December 2023

Research Results Implementation Update

Completed Projects

Efficacy, Cost, and Impacts of Non-Chloride Deicers: An Educational Primer and Product Information Sheets

Results: From this environmental data, investigators recommended environmental testing standards to be added to Test Methods 15 through 20 of Clear Roads *Guidance Document for Material Qualified Products List, Specifications, Test Methods, and Product Purchasing*, which address Toxicity, Ammonia – Nitrogen, Total Kjeldahl Nitrogen, Biological Oxygen Demand and Chemical Oxygen Demand tests.

Anticipated Implementation & Benefit Opportunity: This project produced supporting documents, including educational primers that may be used to inform the public and legislators of these possible alternatives, including their cost, effectiveness, and environmental impact.

Evaluation of Electric Vehicle Technologies and Alternative Fuels for Winter Operations

Results: Investigators research electric vehicle technology, while also identifying what alternative fuels are viable for use in winter maintenance vehicles and heavy equipment. They compared the benefits and challenges each energy source offers. This information was the basis for a synthesis report that agencies can reference in their decision-making process.

Implementation & Benefit Opportunity: The project provided agencies that rely on diesel-powered winter maintenance fleets with a thorough understanding of the available technologies and related operational considerations that would be impacted by a transition to a fleet powered by EVT or alternative fuels.

High Performance Blade Evaluation

Results: Based on lab test results, Clear Roads produced a Quick Reference Guide outlining the features and specifications of each blade along with key test results and cost-benefit ratios in an easy-to-read format. These tests will also be repeatable with future-developed high-performance blades as a standard test protocol was also developed.

Implementation & Benefit Opportunity: This project assessed the cost-effectiveness of high-performance snowplow blades and developed a standard test protocol (for use in this study and in the future) that Clear Roads states can use to evaluate and compare snowplow blades. Both will help states make more informed procurement decisions.

Expanded Use of AVL/GPS Technology

Results: This project helped fleet managers demonstrate the additional return on investment that can be realized using these systems for year-round maintenance activities.

Implementation & Benefit Opportunity: This project helped state transportation agencies optimize the value gained from the acquisition of AVL/GPS units by deploying them year-round, rather than just in

winter maintenance operations. The deliverables of this project helped fleet managers demonstrate the return on investment that this technology can provide to transportation agencies.

Evaluation of Indoor Automated Stockpile Measurement Systems

Results: By automating this process, states could improve their inventory management and minimize costly rush orders of salt.

Implementation & Benefit Opportunity: This project tested and evaluated currently available automatic or semi-automatic indoor salt stockpile measuring systems and developed guidance for agencies on system selection and use. The ultimate objective is to improve agencies' day-to-day management of their salt stockpile inventories.

Understanding the NaCl Phase Diagram

Results: Project deliverables include the development of training materials (a fact sheet and an education video describing the NaCl Phase Diagram) to help provide winter maintenance practitioners with a better understanding of the phase diagram for sodium chloride and how to apply it to yield the best results in roadway deicing.

Implementation & Benefit Opportunity: The two user-friendly training aids will be clear and concise, geared toward easy printing / posting the flyer as well as viewing the video via laptop or mobile device. By providing winter maintenance managers and supervisors with a better understanding of key aspects of the NaCl phase diagram will help winter maintenance agencies apply salt and salt brines effectively for the best performance on winter roadways.

Expanding Application Rate Guidance for Salt Brine Blends for Direct Liquid Application and Anti-icing (December 2021)

Results: A more robust set of data is necessary to provide agencies with the information needed to apply various liquid deicers in a broader range of field conditions, particularly at lower temperatures. This project gathered that data through a survey of practice and subsequent field testing. The test results, along with the survey results and information gathered in a literature review, were used to create a set of application rate tables for brine and brine blend usage for DLA and anti-icing.

Implementation & Benefit Opportunity: This project expanded on the currently available guidelines for the use of brines and brine blends for DLA and anti-icing. By providing a more complete set of application rates for various pavement temperature ranges and road surface conditions, this project will help facilitate expanded use of DLA and anti-icing, as appropriate, at agencies across the country.

Measuring the Efficiencies of Tow and Wing Plows (December 2021)

Results: Through a practitioner survey, testing / simulation, and analysis, this project quantified efficiencies, provided a thorough examination of the extent to which these efficiencies are realized under real-world conditions, and identified the roadways best suited to deployment of the different plow types. Finally, this project produced a decision support tool, user's guide, and best practices guide to help agencies more accurately assess the efficiencies, costs of ownership, and return on investment for this equipment and determine the best locations to deploy it.

Implementation & Benefit Opportunity: This project moved beyond theoretical best-case operating scenarios to quantify the actual efficiencies gained during real-world operation of this equipment. This research compiled and synthesized state DOTs' real-world experiences with tow plows and wing plows and incorporated this information into a detailed analysis of each equipment configuration. The resulting best practices guide and decision support tool provide a more accurate representation of actual life-cycle costs and efficiencies than is currently available.

Synthesis of Technical Requirements and Considerations for an Automated Snowplow Route Optimization RFP Template (October 2021)

Results: Through the survey and follow-up interviews with agencies and vendors, this project captured the technical requirements and considerations involved in selecting a program; provide guidance on these decisions; and provide a list of technical requirements and considerations that states can use to build their own RFPs.

Implementation & Benefit Opportunity: A literature search and online survey identified agencies that have developed RFPs for automated snowplow route optimization programs and vendors that provided this software. Through follow-up interviews with agencies and vendors, this project captured the technical requirements and considerations involved in selecting a program; provided guidance on these decisions; and provided a list of technical requirements and considerations that states can use to build their own RFPs.

Entry-Level Driver Training for Maintenance Equipment Operators (September 2021)

Results: This project developed a training curriculum that meets FMCSA requirements and provided all training materials and resources necessary for states to execute the training program. The training materials consisted of PowerPoint presentations, course guides, exams, videos, eLearning and other training support materials to be used as part of instructor-led classroom (theory) and behind-the-wheel (BTW) training programs at state DOTs.

This project also developed train-the-trainer materials to assist agencies in implementing the training program. In addition, this project developed and documented a process for DOTs to follow to ensure that all of their training locations are added to the TPR before February 7, 2022.

Implementation & Benefit Opportunity: Using this training program will help Clear Roads agencies ensure that they are in compliance with the ELDT final federal rule published in 2016 (81 FR 88732) and amended in 2019 (84 FR 8029) by the Federal Motor Carrier Safety Administration.

AWSSI Enhancements, Phase 2 (August 2021)

Results: This project continued the process of improving the tool developed by the MRCC. This iteration added additional locations to the AWSSI tool; updated the average AWSSI seasonal total map through the 2019-2020 season; added the ability to download the daily seasonal data for any given station during the current season; and provided the user with the ability to add up to five specific historical seasons to be included in any station's current year chart.

Implementation & Benefit Opportunity: With AWSSI, planners can compare current conditions to past. By correlating winter conditions with past usage of materials, equipment and staffing, users can create snow and ice maintenance budget requests and plans.

Synthesis: Retention and Recruitment of Highway Maintenance Workers (August 2021)

Results: This project developed thirteen case studies examining agencies' efforts and experiences in recruitment and retention of highway maintenance workers. Based on these case studies, recommendations were provided that included a list of recommended exit interview questions that agencies can use with departing employees to better understand what aspects of the positions could be modified to attract and retain workers.

Implementation & Benefit Opportunity: Since it is often difficult to significantly increase wages, Clear Roads sought to learn which significant employment factors are within agencies' control to modify in order to increase recruitment and retention. This project identified how state agencies have emphasized factors, other than salary, during the recruiting and hiring process.

Review and Summary of Pre-Wet Methods and Procedures (June 2021)

Results: This compilation provides guidance to transportation agencies seeking to effectively employ the practice of pre-wetting of solid materials in their winter highway maintenance protocols.

Implementation & Benefit Opportunity: A Phase II project is planned that will combine the results of both phases to produce a comprehensive guide to pre-wetting.

Aftermarket Cameras in Winter Maintenance Vehicles (June 2021)

Results: Guidance in the form of a synthesis of current practices and existing data and test results as well as a compilation of lessons learned, best practices, considerations, and recommendations.

Implementation & Benefit Opportunity: This project assists with operational decisions and increases situational awareness for snowplow operators, thus giving state DOTs the best possible information for selecting and employing such cameras.

Evaluation of Storm Severity Indexes (SSI) and Winter Severity Indexes (WSI) Variables (December 2020)

Results: This project gathered statistical data resulting from analysis of each variable for consistency and variability; recommended the most reliable variables, with the highest correlation to storm severity, for developing SSI/WSI; and created a flexible spreadsheet tool that allows agencies to develop a state-specific SSI/WSI.

Implementation & Benefit Opportunity: This project will allow winter maintenance managers, researchers and transportation agencies to more effectively compare winter operations among localized areas, districts and states. Agencies will also be able to compare individual storms and across years to evaluate innovations and new winter maintenance methods.

Integrating Advanced Technologies into Winter Operating Decisions (December 2020)

Results: A user-friendly Best Management Practices guide to the technologies available for winter maintenance operations; what these technologies measure; how to integrate them into a successful winter maintenance operations strategy; and recommendations on how to incorporate future technologies into the strategy.

Implementation & Benefit Opportunity: This project gives state DOTs a better understanding of how to integrate these technologies into their winter maintenance programs.

Defensive Driving Training for Snowplow Operators (August 2020)

Results: This project resulted in the creation of two PPT-based training modules on safe driving and defensive driving for snowplow operators, which include videos that demonstrate defensive and safe driving scenarios.

Implementation & Benefit Opportunity: This project examined key causes of collisions involving snowplows and other vehicles, identified defensive driving strategies that snowplow operators can use to reduce the likelihood of being struck by other drivers, and developed training modules on safe driving and defensive driving for snowplow operators.

Alternative Methods for Deicing (July 2020)

Results: Case studies and recommendations to help state departments of transportation and local transportation agencies better understand the performance, cost and environmental impacts of alternative deicing materials, and the application methods currently used in the field, and to compare the performance and impacts of alternative winter maintenance materials with chloride-based materials.

Implementation & Benefit Opportunity: The outcomes of this project will be used by winter maintenance managers to evaluate and identify alternative deicing materials that can meet current agency level of service standards, while limiting costs and environmental impacts and reducing the use of chloride-based materials.

Standard Specifications for Plow Blades with Carbide Inserts (April 2020)

Results: A set of common standard specification, including but not limited to the following:

- Carbide inserts, geometry, and dimensions
- Blade materials, assembly details, and dimensions
- Plow blade configuration (front, underbody, or tow blade) and blade dimensions (length and height)
- Quality assurance inspections and accept/reject procedures
- Details of procedures to accept/reject inserts

Specifications include text and AutoCAD details of insert dimensions, insert material, blade dimensions, and mounting details, including bolt pattern and inside measurements, amount of insert inside a blade, and the blade/insert mounting configuration.

Implementation & Benefit Opportunity: A set of standard specifications can be used by agencies across the country to specify carbide-insert plow blades. States can simplify and streamline the procurement process for both state DOTs and vendors. The buying power connected to widely accepted specifications would be greater, and procurement coalitions could potentially use the standard specifications for bidding. In addition, if more agencies specified the same product, vendors could reduce their costs and pass those savings on to state DOTs.

Weather Event Reconstruction & Analysis Tool (December 2019)

Results: This project identified easily usable data sources and developed a user-friendly data retrieval interface. A web-based analysis tool, including affiliated support and training materials, were developed to make the data more accessible and usable by DOTs.

Implementation & Benefit Opportunity: By finding, cataloging and categorizing available web-based data sources, this project helps agencies spend less time finding and preparing data and lets them move quickly to analysis and follow up.

Developing Test Bed Software to Qualify Plug and Play Technology (June 2019)

Results: Clear Roads has created a software suite composed of an SQL database, a web portal, and a device test application.

Implementation & Benefit Opportunity: This Test Bed allows Clear Roads to easily and consistently identify vendors that are in compliance with the Plug and Play protocol developed via the Plug and Play Initiative. This gives states the ability to select vendors that can support the "plug and play" approach to adding spreader controllers, sensors and other components.

Standards and Guidance for Using Mobile Sensor Technology to Assess Winter Road Conditions (May 2019)

Results: Through rigorous testing of sensor equipment and development of standardized scales, Clear Roads has created guidance to make better use of road sensor data for decision-making.

Implementation & Benefit Opportunity: The guidance developed from this project will help in multiple aspects of winter maintenance—in the short-term for responding to a winter storm in real time, and in the long-term in making policy and planning decisions based on performance trends. It will also help practitioners avoid guesswork by providing guidance based on vetted equipment and reliable numerical standards.

Synthesis of Material Application Methodologies for Winter Operations (April 2019)

Results: A key deliverable of this project is a concise, authoritative handbook for winter maintenance professionals on the selection and use of winter maintenance materials.

Implementation & Benefit Opportunity: The guide will help winter maintenance professionals make decisions regarding material application rates, methodologies, and material usage. It will also help agencies optimize their winter maintenance processes to improve safety and save money.

AWSSI Enhancements in Support of Winter Road Maintenance (February 2019)

Results: A simple tool that states can use to conduct their own calculations in order to relate storm severity to other factors, such as winter maintenance costs.

Implementation & Benefit Opportunity: With AWSSI, planners can compare current conditions to past. By correlating winter conditions with past usage of materials, equipment and staffing, users can create snow and ice maintenance budget requests and plans.

Developing a Training Video and Manual for Best Practices and Techniques in Clearing Different Interchange Configurations and Other Geometric Layouts (October 2018)

Results: A one-hour video, practice manual, and operator reference cards that showcase the most efficient pass sequences to properly clear ten different interchange and intersection layouts.

Implementation & Benefit Opportunity: The resulting videos should provide an easy way for agencies to train staff on the most efficient ways to clear challenging interchanges.

Utilization of AVL/GPS Technology: Case Studies (July 2018)

Results: This project will help state DOTs make more informed decisions with respect to implementation of winter maintenance AVL/GPS.

Implementation & Benefit Opportunity: Detailed agency case studies developed in this new project will bring to light more nuanced issues related to winter maintenance AVL/GPS. The case studies highlight the types of issues that agencies should consider, provide guidance for successful implementation, and serve as possible templates for agencies to get the best value out of different levels of AVL/GPS applications.

Training Video for the Implementation of Liquid-Only Plow Routes (June 2018)

Results: This project created two videos – a long one for maintenance supervisors and operators and a short one for executives and policy-makers – designed to explain the benefits of liquid-only plow routes, the fundamentals of how and when to use liquid-only plowing, and steps to implement a program of liquid-only plow routes.

Implementation & Benefit Opportunity: This project will help state DOTs garner support for and accelerate the implementation of liquid-only plow routes. The videos will serve educate and obtain buy-in from multiple audiences within a DOT (executives, managers, maintenance staff, and operations staff) and beyond (lawmakers and the public) and give agencies tangible tools with which to make the next step in putting this practice to work.

Emergency Operations Methodology for Extreme Winter Storm Events (May 2018)

Results: This project provides guidance to transportation agencies seeking to develop or improve their current plans and policies for handling severe-to-extreme storm events.

Implementation & Benefit Opportunity: Clear Roads members believe much can be learned by capturing experiences and best practices from their peer agencies. Implementation of such guidance should result in more robust, coordinated plans nationwide, and improved execution of such plans.

Understanding the Chemical and Mechanical Performance of Snow and Ice Control Agents on Porous or Permeable Pavements (January 2018)

Results: Best practice guidelines to help determine the optimum winter maintenance strategies for porous or permeable asphalt pavements.

Implementation & Benefit Opportunity: This project should be used to help construction staff understand the maintenance cost impact of porous and permeable pavements and help maintenance staff identify the most efficient ways to safely clear those pavement types during winter events.

Quantifying the Impact that New Capital Projects Will Have on Roadway Snow and Ice Control (RSIC) Operations (November 2017)

Results: This project produced a decision tool used to quantify the anticipated impact that new capital projects will have on the costs for winter maintenance.

Implementation & Benefit Opportunity: This project helps maintenance and planning staff to better assess the financial impacts on winter maintenance of new construction projects before they are undertaken.

Identification and Recommendations for Correction of Equipment Factors Causing Fatigue in Snowplow Operators (October 2017)

Results: This project identified in-cab and external equipment factors that cause operator fatigue and makes recommendations to reduce, eliminate, or correct these factors.

Implementation & Benefit Opportunity: This project identifies implementable improvements to snowplow trucks that reduce fatigue in operators. The report includes recommendations for quick turnaround and low-cost solutions, which can be implemented by state DOTs and possibly shared with the trucking industry.

Snowplow Operator and Supervisor Training (May 2017)

Results: This project resulted in the production of 22 winter maintenance training materials for operators and supervisors that include presentations, course guides, and assessments/evaluations.

Implementation & Benefit Opportunity: This is an easy, low-cost way to fill any gaps in an agency's training program. Presentations, course guides and exams are available to all member states to modify or update as needed, saving agencies time on developing effective training materials.

Snow Removal Performance Metrics (May 2017)

Results: A matrix of agency goals, performance measures, and measurement costs shared by DOTs around the country.

Implementation & Benefit Opportunity: Agencies can learn from each other regarding collected performance metrics for assessing the efficiency and effectiveness of winter maintenance activities.

Plug and Play Phase II (February 2017)

Results: This project identified the most appropriate standard protocols and made recommendations regarding the transmission of data from vehicle to point location.

Implementation & Benefit Opportunity*:* This project is part of the larger Plug and Play Initiative. By adopting the specifications and standards developed through the initiative, Clear Roads will move one step closer to the integration of new components onboard winter maintenance vehicles to make winter maintenance activities easier and cheaper for all states.

North American Study on Contracting Snow and Ice Response (February 2017)

Results: A compilation and analysis of the snow and ice control contracting practices used by agencies around the country.

Implementation and Benefit Opportunity: This document, which compiles best practices, costs, benefits, and lessons learned by state DOTs when contracting for snow and ice control, will help agencies

determine how best to modify and improve their own practices to save money and more effectively manage resources.

Snowplow Route Optimization (December 2016)

Results: This project provides a synthesis of best practices for route optimization and facility placement, including a matrix that illustrates the project characteristics of RSIC optimization efforts that have been undertaken by winter maintenance organizations to date.

Implementation & Benefit Opportunity: This project provides winter maintenance managers with effective approaches to route optimization to improve their agency's efficiency.

Synthesis on GPS/AVL Equipment Used for Winter Maintenance (September 2016)

Results: A synthesis document, which analyzes the different GPS/AVL systems in winter maintenance, including how well each one performs and their systems requirements and constraints.

Implementation & Benefit Opportunity: This project helps states better understand the systems options available (systems and components) to them for a variety of situations and truck configurations and identify the best solutions for their circumstances.

Identifying Characteristics, Benefits, and Mechanisms of Commonly Used Agricultural and Mineral By-Products in the Deicer Industry (November 2015)

Results: The final report contains a best practices manual that includes, 1) parameters for effective use of agricultural and mineral by-products, 2) specifications that can be used in the procurement for each product, and 3) guidelines for application and storage.

Implementation & Benefit Opportunity: The project furthers knowledge of how nine commonly-used non-chloride liquid agricultural products and one solid complex chloride/mineral product perform, and the environmental impact of these chemicals, so as to guide the states in their use.

Roadway Salt Best Management Practices (November 2015)

Results: A manual of best management practices for procurement, storage, and use of salt.

Implementation & Benefit Opportunity: The manual describes each BMP on a single page, front and back. Researchers organized it this way so that information about each BMP could be separated from the manual and shared with relevant personnel or placed in a break room so staff could review and consider the information in easily digestible chunks.

Use of Equipment Lighting During Snowplow Operations (September 2015)

Results: A summary of best practices by state DOTs regarding their use of headlights, work lights, and warning light technology in snowplow operations.

Implementation & Benefit Opportunity: The synthesis makes recommendations regarding the optimum use of various lighting technologies, including mounting techniques and location guidelines.

Cost Benefit Analysis of Various Winter Maintenance Strategies (September 2015)

Results*:* An assessment of the costs and benefits of three winter maintenance strategies to better understand the safest and most cost-effective approach based on the desired level of service.

Implementation & Benefit Opportunity: This project resulted in a matrix of winter maintenance strategies and impacts that is concisely and clearly written for a broad audience of stakeholders, including winter maintenance professionals, DOT management, legislators and the public. This matrix will help agencies select the most appropriate strategies for a given level of service and gain consensus on the most effective approaches to winter maintenance.

Snow and Ice Control Environmental Best Management Practices Manual (July 2015)

Results: A national *Snow and Ice Control Environmental Best Management Practices Manual* that provides the most up-to-date recommendations, based on a foundation of leading research and resources nationwide.

Implementation & Benefit Opportunity*:* This resource helps to articulate responsible snow and ice control practices for DOT staff, legislators and other interested parties, so that the priorities of safety, efficiency, cost, and environmental protection can be appropriately balanced.

Best Practices for the Prevention of Corrosion to DOT Equipment: A User's Manual (May 2015)

Results: An easy-to-use guide that summarizes in layman's terms the best practices to prevent corrosion to maintenance equipment.

Implementation & Benefit Opportunity: Guidelines for corrosion management on highway maintenance equipment for use by fleet managers, garage supervisors, and staff that will minimize the costs and impacts of corrosion.

Winter Severity Mapping Enhancement (March 2015)

Results: A set of state-specific weather severity maps tailored to each member state's needs.

Implementation & Benefit Opportunity: This project provides a state-focused version of each of the five weather severity maps (hours of blowing snow; hours of freezing rain; hours of snowfall; inches of snow and overall severity) to facilitate more detailed comparisons of weather and operations between states.

Establishing Effective Salt and Anti-icing Application Rates (February 2015)

Results: The project, though terminated early, does provide a collection of information (literature review) and updated guidelines, which contain an overview of liquid and solid chemical usage, including comparative tables for chemical performance; tables for minimum temperature bands for solid and liquid applications; chemical characteristics for most common anti-icers; and state practices regarding chemical usage (weather, costs, application rates).

Implementation & Benefit Opportunity: Provides a basis for pursuing an in-depth synthesis of current practice in the field of anti-icing.

Comparison of Materials Distribution Systems (December 2014)

Results: A photographic catalog of all the different types of material distribution systems identified throughout the project.

Implementation & Benefit Opportunity: This is a great resource for DOTs that want to improve their bounce and scatter performance, improve their pre-wetting systems, or add features to their current systems. The catalogue includes agency contact information for each item pictured to facilitate follow-up connections.

Development of a Totally Automated Spreading System (May 2014)

Results*:* Three guides to help agencies assess the automation technology available and how best to implement the latest components into DOT fleets: Best Practices and Functions of Automated Spreading Systems, Levels of Automation, and Challenges and Currently Available Systems.

Implementation & Benefit Opportunity: This research offers a vision of the features of a totally automated spreader system, which can serve as a guide for equipment manufacturers and state and local agencies contemplating purchases.

Environmental Factors Causing Fatigue in Snowplow Operators (March 2014)

Results: Recommendations for cost-effective solutions to mitigate driver fatigue and potential avenues for further research.

Implementation & Benefit Opportunity: State DOTs may be able to reduce fatigue-related snowplow incidents by implementing policy and training recommendations resulting from this study. In addition, Clear Roads has funded a follow-up project aimed at identifying the *equipment* factors that cause fatigue in snowplow operators.

Determining the Toxicity of Deicing Materials (January 2014)

Results: A final report and a concise quick-reference guide that summarizes the toxicity rankings of deicing chemicals and helps winter highway maintenance managers consider both expected levels of service and potential harm to the environment when selecting a deicer to use.

Implementation & Benefit Opportunity: The results can help agencies balance both cost and environmental impacts of winter maintenance when selecting which deicing chemicals to apply.

Mapping Weather Severity Zones (September 2012) and Understanding the True Costs of Snow and Ice Control Operations (January 2014)

Results: As a first effort, the weather severity project produced a series of maps that depict winter weather severity across the U.S. in a manner similar to the plant hardiness zone maps used for agriculture. The follow-up project on the true costs of winter operations resulted in a tool that allows users to analyze and compare the labor and material costs of up to four different storms or time periods. This tool leverages the weather maps developed to facilitate comparisons among states with similar climates.

Implementation & Benefit Opportunity: If implemented, the True Cost Tool enables what-if testing on unit costs; helps practitioners communicate cost drivers in winter maintenance to policymakers and the public; helps managers to better understand and manage costs; simplifies the comparison of costs across storms, districts or regions, and states; and simplifies comparison of winter maintenance costs over time.

Cost-Benefit Analysis Toolkit (Phase I: November 2010, Phase II: June 2013)

Results: A standard Web-based tool and manual for cost-benefit analysis of specific winter maintenance practices, equipment and operations. Phase II included enhanced features and expanded functionality to address additional materials, equipment and methods.

Implementation & Benefit Opportunity: Many DOTs have put this to good use. For example, it helped Iowa DOT demonstrate that it could achieve significant savings by purchasing and using automatic vehicle location and geographic positioning systems. Massachusetts DOT used the toolkit to assess alternatives for salt spreader controllers and to help support capital spending decisions.

Snow Removal at Extreme Temperatures (March 2013)

Results: A compilation of strategies for winter maintenance during extreme cold that have been used by DOTs and other jurisdictions.

Implementation & Benefit Opportunity: This project confirmed current practices.

Effectiveness of Deicing Materials and Procedures (December 2009) and Training Video for Field Testing of Deicing Materials (December 2011)

Results: The first project on deicer materials and procedures resulted in a practical field guide for testing the effectiveness of deicers. The follow-up project then produced a training video that explains the testing methodologies outlined in the field guide.

Implementation & Benefit Opportunity: DOTs have broadly adopted this testing method, integrated it into training and distributed the video to their districts.

Standardized Test Procedures for Carbide Insert Snowplow Blade Wear (September 2010)

Results: The report identifies lab tests that could be used to predict field performance of carbide insert snowplow blades, provides recommendations for developing a national standard for carbide inserts, and provides recommendations for implementing a purchasing approval framework.

Implementation & Benefit Opportunity*:* If an agency adopts the recommended process for testing and acceptance of carbide inserts, poor performance of carbide-insert blades should be minimized. The carbide inserts will last longer, which will reduce replacement costs, and will also reduce the time, cost and equipment downtime associated with changing plow blades. These benefits would expand if the procedures are accepted as a national standard or are developed into model specifications that any agency could implement. Using standardized tests would improve agencies' purchasing processes, reducing management time and validating purchase decisions.

Identifying Parameters for Effective Implementation of Liquid-only Plow Routes (September 2010)

Results: The report identifies parameters for the safe and effective use of liquid-only routes during winter storm events and provides an assessment of the viability of field testing.

Implementation & Benefit Opportunity: This project identifies the best circumstances to use the innovative technique of direct liquid applications during winter storm events. It also provides a quick-reference guide that makes it easy to implement.

Correlating Lab Testing and Field Performance for Deicing and Anti-icing Chemicals: Phase I (August 2010)

Results: The report provides recommendations for how to proceed with lab and field testing that measures performance characteristics of deicing and anti-icing chemicals.

Implementation & Benefit Opportunity: This project confirmed current practices.

Development of Interface Specifications for Mobile Data Platforms on DOT Vehicles (April 2010)

Results: The report provides communication and data format specifications that support a "plug and play" approach to integrating sensors and other devices with mobile data platforms used by state DOTs.

Implementation & Benefit Opportunity: The implementation efforts for this project have continued in the Clear Roads Plug and Play Initiative, which involves collaborating with the vendor community to develop a protocol that would support a "plug-and-play" approach to integrating electronic devices and sensors on plow trucks. Establishment of this protocol will mutually benefit Clear Roads member states and their vendors by standardizing how critical operational data is shared on modern snow and ice vehicles, namely between compatible Automatic Vehicle Location (AVL) devices and anti-icing/deicing Joystick and Spreader Controller systems.

Development of Standardized Test Procedures for Evaluating Deicing Chemicals (March 2010)

Results: The report identifies standardized tests and procedures that help states determine the relative performance of deicers.

Implementation & Benefit Opportunity: This project confirmed current practices.

Developing and Evaluating Safe Winter Driving Messages (March 2010)

Results: Public service announcements and Internet banner ads targeted at high-risk demographics to change their winter driving behavior.

Implementation & Benefit Opportunity: Almost every Clear Roads member state and many other states have adopted the use of these collaborative materials, saving the money, time and resources that would have been necessary to develop this campaign independently.

Calibration Accuracy of Manual and Ground-Speed-Control Spreaders (February 2008)

Results: The report provides guidelines to help snowplow operators establish and maintain accurate calibration of ground speed controllers. The project also included the development of a Calibration Guide for use in the field.

Implementation & Benefit Opportunity: Member states are reporting reduced net salt usage between 4% and 10% by implementing updated calibration strategies and techniques. For example, if a Clear Roads member state uses 600,000 tons of salt each year at $50 per ton for an annual cost of $30,000,000, a 5% savings in material would result in a savings of $1,500,000 each year.

Research in Progress

Comprehensive Guide to Pre-wetting Application Rate Methods

Expected Results: This project will lead to the development of a comprehensive guide to pre-wetting that will enable departments of transportation; public works agencies; and superintendents, supervisors and other practitioners involved in snow and ice control to incorporate pre-wetting into their snow and ice control equipment. Specifically, the guide will provide optimal application rates for meeting pre-wetting goals and will quantify the benefits of different rates, speeds, and other delivery factors. The guide will also present the findings of using two to four salt spreader configurations and delivery systems.

Expected Completion Date: September 2024

Anticipated Implementation & Benefit Opportunity: A comprehensive guide that will provide optimal application rates for meeting pre-wetting goals and will quantify the benefits of different rates, speeds, and other delivery factors. The guide will also present the findings of using two to four salt spreader configurations and delivery systems (e.g., auger, Monroe hopper, zero-velocity spreader). The evaluation will include a discussion of the advantages and disadvantages of each in meeting pre-wetting goals.

Best Management Practices for Liquid Chloride Storage and Pumping Systems

Expected Results: This project will lead to the development of a manual for deicing liquid storage and pump system equipment and the associated best management practices. The manual will include images and descriptions of typical equipment configurations currently in use. Each system configuration will include a list of primary components, system cost, benefits and challenges associated with each configuration, and detailed information regarding a point of contact within the agency and the division / program responsible for that equipment.

Expected Completion Date: December 2024

Anticipated Implementation & Benefit Opportunity: This project will develop a guidance manual that explores the issues transportation agencies should consider when choosing or replacing deicing liquid storage systems. There are several areas of interest associated with operating a reliable system including safety, environment, and cost-effectiveness. A review of the systems different agencies uses, including system benefits and challenges, will help agencies better understand their options when procuring a new system or updating an existing one.

Effects of Additives in Lowering the Freezing Point of Deicing Salts

Expected Results: Research recommendations can be used to inform the decision-making of state departments of transportation, municipalities, and other winter maintenance practitioners when choosing a deicing salt for winter maintenance operations.

Expected Completion Date: August 2024

Anticipated Implementation & Benefit Opportunity: While manufacturers of deicing salt products claim that additives enhance product performance, there is no definitive evidence to substantiate these claims. Evaluating these products in the lab and in the field will establish the effectiveness of additives to lower eutectic temperatures and will indicate whether additives increase the performance of deicing salts. Research recommendations can be used to inform the decision-making of state departments of

transportation (DOTs), municipalities and other winter maintenance practitioners when choosing a deicing salt for winter maintenance operations.

Evaluation of Direct Liquid Application of Salt Brine vs Granular Salt as Measured Through Various Performance and Safety Metrics

Expected Results: Project findings will identify three to five performance measures for the DLA of salt brine as compared to the application of granular salt. These measures will focus on impacts to the traveling public and might include air / pavement temperature, time to bare / wet pavement, friction / grip rating, speed recovery and other safety-related measures. In addition to a report, an infographic that produces a visually compelling, concise presentation of key project findings in a one- to three-page communication product will be produced.

Expected Completion Date: December 2024

Anticipated Implementation & Benefit Opportunity: Many of the studies conducted to date focus on cost savings and environmental impacts of the DLA of salt brine while not addressing the efficacy and safety impacts of its use. Without performance comparison data to support DLA practices, the traveling public may conclude that while the advantages of DLA in cost savings and environmental impacts are clear, granular salt treatments are still the more effective way to treat winter roadways. This study aims to provide DOTs with the information they need to defend the use of DLA treatments where appropriate.

Use of Dashboards for Winter Operations

Expected Results: Results of this synthesis will provide a more thorough understanding of these dashboards; thus, it may be possible to improve operations through increases in Level of Service, reduction in materials usage, man-hours, and the overall cost of winter maintenance operations. In turn, information from these dashboards may be used to communicate with agency executives and legislators, and potentially the public.

Expected Completion Date: June 2024

Anticipated Implementation & Benefit Opportunity: Advances in information technology offer agencies the capability to capture and track data obtained from winter maintenance equipment. A review of which agencies are using dashboards in winter maintenance operations, including necessary resources and best practices for developing and implementing this tool, will give Clear Roads an understanding of how this data is obtained and displayed through these dashboards. Then, how is the information displayed used to gain efficiencies related to Level of Service, material use, resource allocation, and the cost of winter maintenance operations.

pH Waiver for Deicing Products and the Qualified Products List

Expected Results: A standard set of procedural tests will be developed for identifying appropriate pH levels that can be used to evaluate products going forward to determine whether a product can be placed on the QPL.

Expected Completion Date: April 2025

Anticipated Implementation & Benefit Opportunity: Recommendations from this research could potentially increase the number of available deicing products on the QPL, improving the winter maintenance operations of transportation agencies through competitive pricing and other factors, while

ensuring structural and environmental safety. The research will also help to identify products that should be removed from the QPL

Grip Sensor Technology and Salt Applications

Expected Results: This project will provide winter maintenance teams with an algorithm or decision matrix that incorporates pavement friction and other data to advise the appropriate type and application rate of deicing materials in real time.

Expected Completion Date: August 2023

Anticipated Implementation & Benefit Opportunity: By understanding how other agencies have applied friction data, and with a decision matrix that can recommend treatment strategies based on a variety of factors, maintenance teams will be better equipped to respond quickly and efficiently to changing road conditions.

Best Practices for Protecting DOT Equipment of the Corrosive Effect of Chemical Deicers

Expected Results: The product testing conducted for this project will provide a more robust evaluation of the performance of anti-corrosion coatings that is necessary to provide agencies with the information needed to select suitable anti-corrosion coatings for their valuable equipment.

Expected Completion Date: February 2024

Anticipated Implementation & Benefit Opportunity: The project will look at the various coatings available on the market, from 2013 to the present, and conduct side-by-side comparison testing based on the application method. A more robust evaluation of the performance of anti-corrosion coatings is necessary to provide agencies with the information needed to select suitable anti-corrosion coatings for their valuable equipment.

Training Module Development for Evaluation of SSI and WSI Variables

Expected Results: The outcome of this project will be detailed training modules that synthesize the material from CR 18-03 into 30- to 60-minute segments tailored to the three target audiences. These modules would include audiovisual materials, discussion topics, and interactive exercises (knowledge checks) required to provide complete training on this topic.

Expected Completion Date: June 2023

Anticipated Implementation & Benefit Opportunity: The project will provide training, to accompany *CR 18-03 Evaluation of SSI and WSI Variables*, to help individuals select the appropriate severity index tool for their jurisdiction. Ultimately understanding WSI as it relates to the specific jurisdiction is an important tool for managing staffing levels and budget allocation.

Calculating Plow Cycle Times from AVL Data

Expected Results: This project will result in a methodology to calculate plow cycle times, considering various relevant factors. This methodology will then be used to create the framework for a visualization tool that agencies can format with their own electronic data.

Expected Completion Date: April 2024

Anticipated Implementation & Benefit Opportunity: Agencies will have the ability to track snowplows in real-time and make operational adjustments as needed to maximize efficiency. Additionally, agencies will have greater insight for post-storm analyses, performance evaluations, route optimization strategies, and resource allocation efforts while leveraging data they likely already collect during their routine winter maintenance activities.

Determining the Migration of Chloride-Based Deicers through Different Soil Types

Expected Results: Creation of a series of one-page fact sheets based on the results of a controlled testing program looking closely at how sodium chloride, calcium chloride, and magnesium chloride migrate through different soil textures – and how agricultural-based inhibitors affect that process.

Expected Completion Date: November 2023

Anticipated Implementation & Benefit Opportunity: By understanding how the chloride-based deicers move through different soils, maintenance teams will be better equipped to identify sensitive areas and target winter maintenance treatments accordingly.

Using GIS to Highlight Highway Segments Sensitive to Deicing Materials

Expected Results: This project will develop a geospatial tool that incorporates data about roadways, topography, hydrology, and ecology to model the impact of de-icing chemical application on the local environment. This information can then be used by maintenance personnel to adjust material application to balance mobility and environmental concerns.

Expected Completion Date: September 2023

Anticipated Implementation & Benefit Opportunity: This project will improve operational planning by developing an easy-to-use GIS tool that will help agencies identify the roadway segments where vulnerable environmental resources may be impacted by snow and ice control activities.

Salt Shed Design Template

Expected Results: This project will develop a set of three scalable salt shed designs that can be used as a template to meet the needs of a variety of sites throughout Clear Roads member states. The designs will consider existing building codes and state and federal regulations associated with environmental and related concerns.

Expected Completion Date: July 2023 (extending to January 2024)

Anticipated Implementation & Benefit Opportunity: The designs will provide a basic template for member states to use as a starting point for further design modifications and for bidding for shelter construction.

Standard Test Procedure for Ice Melting Capacity of Winter Maintenance Materials

Expected Results: Clear Roads wishes to standardize product testing to help states meet level of service requirements with the lowest possible procurement costs. In this project, the Mechanical Rocker Test Procedure, developed by Nebraska DOT, will be evaluated for use as a national standard.

Expected Completion Date: July 2021

Anticipated Implementation & Benefit Opportunity: To provide agencies with an objective, repeatable test procedure for evaluating and comparing the quality and performance of winter maintenance materials, and to give agencies the tools to improve their procurement process for winter maintenance materials, streamlining procedures, increasing cost-effectiveness and opportunities for vendor competition.

Research to Award

Development of a Public Service Announcement (PSA) Library

Anticipated Implementation & Benefit Opportunity: This project will produce a set of educational materials on a limited number of winter maintenance topics. These materials will be organized in a library of topics that could be expanded and built upon in the future. The materials will be hosted on the Clear Roads Winter Driving Safety website, which was developed to serve state DOT public information officers and the traveling public. This project will benefit these entities by providing resources that have been reviewed and approved by experienced winter maintenance managers and offer consistent messaging about typical winter maintenance operations and practices.

Quantifying the Economic Value of Snow and Ice Operational Success

Anticipated Implementation & Benefit Opportunity: This project will develop a tool for quantifying the benefits of snow-and-ice operations and the costs associated with those benefits to illustrate the substantial economic and ecological gains of investing in snow-fighting equipment, road treatment programs, and technologies such as road weather information systems. The output of this tool could then be used to inform management about the real-world costs, benefits and value of a sufficiently funded snow-and-ice-control program that could guide state agencies in determining an appropriate annual budget for these programs.

Updating the Impact of Capital Projects Decision Support Tool

Anticipated Implementation & Benefit Opportunity: This project will update the functionality and accessibility of the Impact of Capital Projects Decision Support Tool. Investigators will improve the tool's accessibility by transitioning from its current Excel-based spreadsheet format to a customized web tool or mobile application. Efficiency will be enhanced by updating existing calculations with more accurate formulas. An online database component will be added to allow agencies to aggregate or store operational information for use in forecasting needed resources, route optimizations and other winter maintenance activities. Additional roadway configurations or other improvements will be incorporated along with a GPS component to allow agencies to track their assets. Designers and planners will also be able to use the tool to inform future project planning and forecast the impacts of capital projects on winter maintenance and operations.

Updating the Impact of Capital Projects Decision Support Tool

Anticipated Implementation & Benefit Opportunity: The results of this study will be used to produce guidance for vegetation management that highlights the benefits of reduced chloride use in winter maintenance operations because of solar radiation. Information in the guide will be based on quantifiable results demonstrating the relationship of vegetation management to pavement surface temperatures.