	Contractor Labor Costs							
IL DOT	Fuel	Full-Time Labor Costs	Seasonal Labor Costs						Planning and administrative cost		
Massachusetts Dept. of Transportation	Fuel	Full-Time Labor Costs	Seasonal Labor Costs	Contractor Labor Costs	Training Costs	Mobility Delay Cost (User Delay Cost; Passenger Vehicles and Commercial)	Third Party Data (Weather, Traffic, Etc.)			Roadside investments (snow fence, living snow fence, etc.)	We're aware of substantial escalating costs to healthcare, sanitation, commerce, etc. when roads are closed for a day or more.
City of Farmington Hills, MI	Fuel	Full-Time Labor Costs	Seasonal Labor Costs		Training Costs	Mobility Delay Cost (User Delay Cost; Passenger Vehicles and Commercial)	Third Party Data (Weather, Traffic, Etc.)	Public outreach (including public facing websites)	Planning and administrative cost		

Agency	Fuel	Full-Time Labor Costs	Seasonal Labor Costs	Contractor Labor Costs	Training Costs	Mobility Delay Cost (User Delay Cost; Passenger Vehicles and Commercial)	Third Party Data (Weather, Traffic, Etc.)	Public outreach (including public facing websites)	Planning and administrative cost	Roadside investments (snow fence, living snow fence, etc.)	Other (please specify)
Iowa DOT	Fuel	Full-Time Labor Costs	Seasonal Labor Costs			Mobility Delay Cost (User Delay Cost; Passenger Vehicles and Commercial)				Roadside investments (snow fence, living snow fence, etc.)	
Alaska DOT&PF	Fuel	Full-Time Labor Costs	Seasonal Labor Costs	Contractor Labor Costs	Training Costs				Planning and administrative cost		
Montana Department of Transportation	Fuel	Full-Time Labor Costs	Seasonal Labor Costs	Contractor Labor Costs	Training Costs				Planning and administrative cost	Roadside investments (snow fence, living snow fence, etc.)	
Kansas DOT		Full-Time Labor Costs									Equipment Usage Cost
City of Bozeman MT	Fuel	Full-Time Labor Costs					Third Party Data (Weather, Traffic, Etc.)				
Kiewit Meridiam Partners	Fuel	Full-Time Labor Costs	Seasonal Labor Costs	Contractor Labor Costs	Training Costs	Mobility Delay Cost (User Delay Cost; Passenger Vehicles and Commercial)	Third Party Data (Weather, Traffic, Etc.)			Roadside investments (snow fence, living snow fence, etc.)	
City of Columbus, Ohio	Fuel	Full-Time Labor Costs	Seasonal Labor Costs	Contractor Labor Costs	Training Costs	Mobility Delay Cost (User Delay Cost; Passenger Vehicles and Commercial)	Third Party Data (Weather, Traffic, Etc.)	Public outreach (including public facing websites)	Planning and administrative cost	Roadside investments (snow fence, living snow fence, etc.)	
City of Columbus, Depart. of Public Service		Full-Time Labor Costs	Seasonal Labor Costs	Contractor Labor Costs	Training Costs	Mobility Delay Cost (User Delay Cost; Passenger Vehicles and Commercial)	Third Party Data (Weather, Traffic, Etc.)			Roadside investments (snow fence, living snow fence, etc.)	

Question 7. The cost variables you selected in question 6 are below. Please rank the top 5 most impactful to your operations.

Agency	Material Cost	Salt Spreaders	Facilities and material storage cost	Snow Hauling and Disposal	Plows (Including Blades)	Trucks, Motor Graders, Loaders	AVL Capital Cost	RWIS Capital Cost	MDSS	Route-optimization tools	Equipment Maintenance Costs	AVL Subscription Costs
Texas Department Transportation	1	8	4		7	5					6	
Minnesota Department of Transportation	4	10	7	8	9	11	12	13	14	15	3	16
Ministere des Transports et de la Mobilité Durable du Québec	2	9	8		7	3					11	12
NDDOT	4		5	6	1	7	8	9	10		2	11
WYDOT									2			
Montana	3	4		9	8	5					6	
NDDOT	3				4	2			5			
Town of Middlebury	3	6	4		7	2	8				9	
Kansas DOT	1	4			3	5						
UDOT	1	6	5		3	7	8	9			4	10
Directorate of Roads and Highways	7	1			5	3				4	2	
Rijkswaterstaat Netherlands												
Ville de Pointe-Claire	1	5	10	6	7	8					9	
Kansas DOT	2				5	6					4	
Norwegian Public Roads Administration												
Vermont Agency of Transportation	3				5	2						

Agency	Material Cost	Salt Spreaders	Facilities and material storage cost	Snow Hauling and Disposal	Plows (Including Blades)	Trucks, Motor Graders, Loaders	AVL Capital Cost	RWIS Capital Cost	MDSS	Route-optimization tools	Equipment Maintenance Costs	AVL Subscription Costs
NHDOT	4				5	3					6	
IL DOT	1			6	5	7						
Massachusetts Dept. of Transportation	2	7	5	16	8	9	12	14	19		11	13
City of Farmington Hills, MI	3	4	8		6	9	10	11	12			13
Iowa DOT	5	8			6	3	9	11			2	7
Alaska DOT&PF	4			7	6	1	8	9	10		2	
Montana Department of Transportation	1	7	5	6	2	8	9	10			4	11
Kansas DOT	3											
City of Bozeman MT	3									1		5
Kiewit Meridiam Partners	2	4	7		8	1	9		10	11	6	12
City of Columbus, Ohio	3		4		6	2	7	8	9	10	5	11
City of Columbus, Depart. of Public Service	2					3	5					

Agency	Fuel	Full-Time Labor Costs	Seasonal Labor Costs	Contractor Labor Costs	Training Costs	Mobility Delay Cost (User Delay Cost; Passenger Vehicles and Commercial)	Third Party Data (Weather, Traffic, Etc.)	Public outreach (including public facing websites)	Planning and administrative cost	Roadside investments (snow fence, living snow fence, etc.)	Other (please specify)
Texas Department Transportation	9	2		3		10	11	12			
Minnesota Department of Transportation	5	1	2	18	19		20	21	6	17	

Agency	Fuel	Full-Time Labor Costs	Seasonal Labor Costs	Contractor Labor Costs	Training Costs	Mobility Delay Cost (User Delay Cost; Passenger Vehicles and Commercial)	Third Party Data (Weather, Traffic, Etc.)	Public outreach (including public facing websites)	Planning and administrative cost	Roadside investments (snow fence, living snow fence, etc.)	Other (please specify)
Ministere des Transports et de la Mobilité Durable du Québec	4	1	5	6					10	13	14
NDDOT	12	3	13	14						15	
WYDOT						1	3			4	
Montana	7	1	2	10	11					12	
NDDOT	6	1	7	8							
Town of Middlebury	5	1	10		11			12	13	14	
Kansas DOT	6	2	7	8	9						
UDOT	11	2	12	13	14		15	16	17	18	
Directorate of Roads and Highways	8			10			9		6		
Rijkswaterstaat Netherlands											
Ville de Pointe-Claire	2	4	11	3						12	
Kansas DOT	3	1	7								
Norwegian Public Roads Administration											
Vermont Agency of Transportation	7	1	6	10		4	8		9		
NHDOT	7	1	8	2							
IL DOT	4	2	3						8		

Agency	Fuel	Full-Time Labor Costs	Seasonal Labor Costs	Contractor Labor Costs	Training Costs	Mobility Delay Cost (User Delay Cost; Passenger Vehicles and Commercial)	Third Party Data (Weather, Traffic, Etc.)	Public outreach (including public facing websites)	Planning and administrative cost	Roadside investments (snow fence, living snow fence, etc.)	Other (please specify)
Massachusetts Dept. of Transportation	10	3	4	1	18	6	15			20	17
City of Farmington Hills, MI	7	1	17		14	2	15	5	16		
Iowa DOT	4	1	10			12				13	
Alaska DOT&PF	5	3	11	12	13				14		
Montana Department of Transportation	12	3	13	14	15				16	17	
Kansas DOT		1									2
City of Bozeman MT	4	2					6				
Kiewit Meridiam Partners	13	3	5	14	15	16	17			18	
City of Columbus, Ohio	12	1	13	14	15	16	17	18	19	20	
City of Columbus, Depart. of Public Service		1					4				

Question 8. From the cost variables you selected in question 6, which variable takes up the largest portion of your budget?

Agency	Response	Additional Comments
Texas Department Transportation	Full-Time Labor Costs	
Minnesota Department of Transportation	Full-Time Labor Costs	It only allowed me to check one item. 1 – Labor, 2 Equipment, 2 Materials and these are in order of highest to lowest cost but all are in the 30-35% range.
Ministere des Transports et de la Mobilité Durable du Québec	Material Cost	
NDDOT	Plows (Including Blades)	
WYDOT	Mobility Delay Cost (User Delay Cost; Passenger Vehicles and Commercial)	Have no idea how this cost impacts budget , MDSS and weatther are subscritions not being charged to snow removal. Not calculating savings from roadside investments.
Montana	Full-Time Labor Costs	Labor is always our highest cost
NDDOT		
Town of Middlebury	Full-Time Labor Costs	
Kansas DOT	Full-Time Labor Costs	
UDOT	Equipment Maintenance Costs	Equipment has been our highest with fuel close behind.
Directorate of Roads and Highways	Salt Spreaders	
Rijkswaterstaat Netherlands		
Ville de Pointe-Claire	Material Cost	salt
Kansas DOT	Full-Time Labor Costs	
Norwegian Public Roads Administration	[Insert text from Other]	
Vermont Agency of Transportation	Full-Time Labor Costs	
NHDOT	Full-Time Labor Costs	
IL DOT	Full-Time Labor Costs	

Agency	Response	Additional Comments
Massachusetts Dept. of Transportation	Contractor Labor Costs	If we spend $100 million in a year, $60 million is on Vendor/"Contractor" equipment, $30 million is on deicing materials, and $10 million is employee labor.
City of Farmington Hills, MI	Full-Time Labor Costs	
Iowa DOT	Full-Time Labor Costs	
Alaska DOT&PF	Equipment Maintenance Costs	Our Equipment capital purchases, and maintenance & repairs are lumped into one cost in the rolled-up budget.
Montana Department of Transportation	Material Cost	
Kansas DOT	Full-Time Labor Costs	
City of Bozeman MT	Full-Time Labor Costs	
Kiewit Meridiam Partners	Full-Time Labor Costs	
City of Columbus, Ohio	Full-Time Labor Costs	
City of Columbus, Depart. of Public Service	Full-Time Labor Costs	

Question 9. From the list of cost variables in question 6, what cost components are hardest to estimate and/or most variable? (select all that apply)

Agency	Material Cost	Salt Spreaders	Facilities and material storage cost	Snow Hauling and Disposal	Plows (Including Blades)	Trucks, Motor Graders, Loaders	AVL Capital Cost	RWIS Capital Cost	MDSS	Route-optimization tools	Equipment Maintenance Costs	AVL Subscription Costs
Texas Department Transportation												
Minnesota Department of Transportation	Material Cost											
Ministere des Transports et de la Mobilité Durable du Québec	Material Cost					Trucks, Motor Graders, Loaders						
NDDOT												
WYDOT												
Montana												
NDDOT	Material Cost											
Town of Middlebury	Material Cost											
Kansas DOT	Material Cost											
UDOT			Facilities and material storage cost								Equipment Maintenance Costs	
Directorate of Roads and Highways											Equipment Maintenance Costs	
Rijkswaterstaat Netherlands												
Ville de Pointe-Claire												
Kansas DOT	Material Cost											
Norwegian Public Roads Administration												

Agency	Material Cost	Salt Spreaders	Facilities and material storage cost	Snow Hauling and Disposal	Plows (Including Blades)	Trucks, Motor Graders, Loaders	AVL Capital Cost	RWIS Capital Cost	MDSS	Route-optimization tools	Equipment Maintenance Costs	AVL Subscription Costs
Vermont Agency of Transportation												
NHDOT												
IL DOT												
Massachusetts Dept. of Transportation	Material Cost											
City of Farmington Hills, MI	Material Cost											
Iowa DOT											Equipment Maintenance Costs	
Alaska DOT&PF	Material Cost			Snow Hauling and Disposal			AVL Capital Cost					
Montana Department of Transportation	Material Cost											
Kansas DOT												
City of Bozeman MT										Route-optimization tools		
Kiewit Meridiam Partners	Material Cost										Equipment Maintenance Costs	
City of Columbus, Ohio												
City of Columbus, Depart. of Public Service											Equipment Maintenance Costs	

Agency	Fuel	Full-Time Labor Costs	Seasonal Labor Costs	Contractor Labor Costs	Training Costs	Mobility Delay Cost (User Delay Cost; Passenger Vehicles and Commercial)	Third Party Data (Weather, Traffic, Etc.)	Public outreach (including public facing websites)	Planning and administrative cost	Roadside investments (snow fence, living snow fence, etc.)	Other (please specify)	Additional Comments
Texas Department Transportation						Mobility Delay Cost (User Delay Cost; Passenger Vehicles and Commercial)						
Minnesota Department of Transportation		Full-Time Labor Costs										Labor then materials
Ministere des Transports et de la Mobilité Durable du Québec	Fuel	Full-Time Labor Costs	Seasonal Labor Costs	Contractor Labor Costs								
NDDOT		Full-Time Labor Costs										
WYDOT						Mobility Delay Cost (User Delay Cost; Passenger Vehicles and Commercial)				Roadside investments (snow fence, living snow fence, etc.)		
Montana										Roadside investments (snow fence, living snow fence, etc.)		Not really any by how MDT tracks these costs
NDDOT												Can get monthly totals but would like down to truck.
Town of Middlebury	Fuel	Full-Time Labor Costs										
Kansas DOT												
UDOT	Fuel											

Agency	Fuel	Full-Time Labor Costs	Seasonal Labor Costs	Contractor Labor Costs	Training Costs	Mobility Delay Cost (User Delay Cost; Passenger Vehicles and Commercial)	Third Party Data (Weather, Traffic, Etc.)	Public outreach (including public facing websites)	Planning and administrative cost	Roadside investments (snow fence, living snow fence, etc.)	Other (please specify)	Additional Comments
Directorate of Roads and Highways												
Rijkswaterstaat Netherlands												
Ville de Pointe-Claire	Fuel											
Kansas DOT												
Norwegian Public Roads Administration											[Insert text from Other]	
Vermont Agency of Transportation						Mobility Delay Cost (User Delay Cost; Passenger Vehicles and Commercial)						limited resources to perform the analysis.
NHDOT				Contractor Labor Costs								
IL DOT			Seasonal Labor Costs									

Agency	Fuel	Full-Time Labor Costs	Seasonal Labor Costs	Contractor Labor Costs	Training Costs	Mobility Delay Cost (User Delay Cost; Passenger Vehicles and Commercial)	Third Party Data (Weather, Traffic, Etc.)	Public outreach (including public facing websites)	Planning and administrative cost	Roadside investments (snow fence, living snow fence, etc.)	Other (please specify)	Additional Comments
Massachusetts Dept. of Transportation				Contractor Labor Costs								We have tracked Salt Usage versus Winter Severity (Boselly Method) for 24 years. Our largest program budget variables are contracted labor and deicing materials. FY2024 was the second-mildest of the previous 24 winters.
City of Farmington Hills, MI												
Iowa DOT												
Alaska DOT&PF	Fuel			Contractor Labor Costs								
Montana Department of Transportation												
Kansas DOT												We use actual costs.
City of Bozeman MT												
Kiewit Meridiam Partners												

Agency	Fuel	Full-Time Labor Costs	Seasonal Labor Costs	Contractor Labor Costs	Training Costs	Mobility Delay Cost (User Delay Cost; Passenger Vehicles and Commercial)	Third Party Data (Weather, Traffic, Etc.)	Public outreach (including public facing websites)	Planning and administrative cost	Roadside investments (snow fence, living snow fence, etc.)	Other (please specify)	Additional Comments
City of Columbus, Ohio	Fuel					Mobility Delay Cost (User Delay Cost; Passenger Vehicles and Commercial)		Public outreach (including public facing websites)				Hard to know how much better/worse traffic moves as a result of winter weather, and how much faster it would return to normal if we had done something differently.
City of Columbus, Depart. of Public Service		Full-Time Labor Costs										

<u>Question 10.</u> Select which of the following data elements you currently include or would like to include in your calculation of benefit or ROI impact to winter operations: (select all that apply)

Agency	Freight movement of goods	Safety – reduction of weather related crashes	Congestion/travel time	Reliability of travel time	Other (please specify)
Texas Department Transportation	Freight movement of goods	Safety – reduction of weather related crashes	Congestion/travel time		
Minnesota Department of Transportation					We already do safety and congestion travel time, and would like to add reliability and freight movement of goods
Ministere des Transports et de la Mobilité Durable du Québec		Safety – reduction of weather related crashes			Environmental issues
NDDOT	Freight movement of goods	Safety – reduction of weather related crashes	Congestion/travel time	Reliability of travel time	
WYDOT	Freight movement of goods	Safety – reduction of weather related crashes	Congestion/travel time	Reliability of travel time	
Montana	Freight movement of goods	Safety – reduction of weather related crashes	Congestion/travel time		
NDDOT					Not currently calculating
Town of Middlebury		Safety – reduction of weather related crashes		Reliability of travel time	Undefined acronyms are challenging since different fields may use the same synonym in a different context. ROI is straight forward but some of the prior questions not so much!
Kansas DOT	Freight movement of goods	Safety – reduction of weather related crashes	Congestion/travel time	Reliability of travel time	
UDOT	Freight movement of goods	Safety – reduction of weather related crashes	Congestion/travel time	Reliability of travel time	
Directorate of Roads and Highways			Congestion/travel time		
Rijkswaterstaat Netherlands					
Ville de Pointe-Claire		Safety – reduction of weather related crashes	Congestion/travel time		

Agency	Freight movement of goods	Safety – reduction of weather related crashes	Congestion/travel time	Reliability of travel time	Other (please specify)
Kansas DOT	Freight movement of goods	Safety – reduction of weather related crashes		Reliability of travel time	
Norwegian Public Roads Administration	Freight movement of goods	Safety – reduction of weather related crashes	Congestion/travel time		
Vermont Agency of Transportation					
NHDOT				Reliability of travel time	
IL DOT		Safety – reduction of weather related crashes		Reliability of travel time	
Massachusetts Dept. of Transportation	Freight movement of goods	Safety – reduction of weather related crashes	Congestion/travel time	Reliability of travel time	Tax revenues on impulse purchases or trips that could be made due to passable roads. Nothing guarantees the consumer will later follow through with a purchase that would have occurred if roads had been passable.
City of Farmington Hills, MI		Safety – reduction of weather related crashes	Congestion/travel time	Reliability of travel time	
Iowa DOT					We don't calculate an ROI for Winter Operations
Alaska DOT&PF		Safety – reduction of weather related crashes		Reliability of travel time	
Montana Department of Transportation		Safety – reduction of weather related crashes			
Kansas DOT		Safety – reduction of weather related crashes	Congestion/travel time	Reliability of travel time	
City of Bozeman MT			Congestion/travel time		
Kiewit Meridiam Partners		Safety – reduction of weather related crashes			
City of Columbus, Ohio		Safety – reduction of weather related crashes	Congestion/travel time	Reliability of travel time	
City of Columbus, Depart. of Public Service					Regain time for grip

Question 11. If you selected any of the benefit data elements in question 10, can you briefly explain how you quantify the benefits

Agency	Freight movement of goods	Safety – reduction of weather related crashes	Congestion/travel time	Reliability of travel time	Other (please specify)
Texas Department Transportation	Truck not having to stop or slow down due to conditions.	These are currently tracked via a TC system			
Minnesota Department of Transportation					Follow us dot fhwa methods for safety and travel time.
Ministere des Transports et de la Mobilité Durable du Québec		Crash data monitoring			Road salt reduction / spreading rate per km
NDDOT			Performance Measures	Performance Measures	
WYDOT	do not currently	do not currently	do not currently	do not currently	
Montana	Would get us a cost/delay to talk to decision makers	We track this but not well.	For winter related events		
NDDOT					
Town of Middlebury					
Kansas DOT					
UDOT	would like to include in future so business impact could be measured	already included, based off of accident cost	already included, based off of user cost	would like to include, based off of user cost	
Directorate of Roads and Highways					
Rijkswaterstaat Netherlands					
Ville de Pointe-Claire		number of crashes per time period, vary by gravity of incident	average travel time on main arteries		
Kansas DOT	Not quantified.	Crashes		Time to normal speeds.	

Agency	Freight movement of goods	Safety – reduction of weather related crashes	Congestion/travel time	Reliability of travel time	Other (please specify)
Norwegian Public Roads Administration	We do not include them today, but we wish to do so				
Vermont Agency of Transportation					
NHDOT				Can we provide the public with means of traveling at the speeds we post on our message boards	
IL DOT		we currently dont but may like to.			
Massachusetts Dept. of Transportation	We have never calculated any of these benefits as an agency (to my knowledge). This is where we need much help from this project.				
City of Farmington Hills, MI		Work in progress, need ideas or solutions	Talk with county to see if there camera system can the into an AI system possibly	Depending on timing of event	
Iowa DOT					This is something we have explored but not put into practice yet.
Alaska DOT&PF		Reductions in fatal and sever crashes during winter weather			
Montana Department of Transportation					
Kansas DOT		Crash Records	dont know	dont know	
City of Bozeman MT			We don't quantify but would like to.		

Agency	Freight movement of goods	Safety – reduction of weather related crashes	Congestion/travel time	Reliability of travel time	Other (please specify)
Kiewit Meridiam Partners		Tracking of weather related accidents			
City of Columbus, Ohio		dont use, but would compare crash numbers during event compared to numbers when roads are normal	dont use, but would compare travel times during event and outside event	dont use, not sure how would calculate	
City of Columbus, Depart. of Public Service					We are trying to regain an acceptable amount of friction on a roadway in a reasonal time for the lowest cost possible.

<u>Question 12.</u> Have you tested new technologies or innovative best practices to reduce winter operations costs or increase benefits? (Examples: targeted pretreating/prewetting, or ground speed controls for material spreaders)

Agency	Response	If Yes - please explain what were those technologies or best practices that you tested and how did you determine if it was beneficial?
Texas Department Transportation	No	
Minnesota Department of Transportation	Yes	Maintenance Decision Support System (MDSS), Automated Vehicle Location (AVL), Road Weather Information Systems (RWIS), Increased use of Liquid Deicers/Brine and equipment to generate, store and apply/record, Tow Plows, Alternative Materials, Blowing Snow Control Program, Asset Management System Implementation, Evaluation criteria includes: reduction of overall cost, better performance, enhanced safety.
Ministere des Transports et de la Mobilité Durable du Québec	Yes	Prewetting spreading controllers telemetry (AVL)
NDDOT	Yes	Increased liquid and slurry usage. Operators have reported that the increased liquid use has reduced the amount of time they have spent on snow and ice control.
WYDOT	Yes	pretreating/prewetting-time to bare pavement
Montana	Yes	Tow-plows

Agency	Response	If Yes - please explain what were those technologies or best practices that you tested and how did you determine if it was beneficial?
NDDOT	Yes	Prewetting Ag based deicer use, Slurry use, Towplows, route optimization- all beneficial as determined by experience and attendance at pooled fund and other conferences.
Town of Middlebury		
Kansas DOT	Yes	pre treat, pre wet, use of straight salt, use of liquids, tow plows.
UDOT	Yes	Testing different plow blades - evaluated based on cost and lifespan. Testing different types of deicers - evaluated based on cost, road conditions. Incorporating dash cams into new plows - evaluated based on ability to resolve traffic incidents. Incorporating wing plows and tow plows - evaluated based on labor savings.
Directorate of Roads and Highways	Yes	next winter we will use blades with salt spreading
Rijkswaterstaat Netherlands		
Ville de Pointe-Claire	Yes	- local weather stations allowed us to vary operations throughout the territory based on specific data - improved employee dispatch program allowed 60% reduction in daily employee preparation time
Kansas DOT	Yes	Pretreat/prewet - See if we are using less salt.
Norwegian Public Roads Administration	Yes	GPS salt spreading, online monitoring of winter maintenance equipment.
Vermont Agency of Transportation	Yes	We have implemented many BMPS such as pre-wetting and ground speed controllers to reduce costs.
NHDOT	Yes	We use ground speed controls, pretreatments, and prewetting of salt and they are beneficial.
IL DOT	No	

Agency	Response	If Yes - please explain what were those technologies or best practices that you tested and how did you determine if it was beneficial?
Massachusetts Dept. of Transportation	Yes	We have some excellent data that capture by-District prewetting programs and reflect that salt usage and prewetting are strongly inversely related. Since we started prewetting salt, pretreating (anti-icing) roadways and using ground speed control, we have substantially reduced the amount of salt we use to maintain our roadways per Winter Severity Index point. We recently finished up a research project that tied a salt spreader's material output to the grip level reported by a salter's mobile RWIS. Briefly, the RWIS sits behind the plow blade and assesses the post-scrape roadway condition and assigns a grip level (decimal value). That grip level is matched to a corresponding salting output. This salt spreading program has its time and place (not for very productive storms) but can lead to substantial salt savings during low-productivity events and final or spot treatments.
City of Farmington Hills, MI	Yes	Plow Opps tablet for our younger generation, looking to use tablets for all operations, CDL pre trips etc
Iowa DOT	Yes	We just transitioned to a new GPS/AVL system that includes both forward and rear facing cameras. The intent is to keep the information we share with the public through our 511 website (plow cam pics from the cab of the truck showing current conditions on the system) but to also capture video both forward and rear to help with incidents and claims. Our goal is to reduce the amount of money we spend on settling claims. This coming winter will be our first with the new system so no experience or data to share just yet.
Alaska DOT&PF	Yes	Pretreating, prewetting, anti-icing, long life cutting edges. Crash reduction. Cycle time
Montana Department of Transportation	Yes	Tow Plows, less time to clear more roadway
Kansas DOT	Yes	liquids, wing plows, tow plows, straight salt, bigger trucks
City of Bozeman MT	Yes	Force America controllers and LIGO AVL.

Agency	Response	If Yes - please explain what were those technologies or best practices that you tested and how did you determine if it was beneficial?
Kiewit Meridiam Partners	Yes	Utilization of MDSS, AVL
City of Columbus, Ohio	Yes	regularly pretreat when appropriate; prewet salt as needed. Use AVL for tracking trucks and progress; use pavement sensors for better weather data. Adding friction sensors this winter.
City of Columbus, Depart. of Public Service	Yes	Pretreating, prewetting, anti-icing, ground speed sensors. We have validated them off of previous research from others.

Question 13. Does your agency set aside a portion of the annual budget for investigating new technologies?

Agency	Response	If yes, can you provide an estimated percentage of your agency's annual maintenance budget that is dedicated to new technology?
Texas Department Transportation	Yes	This budget it outside of the MNT Budget.
Minnesota Department of Transportation	Yes	Research funds can be tapped for snow and ice technologies, not part of the Snow and Ice Maintenance budget
Ministere des Transports et de la Mobilité Durable du Québec	No	
NDDOT	No	
WYDOT	Yes	very little
Montana	No	
NDDOT	No	
Town of Middlebury		
Kansas DOT	No	
UDOT	Yes	3%
Directorate of Roads and Highways	No	
Rijkswaterstaat Netherlands		
Ville de Pointe-Claire	No	
Kansas DOT	No	
Norwegian Public Roads Administration	Yes	Very low budget for testing new technologies
Vermont Agency of Transportation	No	
NHDOT	No	

Agency	Response	If yes, can you provide an estimated percentage of your agency's annual maintenance budget that is dedicated to new technology?
IL DOT	No	
Massachusetts Dept. of Transportation	Yes	I cannot.
City of Farmington Hills, MI	Yes	5%
Iowa DOT	No	
Alaska DOT&PF	Yes	mostly FHWA funding
Montana Department of Transportation	Yes	Not sure, but we do some through research and some through field testing
Kansas DOT	Yes	no
City of Bozeman MT	No	
Kiewit Meridiam Partners	No	
City of Columbus, Ohio	No	
City of Columbus, Depart. of Public Service	No	

Question 14. Please describe how your agency determines to fund the testing/implementing of new technologies. If not applicable, please type N/A

Agency	Open-Ended Response
Texas Department Transportation	The Research Technology Innovation division handles all of the up-and-coming tech. Districts and other divisions can also do research, however it is somewhat limited and typically in partnership with RTI.
Minnesota Department of Transportation	Established research program that looks for problems/needs and run it through a selection process; ad hoc, peer to peer, discuss and decide to seek out funding from senior leadership through established Resource Investment Council.
Ministere des Transports et de la Mobilité Durable du Québec	ad hoc decisions
NDDOT	NA
WYDOT	case by case
Montana	N/A
NDDOT	

Agency	Open-Ended Response
Town of Middlebury	
Kansas DOT	
UDOT	Trial runs, research projects, experiments
Directorate of Roads and Highways	N/A
Rijkswaterstaat Netherlands	
Ville de Pointe-Claire	na
Kansas DOT	N/A
Norwegian Public Roads Administration	N/A
Vermont Agency of Transportation	We use Clear Roads research for new technologies and have used research moneys from FHWA in the past for things like route optimization.
NHDOT	
IL DOT	
Massachusetts Dept. of Transportation	Research topics are proposed by would-be Champions and those who oversee the SPR (State Planning and Research - I think) grants choose the proposals they deem worthy.
City of Farmington Hills, MI	Ask management and try to stay progressive with trialing resource's
Iowa DOT	We have a process which starts with our research committee specifically looking at winter operations projects. We use operational funding to cover these expenses.
Alaska DOT&PF	Project specific.
Montana Department of Transportation	Not sure
Kansas DOT	N/A
City of Bozeman MT	We budget it.
Kiewit Meridiam Partners	NA
City of Columbus, Ohio	If i can justify the expense and show there may be value, i usually get the money.
City of Columbus, Depart. of Public Service	N/A

Question 15. Does your agency have a standard annual escalation/inflation rate to winter operations costs? (considering contracted equipment rates)

Agency	Response	If yes, please elaborate on what type of escalation rate or index is used within your agency
Texas Department Transportation	No	
Minnesota Department of Transportation	No	Review national and regional indices for materials including salt and fuel and association to major cost items, add 3% per year for base inflation for all operations not just for snow and ice.
Ministere des Transports et de la Mobilité Durable du Québec	No	
NDDOT	No	
WYDOT	No	
Montana	No	
NDDOT	No	
Town of Middlebury		
Kansas DOT	No	
UDOT	Yes	CPI (standard inflation rate)
Directorate of Roads and Highways	No	
Rijkswaterstaat Netherlands		
Ville de Pointe-Claire	Yes	standard country inflation rate
Kansas DOT	No	
Norwegian Public Roads Administration	Yes	Depending of the average inflation and weather situation
Vermont Agency of Transportation	No	
NHDOT	No	
IL DOT	No	
Massachusetts Dept. of Transportation	No	
City of Farmington Hills, MI	No	
Iowa DOT	No	
Alaska DOT&PF	No	
Montana Department of Transportation	No	
Kansas DOT	No	
City of Bozeman MT	No	
Kiewit Meridiam Partners	Yes	CPI
City of Columbus, Ohio	No	

Agency	Response	If yes, please elaborate on what type of escalation rate or index is used within your agency
City of Columbus, Depart. of Public Service	No	

Question 16. If budget wasn't an issue, what aspect of your operations would you invest additional money?

Agency	Open-Ended Response
Texas Department Transportation	Labor, facilities, and equipment
Minnesota Department of Transportation	Liquid expansion, storage capacity, equipment and staffing,
Ministere des Transports et de la Mobilité Durable du Québec	Tranning / knowledge transfer
NDDOT	Equipment and facilities to provide more liquid capabilities.
WYDOT	management says asphalt patching or more maintenance overlays
Montana	Winter Materials, Facilities and Equipment
NDDOT	The NDDOT needs to invest in more brine making and storage.
Town of Middlebury	
Kansas DOT	Training Retention of experienced staff
UDOT	More trucks, more drivers, more mechanics
Directorate of Roads and Highways	better reporting and planning software
Rijkswaterstaat Netherlands	
Ville de Pointe-Claire	new vehicles and equipment
Kansas DOT	Equipment
Norwegian Public Roads Administration	Developing new equipment, testing new methods and material. RWIS and follow up system.
Vermont Agency of Transportation	purchase of tow plows, as hiring full time staff is still an issue in some areas and temporary/ seasonal employees are not filling the void, nor are our efforts to hire contractors to operate our equipment for winter operations.
NHDOT	More liquid application tools and more RWIS stations
IL DOT	Full Time/Temporary Employees.

Agency	Open-Ended Response
Massachusetts Dept. of Transportation	Mobile RWIS on all salt spreaders. I believe the potential salt savings justify the cost.
City of Farmington Hills, MI	Training and Trying new technologies
Iowa DOT	Increase fulltime staffing and new equipment.
Alaska DOT&PF	Compensation for employees. Safety Gear. Upgrade to buildings that support our operations.
Montana Department of Transportation	Snow plow trucks
Kansas DOT	Labor Salary dollars
City of Bozeman MT	Route optimization and training new operators.
Kiewit Meridiam Partners	New plow bit technology and equipment to utilize liquid de-icers more.
City of Columbus, Ohio	staffing and trucks
City of Columbus, Depart. of Public Service	Technology, equipment, and people

Question 17. What are some data gaps that currently exist for your agency when conducting a realistic benefit-cost analysis or ROI?

Agency	Open-Ended Response
Texas Department Transportation	
Minnesota Department of Transportation	Determining how much of the system wide performance is due to snow and ice operations, Travel time
Ministere des Transports et de la Mobilité Durable du Québec	Quality of material composition data Hours of operation
NDDOT	AVL would be helpful in providing much of the data needed for the costs. It is very difficult to determine a benefit value that is realized by the travelling public.
WYDOT	unsure
Montana	Delay time, safety
NDDOT	N/A
Town of Middlebury	
Kansas DOT	
UDOT	Assuming a consistent salt distribution rate instead of having a more precise measurement.

Agency	Open-Ended Response
Directorate of Roads and Highways	
Rijkswaterstaat Netherlands	
Ville de Pointe-Claire	no service baseline to measure against
Kansas DOT	Ways of measuring benefits.
Norwegian Public Roads Administration	A good road condition model for different roads and climate, and information on the accident rate under different winter condition.
Vermont Agency of Transportation	personnel to analyze data and determine what analysis should be conducted.
NHDOT	Lack of ability to capture a way status of road surface conditions around the State due to lack of RWIS stations on all areas of the State
IL DOT	N/A
Massachusetts Dept. of Transportation	We capture most costs well, but not the benefits. The value of this research effort is it will allow us to estimate a reasonable agency winter operations budget, and then hopefully quantify the benefits, which should substantially exceed costs.
City of Farmington Hills, MI	Need to tie in our AVL with operations and management software
Iowa DOT	Having access to all of the data points that we would need to conduct a realistic ROI.
Alaska DOT&PF	Accurate costing
Montana Department of Transportation	
Kansas DOT	
City of Bozeman MT	Variables that affect plow route completion time.
Kiewit Meridiam Partners	Accident reports are latent.
City of Columbus, Ohio	we dont really have any data to use beyond what people remember and some general stats-cost of OT, inches of snow, and amount of material used.
City of Columbus, Depart. of Public Service	The ability to easily pull cost data from our asset management system.

Question 18. What would be your agency's desired outputs/functions from a benefit-cost tool for quantifying the economic value? (Consider these outputs in terms of annualized cost or overall capital cost of snow and ice operations)

Agency	Open-Ended Response
Texas Department Transportation	
Minnesota Department of Transportation	Being able to test different operation scenarios to determine best practices. Blowing snow cost benefit tool is an example of targeted evaluation method: https://snowcontroltools.umn.edu/cost-benefit-tool
Ministere des Transports et de la Mobilité Durable du Québec	To be able to compare many options to choose the best / cheaper Decision support function
NDDOT	
WYDOT	unsure
Montana	the benefits of Snow and Ice removal compared to the costs
NDDOT	
Town of Middlebury	
Kansas DOT	
UDOT	In addition to what we already have, we would like to have the impact of freight travel and how that affects businesses
Directorate of Roads and Highways	
Rijkswaterstaat Netherlands	
Ville de Pointe-Claire	average level of service delivered to the population vs normalized cost where the normalized cost would be a function of the cost that year compared to expected cost for a winter of that severity
Kansas DOT	
Norwegian Public Roads Administration	It will be easier to get enough money for winter maintenance
Vermont Agency of Transportation	I feel that benefit-cost would be around the mobility of the traveling public and performance measures relating to road conditions/ mobility.
NHDOT	We would want to be able to show that investing in new equipment, materials and technology allows us to keep the roads safer and cleaner in a shorter time with less cost.
IL DOT	

Agency	Open-Ended Response
Massachusetts Dept. of Transportation	Apples to Apples. For a dollar spent on winter operations, what is the benefit returned, in dollars.
City of Farmington Hills, MI	To have some rough #'s at the end of the winter season…snow and Ice is all melted and gone but other than safety and mobility we need to quantify the economics etc
Iowa DOT	
Alaska DOT&PF	Cost vs LOS targets. Would increasing or decreasing LOS impact budget vs mobility.
Montana Department of Transportation	
Kansas DOT	
City of Bozeman MT	Not following this question.
Kiewit Meridiam Partners	NA
City of Columbus, Ohio	some way to quantify benefits would honestly be a huge win, as well as a way to set a target performance metric.
City of Columbus, Depart. of Public Service	Regaining of grip on the road in a reasonable time for the lowest cost possible.

Question 19. Do you monitor, manage, or quantify environmental impacts from your operations? (i.e. low salt or sand routes near certain environmentally sensitive sites; monitoring and selecting less corrosive chemical materials or coat bridge decks to protect.)

Agency	Response	If yes, please explain
Texas Department Transportation	No	
Minnesota Department of Transportation	Yes	We work with the Minnesota Pollution Control Agency (MPCA) on chloride reduction strategies and messaging, using MDSS and AVL to guide and inform our operations, Use non-chloride deicers and corrosion resistant components on high value bridges and surface coatings on bridge decks to address corrosion and concrete impacts associated with deicer migration, we monitor and manage, but don't quantify. MCPA has a monitoring program for surface waters and Minnesota Department of Health monitors drinking water/groundwater.

Agency	Response	If yes, please explain
Ministere des Transports et de la Mobilité Durable du Québec	Yes	We have "ecoroute" witch is an no salt route, near salt sensitive sites (about 30 in the province)
NDDOT	No	
WYDOT	No	
Montana	No	
NDDOT	No	
Town of Middlebury		
Kansas DOT	No	
UDOT	Yes	Some of our counties have PM2.5 and PM10 restrictions which limit which products we can use.
Directorate of Roads and Highways	Yes	we monitoring effect of salt near to road (like ground and rivers, drinking water source)
Rijkswaterstaat Netherlands		
Ville de Pointe-Claire	No	
Kansas DOT	No	
Norwegian Public Roads Administration	Yes	Sand-salt amount and plowing-km is analyzed. Climate emissions is calculated.
Vermont Agency of Transportation	No	We have implemented low salt areas on all routes to provide for safe roads at safe speeds. We don't spread to bare off the roadways during the storm and ensure our customers are aware of the expectations.
NHDOT	Yes	We work closely with our Department of Environmental Services that monitors these areas
IL DOT	No	

Agency	Response	If yes, please explain
Massachusetts Dept. of Transportation	Yes	We have a Salt Remediation Program that is house within our Environmental Services Division. If we spend $100 million a year on snow and ice, they spend $1-$2 million remediating constituents' drinking water complaints. Costs may be minor, such as providing bottled water to residents of a home using a well we've likely tainted. The costs may escalate: maybe we need to get them a reverse-osmosis filtering system. Worse, maybe we need to connect them to DPW water. We recently did just that in the town of Wrentham. To connect 22 homes cost us $2 million. That's entirely unsustainable. This has been a very wet first 2/3 of a year regionally, which I LOVE to see.
City of Farmington Hills, MI	Yes	Training, calibration of solids, liquids etc
Iowa DOT	Yes	We monitor sensitive areas and our related salt usage. We thoroughly review any new products to fully understand their chemical makeup and what impact they would have on the environment.
Alaska DOT&PF	Yes	Monitor discharges to waters of US on areas with MS4's
Montana Department of Transportation	No	
Kansas DOT	No	
City of Bozeman MT	No	
Kiewit Meridiam Partners	No	
City of Columbus, Ohio	No	
City of Columbus, Depart. of Public Service	Yes	We have areas marked where we do not sand. We track salt use for MS4 permit. We do not salt a newly constructed bridge.

Question 20. How is risk considered or included in cost of your operations?

Agency	Open-Ended Response
Texas Department Transportation	

Agency	Open-Ended Response
Minnesota Department of Transportation	We can draw on all resources to reduce risk and will pull from other sources to mitigate risk.
Ministere des Transports et de la Mobilité Durable du Québec	Risk sharing in contracts for fuel cost and salt quantity
NDDOT	It is assumed every winter will be different, but it typically averages out over time. That is why we typically use 5 year average to determine a snow and ice control budget.
WYDOT	
Montana	no
NDDOT	
Town of Middlebury	
Kansas DOT	
UDOT	We assume a minimum of 25 storms statewide that will require a response.
Directorate of Roads and Highways	N/A
Rijkswaterstaat Netherlands	
Ville de Pointe-Claire	impacts how we prioritize routes
Kansas DOT	Not considered directly.
Norwegian Public Roads Administration	?
Vermont Agency of Transportation	We try to balance risk with environmental and budgetary considerations.
NHDOT	
IL DOT	
Massachusetts Dept. of Transportation	I can't say that it is, or isn't considered, but we are conducting operations during inclement conditions to mitigate the average motorist's risk to operate. We're also trying to reduce the risk that poor roadway conditions lead to a disruption that closes road(s) and mobility grinds to a halt.
City of Farmington Hills, MI	Not sure we can do that now ????
Iowa DOT	
Alaska DOT&PF	Not considered
Montana Department of Transportation	The goal is always reduce risk to the traveling public
Kansas DOT	

Agency	Open-Ended Response
City of Bozeman MT	Isn't.
Kiewit Meridiam Partners	We are required by contract to maintain bare and wet roads 24x7. The amount of chlorides needed to try and accomplish this are a risk concern for the environment but we have not performed testing yet.
City of Columbus, Ohio	its not
City of Columbus, Depart. of Public Service	We make the roadways passable so they are safe.

Question 21. How many hours of refresher training do you provide to your winter maintenance staff/operators per season?

Agency	Response
Texas Department Transportation	5-10hrs
Minnesota Department of Transportation	5-10hrs
Ministere des Transports et de la Mobilité Durable du Québec	<5hrs
NDDOT	10-20 hrs
WYDOT	<5hrs
Montana	5-10hrs
NDDOT	10-20 hrs
Town of Middlebury	
Kansas DOT	5-10hrs
UDOT	<5hrs
Directorate of Roads and Highways	>30hrs
Rijkswaterstaat Netherlands	
Ville de Pointe-Claire	<5hrs
Kansas DOT	5-10hrs
Norwegian Public Roads Administration	N/A No refresher training is provided
Vermont Agency of Transportation	<5hrs
NHDOT	10-20 hrs
IL DOT	5-10hrs
Massachusetts Dept. of Transportation	5-10hrs
City of Farmington Hills, MI	5-10hrs
Iowa DOT	5-10hrs

Agency	Response
Alaska DOT&PF	<5hrs
Montana Department of Transportation	5-10hrs
Kansas DOT	10-20 hrs
City of Bozeman MT	10-20 hrs
Kiewit Meridiam Partners	<5hrs
City of Columbus, Ohio	10-20 hrs
City of Columbus, Depart. of Public Service	10-20 hrs

Question 22. How many hours of new staff/operator training do you provide to your winter maintenance staff/operators per season?

Agency	Response
Texas Department Transportation	5-10hrs
Minnesota Department of Transportation	>30hrs
Ministere des Transports et de la Mobilité Durable du Québec	10-20 hrs
NDDOT	>30hrs
WYDOT	>30hrs
Montana	10-20 hrs
NDDOT	>30hrs
Town of Middlebury	
Kansas DOT	10-20 hrs
UDOT	5-10hrs
Directorate of Roads and Highways	>30hrs
Rijkswaterstaat Netherlands	
Ville de Pointe-Claire	10-20 hrs
Kansas DOT	10-20 hrs
Norwegian Public Roads Administration	
Vermont Agency of Transportation	10-20 hrs
NHDOT	>30hrs
IL DOT	
Massachusetts Dept. of Transportation	10-20 hrs
City of Farmington Hills, MI	10-20 hrs
Iowa DOT	10-20 hrs
Alaska DOT&PF	5-10hrs

Agency	Response
Montana Department of Transportation	>30hrs
Kansas DOT	>30hrs
City of Bozeman MT	>30hrs
Kiewit Meridiam Partners	10-20 hrs
City of Columbus, Ohio	>30hrs
City of Columbus, Depart. of Public Service	20-30 hrs

<u>Question 23.</u> Please summarize your perceived value and/or benefits of training including any metrics you may use to quantify the benefits of training staff.

Agency	Open-Ended Response
Texas Department Transportation	High value on education to better utilize the available resources.
Minnesota Department of Transportation	Safer Operators, optimize materials, liability reductions, qualified staff, safety to the public, reduced costs
Ministere des Transports et de la Mobilité Durable du Québec	Training is one of the key of success for winter maintenance operation. We work to improve our training program and to develop tools to monitor that aspect
NDDOT	
WYDOT	less damage to equipment
Montana	We do not use any
NDDOT	No metrics but recognize value.
Town of Middlebury	
Kansas DOT	Training and experience are essential to an effective and efficient winter operation
UDOT	Incorporating the use of simulators for training has reduced accidents ten fold.
Directorate of Roads and Highways	
Rijkswaterstaat Netherlands	
Ville de Pointe-Claire	reduction in accidents, improved quality, speed and cost of operations
Kansas DOT	No metrics, but we believe we have less accidents.

Agency	Open-Ended Response
Norwegian Public Roads Administration	The contractors are responsible for the training of their staff. We provide the text books.
Vermont Agency of Transportation	We don't have metrics, but training our employees is paramount to ensuring they understand our level of service and expectations so that they can adjust as needed on the road to provide for safe and efficient movement of people and goods.
NHDOT	We see less accidents and better treatment of our roads the more training our staff has on the materials they are applying and timing of plowing/treatments
IL DOT	
Massachusetts Dept. of Transportation	Not just staff: we hold tailgate trainings where I get to speak with almost 1,000 contractors/drivers with whom we work. Our message has 3 points: Safety, Operations, Environmental. It is an important opportunity we get annually to reiterate how important it is that we maintain salt usage efficiency. I always say our goal is to establish and maintain safe roadway conditions while using as little salt as possible to do so.
City of Farmington Hills, MI	Any tools that we can try or pilot to use would be exciting
Iowa DOT	Training is a very important part of our overall Winter Operations program. All field staff members take part in the training program and it is viewed as a continuous learning environment regardless of years or service.
Alaska DOT&PF	Not quantified
Montana Department of Transportation	I believe it is of high value in reducing material costs/ equipment damage/ and overall safety, but it is very difficult to quantify
Kansas DOT	
City of Bozeman MT	We see short term value to train just to get through the winter. It is so expensive to live here that most workers move on after one year. Our average experience for our crews are <1 year.
Kiewit Meridiam Partners	Very important
City of Columbus, Ohio	reduction in accidents, more efficient staff, more efficient operations

Agency	Open-Ended Response
City of Columbus, Depart. of Public Service	We train our staff to safely operate the equipment, to use the correct amount of deicers, to make roads passable.

Question 24. May we contact you with follow-up questions?

Agency	Response
Texas Department Transportation	Yes
Minnesota Department of Transportation	Yes
Ministere des Transports et de la Mobilité Durable du Québec	Yes
NDDOT	Yes
WYDOT	Yes
Montana	Yes
NDDOT	Yes
Town of Middlebury	
Kansas DOT	Yes
UDOT	Yes
Directorate of Roads and Highways	Yes
Rijkswaterstaat Netherlands	
Ville de Pointe-Claire	Yes
Kansas DOT	Yes
Norwegian Public Roads Administration	Yes
Vermont Agency of Transportation	Yes
NHDOT	Yes
IL DOT	Yes
Massachusetts Dept. of Transportation	Yes
City of Farmington Hills, MI	Yes
Iowa DOT	Yes
Alaska DOT&PF	Yes
Montana Department of Transportation	Yes
Kansas DOT	Yes
City of Bozeman MT	Yes
Kiewit Meridiam Partners	No

Agency	Response
City of Columbus, Ohio	Yes
City of Columbus, Depart. of Public Service	Yes

CLEAR ROADS
research for winter highway maintenance

Lead state:
Minnesota Department of Transportation
Research Services
395 John Ireland Blvd.
St. Paul, MN 55155