

# Snow Removal Performance Metrics

Washington State University



research for winter highway maintenance

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# **Clear Roads Project 14-05 Snow Removal Performance Metrics**

## **Final Report**



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## **Executive Summary**

Snow and ice removal operations is one of the most critical functions of state and local transportation agencies in cold regions. Departments of transportation (DOTs) need to measure how well they are doing in snow/ice maintenance operations by establishing service standards and performance measures. According to the literature review, LOS-based performance metrics, pseudo-performance based metrics, and performance-based metrics were adopted by different transportation agencies to measure snow removal performance. Different metrics focused on different indicators; such as traffic-flow data, bare pavement regain time, etc. Obviously, the metrics are highly dependent on the regional agencies interests, and there is no need to mandate to use standardized methods, but the use of performance-based metrics should be encouraged for snow removal operations.

The use of snow removal performance metrics is increasingly of interest among transportation practitioners and academics. Current performance metrics used by state DOTs for snow/ice removal operations are not standardized. The increased push for government accountability to the public has pushed agencies to (1) transparently communicate their performance with the public and (2) to gather data on performance using customer feedback. This trend has pushed agencies toward more outcome-oriented metrics that motorists can easily evaluate. The general public has also helped agencies set outcome targets based on what the public prioritizes.

The recent development of information technology, information collecting systems, and mobile sensing technologies makes it possible to collect performance-related data easily; which in turn increases the demand for snow removal performance measuring and reporting systems. These new technologies will facilitate the communication and engagement between the public and transportation agencies, which can lead to a more efficient and effective program for snow/ice removal.

A survey was conducted as part of this study to gather information about the use of performance metrics in different transportation agencies. The results indicated the average ranking of each performance goal as following: Safety, 4.98; Mobility, 4.5; Economy, 4.1; Essential Functions, 4.0; Environment, 3.5; Infrastructure, 3.3; and Livability, 2.9. Most agencies reported that using performance metrics has become a routine part of their duties. Survey results also indicated that division and departmental managers are the predominant audiences for the communication of performance measurement.

Through this project, the research team has organized performance measurement technique according to (1) method and cost and (2) timeliness, effectiveness, and reliability. Performance measurement by geographic area was also investigated, but no clear trend was found through this study. A matrix of method and cost was developed to facilitate the analysis of survey results. According to the analysis, the goal of snow and ice control by transportation agencies is to sufficiently restore safety and mobility to highways, roads, and streets within acceptable time frames following winter weather events. In addition to safety and mobility, achieving an established LOS is also a high priority for all agencies.

The research team also summarized key themes from analysis and found that: *input* and *output* measures are important for operational assessment and budgetary purposes. Transportation agencies use either total time to achieve an established objective or as a percentage of times the objective is met within time goal more than any other measures. Winter severity indices (WSI) are able to provide a way to compare performance results between storms of different characteristics. It is interesting to note that social media and the widespread use of personal communication devices have greatly increased the capability of agencies to communicate performance with the public. Also, the use of performance measures is able to sustain satisfactory performance and to motivate agencies to seek further improvements.

Some of the recommendations for future research include:

- Investigation of agency preferences regarding data gathering methods are needed to determine if the effectiveness of performance measurements can be improved.
- Some studies are needed to address snow operation improvement by using a performance metric specifically. Evaluation is required regarding the need for resources and training to assist comparison between a performance metric and conventional LOS.
- Further investigation is required for the role of performance measurements in the snow removal operation, as this may be a cost-effective option. The literature review found that a structured performance-based program offered better benefits.
- The development of methods to investigate long-term outcomes of performance metrics, including appropriate comparison groups, is required.
- The optimal circumstances for adding a performance metric into the current system of agencies with snow removal operations, including which agencies, for how much resources needed, and in conjunction with what additional training.
- The survey did examine agencies' efforts towards the performance metric application; however, the examination of which agencies are collecting performance metric data, how agencies are utilizing the data to evaluate their program, and making improvements is an important area of potential future research.

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# Chapter 1

## Introduction

### 1.1 Background

Effective and efficient snow and ice removal is a challenge to many transportation agencies in charge of winter highway operations. Assessing the current snow/ice removal performance metrics and data will help to measure service levels, compare service across regions, and justify budget allocations. In this context, it is important to establish service standards and performance metrics for winter highway operations.

Transportation agencies continue looking for new approaches to evaluate winter maintenance operations, and performance measurement is considered as one of the important focuses of new approaches (Hamilton and Hyman 2006). In order to evaluate how well they are doing in snow/ice removal operations, state departments of transportation (DOTs) and others need standardized measurements and methods that take into consideration the diverse road weather conditions and other factors (Reed et al. 1993). As such, the performance measurement is of increasing interest among transportation practitioners and academics.

As a variety of agencies measure the performance of their snow removal operations, there are a variety of performance metrics used as well (Karlaftis and Kepaptsoglou 2012; Missouri Department of Transportation 2013; Murphy et al. 2012; Zwahlen et al. 2006). States such as Idaho (Veneziano et al. 2014) and Minnesota (CTC & Associates LLC 2013; Frederickson et al. 2005) have researched success of their own winter maintenance practices based on performance metrics. In addition, some groups, such as Clear Roads, I-80 Winter Operations Coalition, and the I-95 Corridor Coalition, are looking at innovations (Atkins North America et al. 2014; INRIX 2015) and establishing a structure for sharing information and coordinating winter maintenance operations across jurisdictional boundaries (Cempel et al. 2013).

Nearly all agencies have established level of service (LOS) guidelines for the various classifications of highways and major roads (TRB 2010). LOS is a qualitative measure used to assess traffic flow by ranking traffic service based on speed, density, and other measures. In recent years, agencies have realized that LOSs need to be better defined so that there are common, easily understood criteria for evaluating the performance (Sinha and Labi 2007).

The National Cooperative Highway Research Program (NCHRP) project 6-17 (NCHRP 2009) identified both methods and measures for assessing agency and contractor performance in snow and ice control operations. This research provided a snapshot of how agencies were measuring snow and ice performance and a framework for future practices. However, some of the information in that report needs to be updated with current practices. Moreover, technological advances in maintenance operations have allowed for enhanced collection and processing of data from the field, and have drastically altered the ability to assess metrics (Persaud et al. 2000; Shi et al. 2006).

## 1.2 Purpose and Objectives

The objective of this research is to “*identify effective performance metrics for snow and ice maintenance operations*”. To achieve this goal, this research 1) first gathered existing information in both the published domain and winter road maintenance operations community and then 2) analyzed the information in depth, with a focus on performance measures of snow/ice maintenance operations, their temporal evolution and effectiveness, costs of gathering and analyzing the performance data, and methods of communicating the level of success inside the organization and beyond.

## 1.3 Approach

The approach to this work encompassed four tasks, as detailed following.

### *Task 1. Literature Search*

The research team conducted a comprehensive literature search, both nationally and internationally, on the use of performance measures by transportation agencies for winter highway maintenance activities, with a focus on recent advances.

### *Task 2. Survey*

The research team surveyed all snow and ice states to gather information about their use of performance measures, how they have evolved over time, which ones they have found most useful (or not useful), how they have tied them to agency goals, and the costs of gathering and analyzing the performance data. Based on the literature search, a survey was conducted to capture the experience and insights of the winter maintenance community/practitioners. The goals and performance measures were identified for all the snow and ice states, but focus especially on the 13 states that participated in NCHRP Project 6-17 (Table 2 on page 25 of NCHRP Web-Only Report 136 lists 19 state DOTs, 7 cities, 10 counties 4 provinces, 1 Canadian city and 2 international countries.) All 29 Clear Roads member states were invited to take the survey, along with other states, provinces and international agencies. A pilot survey was conducted using the 7 states participating on the Clear Roads subcommittee guiding this project. Clear Roads reviewed the survey questions and provide feedback on pilot results to help the team fine-tune the final version of the survey for release to all recipients.

### *Task 3. Analysis and Matrix Development*

The team tabulated and analyzed survey results to identify commonalities and differences between agencies and to develop a matrix of performance measures and how they are helping agencies to achieve their goals. The cost of gathering and analyzing metrics were included in the resulting matrix. A follow-up survey might be necessary to solicit respondent feedback on realistic range of key values if there is significant scatter among the values collected during Task 2. This could be done via the Delphi method, which is a structured communication technique that relies on a panel of experts to provide feedback on potential values of a variable. In the case of this work, experts would be winter maintenance professionals asked for their input and feedback on cost estimate of gathering and analyzing winter operations performance metrics.

#### *Task 4. Recommendations*

Recommendations will be developed for scoping future research projects that would help agencies develop and implement a performance measurement program that meets agency goals. Based on the evaluation completed in Task 3, recommendations will be made regarding the performance measures that should be considered for further evaluation during future research. Recommendations will also be made for cases where existing measures may be modified (in light of their identified deficiencies) or new measures developed for evaluation during future research. If the shortcomings of existing performance measures are readily identified during the course of Task 2 and feasible modifications can be made to address them, then these would be recommended for further consideration.

### **1.4 Outline of Report**

This report is divided into six sections, including this Chapter 1 of introduction. Chapter 2 presents findings from the literature review and survey to answer the important research questions. Chapter 3 provides conclusions and recommendations. Appendix A provides a comprehensive literature review, and Appendix B provides the summary of agency responses. More detailed individual agency responses are presented in Appendix C.

## Chapter 2

### Summary of Analyses and Findings for Research Questions

This chapter presents the summary of analyses and findings from the literature review and survey to answer the important research questions. The definitions of basic terminologies and concepts are introduced first as following:

#### 2.1 Definitions of Basic Terminologies and Concepts

*Metric, Measure, and Measurement:*

Measure denotes a concrete or objective attribute, and metric is used for more abstract or higher-level attributes. Here, the terms will be used somewhat interchangeably, but measure will generally be used to denote the specific information gathered and analyzed to constitute a metric. Measurement is the practice of evaluating performance by using measures and metrics.

*Input-based performance metrics:*

This metrics is based on resources spent or utilized to perform snow removal operations, including fuel usage, labor hours, machinery or equipment hours, anti-icing materials, and so on.

*Output-based performance metrics:*

This metrics quantifies the resulting physical accomplishment from inputs mentioned above. Typically, outputs are quantified in terms of lane miles per unit of time plowed, lane-miles deiced, truck plowing speed, material application rates, payments for winterizing and other accomplishments. For performance measurement, outputs are more useful than inputs alone, since it shows how well the inputs are converted to outputs to some extent.

*Outcome-based performance metrics:*

Outcomes are generally abstract concepts and measured through indicators, which are able to assess the effectiveness of snow removal operations directly. These concepts include safety improvements, mobility, and user satisfaction. Bare pavement regain time, friction, and user satisfaction survey are popular ones used for performance metrics.

*Level of service (LOS):*

LOS is a qualitative measure used to assess traffic flow by ranking traffic service based on speed, density, and other measures. The rankings are alphabetical: A through F, with A being best quality of traffic service (free-flow) and F being the worst (breakdown, congestion).

## 2.2 Snow Removal Performance Measurement

Snow/ice removal policies and practices have evolved into their current forms over the last few decades due to technology improvements and social and political pressures. Current performance measurements adopted by state DOTs for snow/ice control operations are not standardized (Karlaftis and Kepaptsoglou 2012; Missouri Department of Transportation 2013; Murphy et al. 2012; Zwahlen et al. 2006). To assess the different metrics, NCHRP Report 551 (Cambridge Systematics et al. 2006) proposed an assessment which can generally apply to winter maintenance. Karlaftis and Kepaptsoglou (Karlaftis and Kepaptsoglou 2012), working with information from NCHRP Report 446 (Cambridge Systematics et al. 2000), summarized important properties for effective performance metrics, as follows:

- *Relevance*: the metric must be applicable to planning and budgeting needs of the agency.
- *Clarity*: the metric must be clearly defined to avoid misinterpretation.
- *Reliability*: the measurement process should be standardized to avoid bias or errors.
- *Precision*: the collection of data should be as precise as possible.
- *Availability*: the data should be cost-effectively collectable and outcomes should be readily accessible by management and other stakeholders.

As DOTs use different metrics or indicators to measure the performance of snow removal operations in their own regions, it is difficult to benchmark or compare performance between regions. However, all performance metrics can be categorized into three groups detailed as follows {(Karlaftis and Kepaptsoglou 2012; Maze et al. 2008), and references therein}:

- *Inputs*: this category represents resources spent or utilized to perform snow removal operations, including fuel usage, labor hours, machinery or equipment hours, anti-icing materials and so on.
- *Outputs*: this category quantifies the resulting physical accomplishment from inputs mentioned above. Typically, outputs are quantified in terms of lane miles per unit of time plowed, lane-miles deiced, truck plowing speed, material application rates, payments for winterizing and other accomplishments.
- *Outcomes*: outcomes are generally abstract concepts and measured through indicators, which are able to assess the effectiveness of snow removal operations directly. Bare pavement regain time, friction and user satisfaction survey are popular outcome-based performance measures (Transportation Research Board and National Academies of Sciences, Engineering, and Medicine 2004).

Adams et al. (Adams et al. 2014) highlighted that setting performance goals or targets is an effective way to measure success or deficiency in highway maintenance performance. Snow removal performance and public interest are intrinsically linked; many DOTs also choose to use customer satisfaction as a performance measurement. Transparency with the public (i.e., communicating performance through online “scorecards” or reports) is one way agencies hold themselves accountable to the public, though many DOTs also gather feedback directly from the public through surveys which has ultimately altered measurement methodology itself (Yurek et al. 2012).

## 2.3 Application of Snow Removal Performance Measurements

Table 2.3.1 provides some representative examples of performance measurement applications identified from literature. PIARC (Technical Committee 2.4 2015) reported performance measurement applications in eleven European countries which adopted visual measures, physical measures (depth and width of snow/ice features on the roads), friction measures and associated time to reach preset thresholds to assess the performance. Direct measurement of friction for the performance measurement is used internationally, the improved pavement friction was reported to have a positive impact on the traffic safety [(Qiu 2008), and references therein]. One major difference between the US and other countries in the application of performance assessment is that many other countries use the performance measurement to gauge how contracted maintenance companies are reimbursed for their services rather than reimbursing based on work completed (Karlaftis and Kepaptsoglou 2012).

**Table 2.3.1 Application examples of performance measurements**

Ref.	Performance Measurement	Application
Neimi (2006)	Post-storm bare lane regain time	The post-storm bare lane regain time targets are set per Average Daily Traffic (ADT) category.
Zwahlen et al. (2006)	Surface traffic speed levels during a storm	LOS is defined by comparing surface traffic speed levels during a storm with the average dry surface speed.
Caltrans (2009)	Snow and Ice Levels of Service (SNOW LOS)	To measure the effectiveness of the department's snow removal operations on high traffic volume routes.
Cuelho et al. (2010)	Effective temperature and application rate of chemicals	Based on these, guidelines were developed for optimal snow and ice removal operations.
Usman et al. (2010)	Traffic and safety	A model integrates weather, road surface conditions, traffic and maintenance, and relates those elements to accidents.
Kwon et al. (2012)	Traffic speed, flow rate, density data and speed-change patterns	Traffic flow data is associated with road condition recovery time and is incorporated into Traffic Information and Condition Analysis System.
Lee et al. (2004, 2008)	Automatic traffic recorder data	Speed recovery duration was identified as an appropriate performance measure for winter maintenance operations.
Adams et al. (2003)	Data collected by differential Global Positioning System on winter maintenance vehicle	LOS is defined by a set of performance measures for winter operations that are tied to business goals and objectives.
Murphy et al. (2012)	Winter performance index (WPI)	Idaho Transportation Department (ITD) use the WPI that measures the duration of ice per unit of storm severity.

The application of performance measures in snow and ice control operations was found to have a significant impact, not only on meeting an agency's mission and directives, but also on the safety and the mobility of travelers and various sustainability metrics (economic, societal and

environmental, and infrastructure implications) (CTC & Associates LLC 2013; Frederickson et al. 2005; Hamilton and Hyman 2006; Karlaftis and Kepaptsoglou 2012; Missouri Department of Transportation 2013; Murphy et al. 2012; Reed et al. 1993; Veneziano et al. 2014; Zwahlen et al. 2006). In light of these multiple dimensions of snow and ice control operations, performance measures should be categorized and evaluated for their suitability in winter maintenance applications, and the potential measures also need to be identified for implementations.

## **2.4 Challenges in Implementing Snow Removal Performance Metrics**

Performance metrics are not universally used by U.S transportation agencies (Zietsman and Ramani 2011). Although performance or pseudo-performance measurements have been studied and adopted by some transportation agencies, there are still a large number of agencies lacking systematic means of snow removal performance evaluations. Maze et al. (Maze et al. 2008) summarized the reason why performance measurement has not been widely adopted: Generally, U.S. transportation agencies have historically set static (as opposed to variable) standards, which make it difficult or impossible to incorporate performance measurements as variables for financial and condition evaluations.

Often, the challenges of implementing performance measurement are related to the cost of collecting data. Hardware, instrumentation, and software can be expensive, but are usually also utilized for general operations, and so the benefits of these technologies are realized in many other ways. Missouri DOT conducts a yearly public phone survey at a price of approximately \$200,000 per year (Yurek et al. 2012). Because of the exclusive cost, not all agencies are able to regularly maintain this method of performance measurement (Yurek et al. 2012).

Other challenges with customer satisfaction are that the results can be easily biased by external influences. For example, before suspending its customer survey program, Kansas DOT learned that the media play a significant role in how the public views performance (Yurek et al. 2012). When local news promoted an upcoming winter storm as major, but the storm was minor from a mitigation perspective (e.g., a large amount of easily-plowable snow), the public is more likely to rate the DOT's performance highly. Unfortunately, the opposite can also occur, in which a storm billed as minor to the public can be very difficult to mitigate, thus driving down customer satisfaction. These external influences should be noted when the results are evaluated, as they inform the context of the feedback received (Niemi 2006).

## **2.5 Innovative Technology for Performance Measuring and Reporting**

With increased utilization of information technologies and information collecting systems in maintenance operations, it has become more possible to collect performance-related data easily, which in turn has increased the demand for snow removal performance measuring and reporting systems (NCHRP 2009). The following paragraphs summarize innovations that have contributed to technologically-based performance measurements.

Mobile-based weather and pavement sensors have great potential to enhance the collection of performance-related data. These sensors allow overlays of weather and pavement conditions with a vehicle's locations and control actions (Mahoney and o'Sullivan 2013; Shi et al. 2006). Automated Vehicle Location (AVL) and related technologies are already able to track plow trucks and their material usage, and a rich AVL database has been established in recent years (McCullough et al. 2009). DOTs are gradually adopting these technologies for the use in operations and for the performance measurement.

Relatively old technologies, webcams and road weather information system (RWIS), are still in use (Boon and Cluett 2002), and greater bandwidths have allowed for enhanced data collection. Webcams {either roadside or mounted on plow trucks (Iowa Department of Transportation 2014)} view highways and provide visually-based performance information. Despite the surge of mobile sensors, the stationary RWIS remains a critical element of atmospheric and pavement data collection (Manfredi et al. 2008).

Because mobile observations greatly enhance the resolution of environmental data collected along the roads, they will greatly improve the calculation of storm severity indices. Agencies have taken a number of approaches to calculating severity indices for winter storms {(Farr and Sturges 2012), and references therein}. The severity index distills a storm's characteristics (precipitation amount, duration, intensity, type, etc.) into a single value, enabling the direct comparison of one storm to another. From this index, an agency can compare, for example, material usage across similarly severe storms and from maintenance shed to maintenance shed (Farr and Sturges 2012).

Vonderohe et al. (Vonderohe et al. 2006) reported on "the development, implementation, and installation of a geographic information system (GIS) application for assessing performance of winter highway applications" at Wisconsin DOT. The software, called "Wisplow," accepts data recorded from winter maintenance vehicles during operations and combines it with spatial data representing roadways and vehicle patrol sections. Analysts can then select among several performance measures and decision management tools for outputs from the system.

## **2.6 Communicating Performance with the Public**

Many agencies (e.g., Wisconsin DOT, Iowa DOT, Idaho Transportation Department, etc.) share their winter maintenance performance with the public via website interfaces ("dashboards") or reports that state the DOT's maintenance goals and summarize success at meeting those goals. Most dashboards display performance outcomes from past seasons, so that the public can see trends. A winter severity index is also a typical part of the display, as it is a key input to the performance calculations and helps the public understand what contributes to improvements or declines in performance.

In 2012, Wisconsin DOT launched a public-facing dashboard to improve communication and engagement with the public regarding performance. The dashboard, called "MAPSS (Mobility, Accountability, Preservation, Safety, Service) Performance Improvement Program" shares a number of key performance outcomes, and explains the results.

Iowa DOT has a public-facing winter maintenance performance website (available: [www.iowadot.gov/performance/winter\\_operations.html](http://www.iowadot.gov/performance/winter_operations.html)). There are a number of metrics displayed visually on the site. Key metrics are cost (labor, equipment, materials) and time to bare pavement for category A, B, and C roads (which are interstates, other major highways and rural, low-volume roads, respectively).

Missouri DOT discusses some of its snow removal performance measures in its “Tracker” report (Missouri Department of Transportation 2013), which examines a wide range of departmental performance measures.

Australia and New Zealand’s association of road transport and traffic agencies (Austroads) disseminates performance measurement results via their National Performance Indicators website (<http://algin.net/austroads/site/index.asp?id=5>). The website offers a useful example of publicly-accessible graphics that display the relative success of transport agencies in meeting certain targets. The measures are standardized across each state, allowing for an easy direct comparison in performance from state to state.

## **2.7 Survey Respondent Summary**

A survey was distributed to 75 transportation agencies, including state DOTs, city and county public works departments, Canadian ministries of transportations, European agencies, and private maintenance firms. The survey response rate is 68% with a total of 51 completed responses received (Table 2.7.1). The percentage of each category is as follows: U.S. State DOTs = 68.6%; European agencies = 15.7%; City/County governments = 7.8%; Canadian agencies = 3.9%; Private firms = 3.9%.

**Table 2.7.1 Responding Agencies**

<b>State DOTs</b>		<b>City/County Governments</b>
Alaska†	Nevada†	City of Farmington Hills, MI
Arizona†	New Hampshire†	City of Omaha
California†	New York†	City of West Des Moines†
Colorado†	North Dakota	Otter Tail County, MN
Connecticut	Ohio†	
Delaware	Oregon	<b>Canadian Ministries of Transportation</b>
Idaho	Pennsylvania†	Alberta†
Illinois†	South Dakota†	Ontario†
Iowa†	Tennessee	
Kansas†	Texas	<b>European Agencies</b>
Maine	Utah	City of Oslo, Norway
Maryland†	Vermont	Danish Road Directorate
Massachusetts†	Virginia†	Finnish Road Administration
Michigan	Washington†	Middelfart Municipality, Denmark‡
Minnesota†	West Virginia	Norwegian Public Roads Administration
Missouri†	Wisconsin†	Slovenia (expressways)*
Montana	Wyoming	Swedish Transport Administration†
Nebraska†		Transport Scotland
<b>Private Firms</b>		
Care Enterprises**	Hy-tech Property Services	

†Agency was part of NCHRP Project 6-17 Report

‡Response delivered by AIBAN Vinterservice

\*Response delivered by DARS d.d.: a company responsible for operating expressways only

\*\*Contracted to small property management firms in semi-rural Colorado

## 2.8 Goals for Snow and Ice control Operations

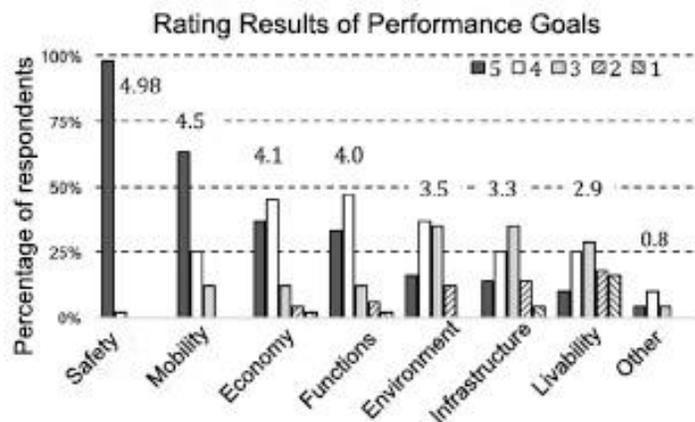
Agencies were asked to rate the following goals according to their agency's priorities:

- *Safety* (minimize collisions or run-offs caused by slick roadways)
- *Mobility* (provide adequate traction to keep traffic flowing near to or at normal speeds)
- *Economy* (reduce impact on commerce caused by delays in worker commuting and transport of goods and services)
- *Essential Functions* (lessen disruption of essential activities such as school, medical appointments, trash collection, police and emergency services, etc.)
- *Livable Communities* (quality of life related to alternative modal choices, such as bike and pedestrian lanes and interface points such as bus lanes, trams and light rail)
- *Environmental Stewardship* (reduce impact to soil, water, air, plants, wildlife, etc.)
- *Infrastructure Preservation* (reduce impact to pavements, bridges, vehicles, etc.)
- *Other*

A ranking evaluation was performed by rating different goals from 5 (being most important) to 1 (being least important), and the survey results are presented in Figure 2.8.1, organized by scoring order. The average rating of each performance goal is as follows: Safety, 4.98; Mobility, 4.5; Economy, 4.1; Essential Functions, 4.0; Environment, 3.5; Infrastructure, 3.3; and Livability, 2.9.

All but one of the respondents assigned "most important" to Safety. Mobility was rated at "4" or above by 88% of respondents. Economy and essential functions were next most important after Safety and Mobility. 73% of respondents placed a medium-level importance on Environment, i.e. rating "3" or "4", though no respondent rated Environment as least important. Infrastructure and Livability received the fewest "4" and "5" ratings. Livability received more "1" ratings and fewer "5" ratings, relative to any other, making it the lowest priority goal on average.

Nonetheless, European agencies tended to rate Livability more highly than their American counterparts. Of the eight European agencies that responded to the survey, five rated Livability as a "4" or "5" level importance. According to the European responses, Livability outranks Essential Functions, Environment and Infrastructure. Fill-in responses for "Other" included saving money for the agency itself and customer satisfaction.



**Figure 2.8.1 Allocation of responses rating each performance goal on a scale of 5 (most important) to 1 (least important) with average ratings on the top of each goal.**

## 2.9 Answers to Essential Research Questions

*How is the data turned into useful information to be used and by whom? What value is it? Is it still relevant? Is other data needed?*

Table 2.9.1 summarizes survey results of the data collection and utilization for each agency. In general, the data collected show great values in qualitatively comparing the measures. At agency's level, the quantification of snow/ice operation performance by those data will help agencies to restore safety and mobility consistently, and to transparently communicate their snow/ice operations performance with the public.

**Table 2.9.1(a) Data collection and utilization: Part-1**

<b>Metric</b>	<b>Method</b>	<b>Comment</b>	<b>Agency</b>
<b>Time to Bare Pavement</b>	<p><b>Manual Condition Entry</b></p> <ul style="list-style-type: none"> <li>- Plow drivers</li> <li>- Supervisors</li> <li>- TMC (CCTV)</li> </ul> <p>Or: RWIS pavement condition observations +</p>	<p>It necessitates logging when storm ended; This can be accomplished using same manual reporting tools or RWIS with precipitation sensor.</p> <p>It features lower cost because the technology and manpower used to do the reporting are frequently associated with regular operations.</p> <p>Technology: Plow driver input through AVL, mobile apps, or RWIS<sup>+</sup></p>	<p><b>State</b> CO, CT, DE, MD, MN, OR, TN, UT, WA</p> <p><b>International</b> Germany, Scotland, Sweden<sup>+</sup> Ontario/Canada</p>
<b>Time to Recover Speed</b>	<p><b>Traffic Speed Devices</b></p> <p><b>Speed Data from private sources</b></p>	<p>While expensive, costs of this method are typically shared with Traffic Operations</p>	<p><b>State</b> IA, MI, MO, NE, OH, TN</p> <p><b>Local</b> Omaha</p>
<b>Friction</b>	<p><b>Friction Devices</b></p> <p>Wheels</p> <p>Non-Invasive (RWIS)</p>	<p>Friction wheel is expensive initially and moderately expensive to maintain</p> <p>Non-invasive RWIS devices are being produced by multiple companies.</p> <p>New Technology: Mobile non-invasive sensors (relatively expensive)</p>	<p><b>State</b> ID, ME, NH, UT</p> <p><b>Local</b> W. Des Moines</p> <p><b>International</b> Norway*</p>
<p><b>System Related Outcomes</b></p> <ul style="list-style-type: none"> <li>- Incidents</li> <li>- Closures</li> <li>- Chain law active</li> </ul>	<p><b>Traffic Ops Software and Data</b></p>	<p>Costs can likely be shared with Traffic Operations</p>	<p><b>State</b> AK<sup>++</sup>, CA<sup>**</sup>, IA<sup>+++</sup>, OR, MN<sup>***</sup>, MO</p> <p><b>International</b> Denmark, Ontario<sup>**</sup></p>
<b>Customer Satisfaction</b>	<p><b>Customer Survey and Survey Analysis</b></p>	<p>Cost is realized once annually</p>	<p><b>State</b> MI, MN, MO, ND</p> <p><b>International</b> France</p>

**Table 2.9.1(b) Data collection and utilization: Part-2**

<p><b>Storm Severity</b></p>	<p><b>Multiple Methods</b></p> <p>Internal</p> <p>Private</p>	<p>Internal – States implement their own storm severity index or analysis internally.</p> <p>Private – Market is emerging for private companies to provide storm severity index post season as a product.</p> <p>Initial cost depends on how much resources are expended in developing the index. Costs associated with measuring atmospheric and road conditions and computing an index value.</p>	<p><b>State</b> ID, IA, ME, NH, OH, UT, WI</p> <p><b>International</b> Czech Rep, Germany, Belgium</p>
<p><b>Material Usage</b></p>	<p><b>Manual – Plow Drivers</b></p> <p><b>Automated – AVL</b></p>	<p>AVL costs for performance metrics are absorbed in the AVL budget for regular operations.</p>	<p><b>State</b> ME, ND, TN</p> <p><b>International</b> Belgium, Denmark, France, Germany</p>
<p><b>Equipment</b></p> <ul style="list-style-type: none"> <li>- Hours</li> <li>- Fuel</li> </ul>	<p><b>Manual Input</b></p>	<p>This is usually a standard procedure in operations.</p>	<p><b>State</b> ME</p> <p><b>International</b> Denmark</p>
<p><b>Cost of Operations</b></p> <ul style="list-style-type: none"> <li>- Total</li> </ul> <p>Per lane mile</p>	<p><b>Manual</b></p>	<p>This is usually a standard procedure in operations.</p>	<p><b>State</b> AK, ID, ME, MO, ND</p> <p><b>International</b> France</p>

+ Sweden uses the friction and road snow data from RWIS to track the time to achieve bare pavement.

\* In addition to the measured grip/friction, Norway measures time to established LOS, thickness of ice, and max snow depth. Cycle time is found using AVL, whereas regain time is normally measured using RWIS instrumentation.

++ Alaska DOT and Public Facilities tracks the percent of system meeting LOS and time to return to LOS (as well as cost per lane mile).

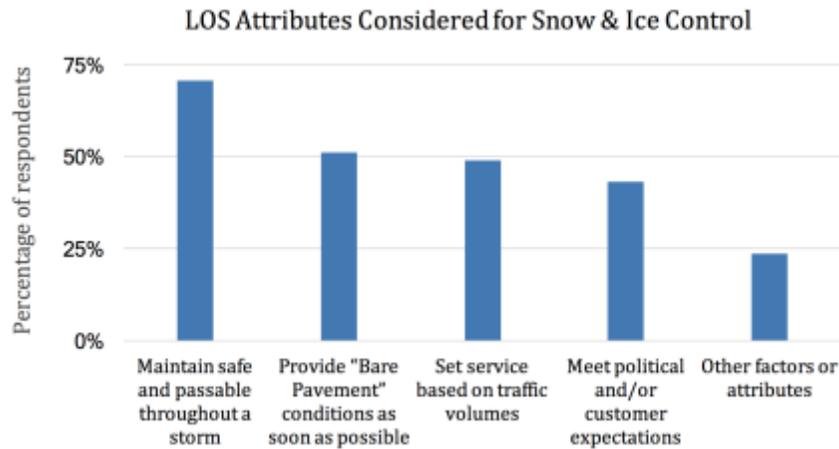
\*\* Both California DOT and Ontario use the time to achieve the established LOS condition for performance measurement.

+++ Iowa DOT measures the performance by the percent of road segments of a particular class returned to normal within its specified time.

\*\*\* Minnesota DOT measure the performance by the "frequency of meeting bare lane target" or the percentage of events within the target range set for each maintenance route by designated classification.

*Other than visually judging when the stated LOSs are reached each winter event, how else can one measure performance? What are practical, quantifiable, empirical attributes? How much material, personnel hours, and equipment time and fuel did it take to achieve that? How much time did it take? How to factor for variances in weather conditions (snowfall rate, duration, type and amount, ice accumulation, temperature ranges, winds, etc.) each storm? Does the type of de-icing materials affect when LOS is reached? How does the cost per storm or event compare with others that season or previous seasons?*

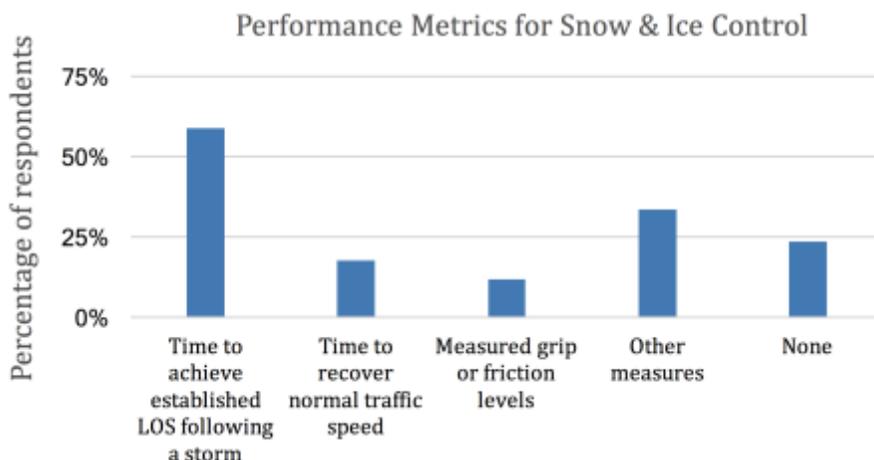
Figure 2.9.1 shows that 71% of respondents considered maintaining roads safe and passable throughout a storm as a part of their LOS policy. 51% of respondents reported focusing on providing bare pavement as soon as possible, 49% set their LOS priorities by traffic volumes, and 43% focused on meeting political or customer expectations. The 24% of respondents replying “Other” listed alternative LOS attributes, including: returning pavement conditions to “mostly clear” or “80% clear” rather than “bare”; providing bare wheel tracks; returning to normal cycle times and average speeds; using a corridor designation that is unrelated to traffic volumes (such as tourism, commercial use, intermodal hub locations, route geometry, etc.); and using a flexible LOS based on staffing and budget levels. It is important to note that 100% of respondents reported using some form of LOS criteria.



**Figure 2.9.1 Percentage of respondents choosing the options provided for the following: Please identify the LOS attributes your agency considers for its snow and ice control policy.**

Figure 2.9.2 shows that 59% of respondents tracked the time to achieve established LOS criteria following a storm, while fewer respondents used metrics related to the time to recover traffic to normal speeds or the road surface friction (18% and 12%, respectively), the responses for “Time to LOS” are inclusive of those for “Time to recover normal speeds”. 33% of responses replied to “Other” including fraction of achieving bare pavement within a preset amount of time following a storm, fraction of system meeting LOS, reported road condition, thickness of ice or snow depth, level of effort expended, amount of material used, cost expended (total or per lane mile, weighted by number of storms), fleet incidents during winter operations, absence of customer complaints, and anecdotal observation. 24% of respondents reported that no performance metrics are used, and some of those agencies are in the process of developing metrics.

According to survey responses, fourteen agencies (27% of respondents) are currently working on changing their metrics or adding new metrics. Among these fourteen agencies, five agencies specified interest in adding speed-based metrics, five agencies specified interest in pursuing friction-based metrics and the rest were improving their current metrics.



**Figure 2.9.2 Percentage of respondents provided for the following: Please identify the Performance Metrics your agency considers for the snow and ice control program.**

Severity index-based performance metric is of relatively strong interest. 37% of respondents reported currently using a severity index. Of these, seven DOTs (14% of respondents) reported to utilize a storm severity index as part of their performance metrics, and twelve agencies (23% of respondents) noted that they are using some form of a severity index, but not incorporated into the performance measurement yet. There are also eight agencies (16% of respondents) currently developing one. Friction-based metric is another relatively popular one, 12% of respondents reported using it, and eight agencies (16%) are currently investigating or showing interest in friction as a metric.

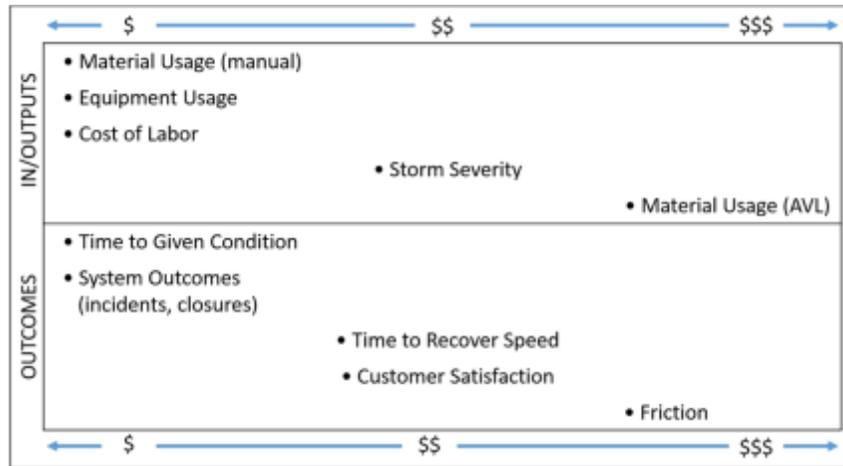
A total of 71% of respondents reported using outcome-based measurements, such as time to certain conditions and friction, and an additional 16% of respondents are interested in these measurements. Moving toward outcome-based measurement was a general theme noted by many responding agencies.

***What information in the form of commonly accepted performance measures (CAPM) can be presented to justify increased funding for future seasons?***

Figure 2.9.3 shows a typology matrix classifying different metrics to the cost. The cost dollar signs are to be viewed as relative, not absolute values. That is “\$” denotes less cost for the method compared to “\$\$” (medium relative cost) and “\$\$\$” (higher relative cost). In some instances, because devices and data can be shared with other operational departments (namely, traffic operations), the cost to maintenance departments can be lowered, an attempt to consider the sharing potential was taken into account here.

The metrics based on material usage, equipment usage, labor cost, time to given conditions and system outcomes feature less costs because the technology and the manpower used for these are frequently associated with regular operations. 61% of respondents reported to use metrics in the less cost category. The metrics based on storm severity, time to recover speed and customer satisfaction have medium relative costs which is associated with the initial cost of development and the later operation cost. 31% of respondents reported to use metrics in the medium cost category. The metrics in the category of higher relative cost are those using material usage based on AVL and friction since the equipment and vehicle are expensive initially and moderately expensive to maintain. 21% of respondents reported to use higher cost metrics.

Although storm severity and friction based metrics have the relatively higher cost, the increasing use of and interest in them were noticed. 26% of respondents are currently using them, and 34% of respondents are pursuing these two as a metric.



**Figure 2.9.3 Cost information of different performance measurements.**

Figure 2.9.4 qualitatively compares the measures based on their relative timeliness, reliability (of the methodology) and effectiveness. Generally, the most reliable methods are also the timeliest, because they are typically automated as opposed to manually generated. Manually-generated methods such as equipment, labor and material costs are time-consuming to catalog and can be inexact. Instrumentation is automated and removes subjectivity.

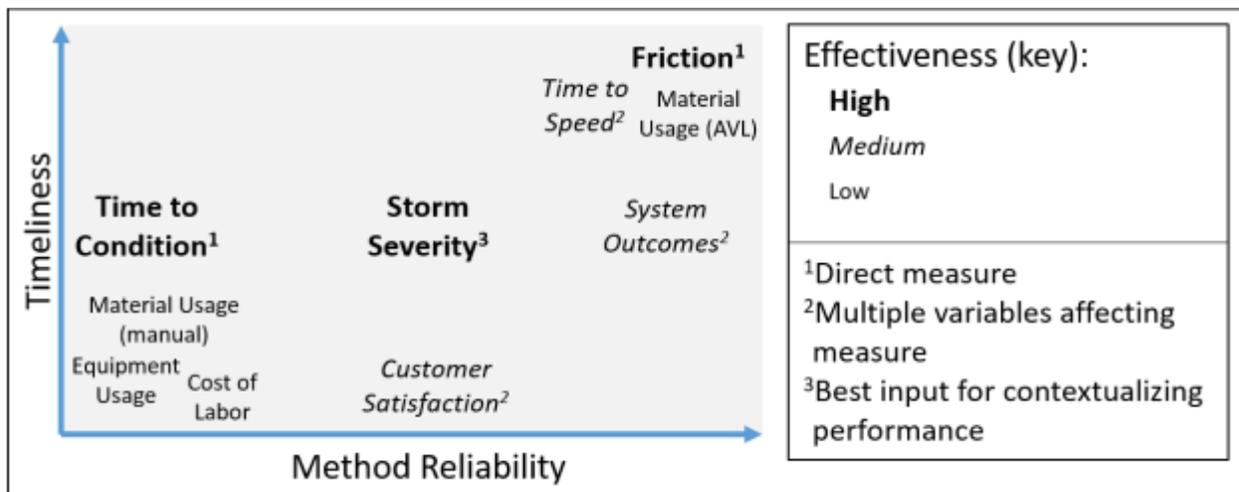
Effectiveness compares how well each measure is a reflection of performance. For example, friction is rated highly effective, because it directly measures how well the operations aimed at increasing the friction of the road surface are doing their job. Material usage is rated less effective, because it does not relate the usage to the storm severity.

Also, while customer satisfaction is a direct measure of performance from the public’s point of view (which has a great deal of merit), other variables (such as perceptions and misperceptions, changes to taxes, severity of storms, etc.) can affect the results. Thus, customer satisfaction is rated medium for effectiveness.

While metrics based on friction, storm severity, and time to condition feature a high effectiveness, they have varying degrees of reliability. Customer satisfaction is low in timeliness and medium in both cost and reliability, but the push to measure performance based on what the customers would rather than the DOT prioritize was noticed in the survey and literature. For example, MnDOT shifted their bare pavement metric to bare lane, rather than full-width, to match motorists' expectations.

Most of outcome-based measures (friction, time to speed and system outcomes) are in the high-timeliness and high-reliability zone. This may be the reason why 71% of respondents reported to use outcome-based metrics. Outcomes provide a more complete picture of performance, and the increase in instrumentation and observation capabilities has increased the ability to track outcome-based measures notably.

Coupling the cost-method matrix with the timeliness-effectiveness-reliability chart, each transportation agency can determine the best practices to meet its goal of snow and ice control. For example, agencies may choose a friction-based metric as the best practice if their budget allows, or select a lower-cost storm severity based metric with medium timeliness and reliability if budgetary constraints exist.



**Figure 2.9.4 Performance measurement by timeliness, reliability and effectiveness**

Due to the recent development of information technology, information collecting systems, and mobile sensing technologies; it is possible to collect outcome-oriented data easily, which in turn increases the demand for snow removal performance measuring and reporting systems. These new technologies will facilitate the communication and engagement between the public and transportation agencies.

The following list summarizes the ways in which responding agencies communicate performance with the public (and also with legislatures/governors).

- **Alaska DOT&PF:** Annual reports
- **City of Farmington Hills, MI:** “The city's website and local cable channel, as time permits”
- **City of Omaha:** Social media and news media
- **Idaho Transportation Department:** Online dashboard (<http://itd.idaho.gov/dashboard/>); individual responses to public inquiries
- **Iowa DOT:** Online dashboard ([http://www.iowadot.gov/performance/winter\\_operations.html](http://www.iowadot.gov/performance/winter_operations.html))
- **Maine DOT:** Annual Report, including graphs showing salt usage, storm count, cost per mile, etc. (2014 Report: <http://www.maine.gov/mdot/docs/2015/reports/mainedot-delivers-2014-annualreport.pdf>); plus, weather summaries from the National Weather Service. Outcomes such as time to bare pavement or grip are not included.
- **Minnesota:** Annual performance scorecard (<http://www.dot.state.mn.us/measures/>); annual report called “winter at a glance” posted to website
- **Missouri:** Quarterly “TRACKER” report posted online (<http://www.modot.org/about/Tracker.htm>)
- **Nebraska:** Annual reports
- **New Hampshire:** “Department’s Balanced Scorecard” and an annual report
- **Norwegian Public Roads Administration:** Meeting between contractor and client internally, and communicate with the public via websites.
- **City of Oslo, Norway:** Communicate with the public via websites.
- **Swedish Transport Administration:** Dialogue with contractors and communicate with the public via websites.
- **Wisconsin:** Online dashboard ([MAPSS Performance Improvement Program, http://wisconsin.dot.gov/Pages/about-wisdot/performance/mapss/default.aspx](http://wisconsin.dot.gov/Pages/about-wisdot/performance/mapss/default.aspx))

*How does the cost compare with another agency with similar parameters? What would it cost per lane-mile/kilometer for a more severe storm?*

A winter severity index (WSI) used by most agencies for the evaluation of performance can be applied in context with an agency-to-agency comparison. Because mobile observations greatly enhance the resolution of environmental data collected along the roads, they will greatly improve the calculation of storm severity indices. Agencies have taken a number of approaches to calculating severity indices for winter storms. The severity index distills a storm’s characteristics—precipitation amount, duration, intensity, type, etc.—into a single value, enabling the direct comparison among different agencies. The Federal Highway Research Institute in Germany developed a winter index in order to compare weather severity to snow and ice control.

The WSI is often incorporated into the performance measures, e.g., bare pavements regain time and average cost per lane mile per event. From this index, an agency can compare, for example, material usages in storms of different severity.

## Chapter 3 Conclusions and Recommendations

### 3.1 Introduction

This chapter provides the key themes from Task 3 analysis. Remaining knowledge gaps were identified based on survey results and Task 3 analysis. Finally, recommendations for addressing identified gaps are provided, followed by the future research plans. Based on the evaluation completed in Task 3, recommendations were made regarding the performance measures that should be considered for further evaluation during future research projects. Recommendations were also made for cases where existing measures may be modified (in light of their identified deficiencies) or new measures developed for evaluation during future research.

The agencies which indicated that they used LOS or other metrics reported different approaches that were in use. These included:

- Time to complete maintenance following a storm (ranging from 4 - 48 hours).
- Providing bare pavement conditions as soon as possible.
- Meeting political and/or customer expectations.
- Route classifications.
- Maintaining roads as safe and passable throughout a storm.
- Using observed travel speeds.
- Setting service based on traffic volumes.
- Prioritizing corridors.
- Based on measured friction levels.

In some cases, agencies used different objectives or metrics or in combination with others listed. Collectively, agencies appear to use those metrics that are prioritized in their locale for any number of reasons, including (but not limited to) political and customer feedback and expectations. For respondents whose agency did not use LOS or other metrics to establish how a road was maintained, responses generally indicated that these agencies do in fact employ a standard for winter maintenance. In these cases, time to clear a class of roads, clearing a road until it is deemed safe, and the use of maintenance standards based on length of route, number of lanes, and traffic could be considered the metrics being used.

### 3.2 Key Themes from Analysis

- *Input* and *output* measures are important for operational assessment and budgetary purposes. However, agencies are also using *outcome* measures that more accurately reflect how well agencies meet their snow and ice control goals.
- More respondents use either total time to achieve an established objective, or as a percentage of times the objective is met within time goal, than any other measure.

- *LOS Time (LOST)* is most commonly used. However, an agency must have a clearly-defined LOS goal in order to track this measure properly. Time to LOS is an umbrella term that may include time to bare pavement or other LOS goals.
- *Bare Pavement Time (BPT)* is a widely used and effective outcome measure. There are many different ways to calculate this measure, and some methods such as visual inspection and CCTV system are more reliable than others.
- *Speed Recovery Time (SRT)* is another widely-used measure, Speed data may be acquired in different ways, from agency-owned devices to purchasing data from providers.
- *Winter Severity Indices (WSI)* provide a way to compare performance results between storms of different characteristics. The use of indices accounts for and normalizes the variables for consistency. A winter index (also known as severity index, storm index, salt index, etc.) can be calculated in many different ways depending upon available observation tools. It is the most effective means of comparing performance results from storm -to-storm, season-to-season crew to crew.
- *Friction (F)* is gaining interest as a measure. When in situ surface sensors are available, it is an effective, timely and reliable outcome measure. Conversely, the costs of measuring friction levels can be prohibitive for many agencies that do not have such sensors.
- Technology—sensors, on-plow hardware, software, and sophisticated computation—is increasingly used in operations,—and readily provides empirical data for performance measurements. In contrast, manual observations are more common, available and inexpensive but can be too subjective and inexact for standardizing performance measurement.
- Safety is a high-priority goal for all agencies, yet performance measures only *indirectly* measure safety enhancement from snow/ice control. There are too many variables to properly use safety as a winter maintenance performance measure. For instance, determining if actual road conditions are the primary cause of wrecks vs. driver inexperience, inattention and over-confidence in the capabilities of their vehicles. There is obvious correlation between crash rates and “wet” pavement, whether from rain, ice or snow, but at what point, short of total clear and dry pavement, does the LOS cease to be the primary cause of crashes?
- Social media and the widespread use of personal communication devices, such as smart phones, have greatly increased the capability of agencies to communicate performance with the public, and allows the public to provide feedback, often in “real-time”, on performance.
- Performance measures should be used to sustain satisfactory performance and to motivate agencies to seek further improvements. However, if performance goals are always met, an agency should evaluate whether goals should be revised to a higher standard. In other words, an agency should periodically review the measures for relevancy, reasonableness and reliability. Good performance measures should align with Levels of Service that an agency is fully capable of providing. If set too high an agency will always appear to be underperforming. On the other hand, if set too low than it can mask the need for adjusting LOS or for additional resources. In essence, this is the “Goldilocks” conundrum.

### 3.3 Remaining Gaps in Knowledge

1) The following measures require a set of standardized terms, and more detail is needed on the methods used to evaluate them:

- TGC: Time to Given Pavement Condition: When does the clock start and how is start time logged? How is various road condition evaluated? How is end time logged? How does an agency choose an appropriate condition to aim for? What are the associated costs, advantages or disadvantages for each method?
- SRT, Speed Recovery Time: When does the clock start and how is start time logged? How is speed measured? How is end time logged? How is the target recovery speed chosen (e.g., posted, average, “expected,” or some percentage of average)? What are the associated costs, advantages or disadvantages for each method?
- WSI, winter Severity indices:
  - i. What makes a “good” severity index?
  - ii. What are the inputs to and outputs from the calculations, and?
  - iii. how were the calculations derived?
  - iv. Is there a way to calculate it without using instrumentation?
  - v. Are there other ways to normalize storm -to-storm and seasonal variances?
- F, Friction:
  - i. How is friction used in real time as a performance measure?
  - ii. What are the data or details needed and how calculated?
  - iii. What are low-tech/low-cost methods for measuring friction?

2) Further exploration and clarification is needed on the following:

- What is the best way to shift input/output measures toward outcomes?
- How can the effectiveness of data gathering techniques for the performance measurement themselves be evaluated?
- Which outcome measures are best at reflecting performance?
- How does an agency use performance results to improve operations (using each method)?
- What is the process from tracking performance, to reporting performance, to making changes?
- What agencies are doing this?

### 3.4 Next Steps: Recommendations for Addressing Gaps

1) Identify and interview agencies (from using maturity matrix Task 2 results) that use:

- a) TGC: Time to Given Pavement Condition.
- b) TRS time to recover speed.
- c) WSR winter severity indices.
- d) Friction.

- 2) The project team will develop a matrix outlining levels of agency maturity in performance measurement. For example, three levels of maturity may be identified, each describing in general terms how the least to most mature agencies would do the following.
- a) Setting goals that consider public or political expectation and the realistic operational capabilities or budgetary constraints of the program;
  - b) Identifying inputs and outputs that are best for bookkeeping and tracking operational tools and resources;
  - c) Establishing outcome measures that are best at reflecting how well those goals were met;
  - d) Applying performance measurements to making improvements in operations.

See table below for example.

***Example Maturity Framework***

	Least mature	Medium maturity	Most mature
Establishment of performance goals and LOS	<i>General description</i>	...	...
Inputs/outputs that track resources	...		
Outcomes that reflect performance	...		
Applying performance outcomes to operations	...		

Examples will be gathered from agencies that routinely use their performance results to improve their operations.

A companion framework will be developed that recommends ways for an agency to move from one maturity level to the next.

***Example Dynamic Maturity Framework***

	Move from Least to Medium	Move from Medium to Most
Establishment of performance goals and LOS	<i>General steps to take</i>	...
Inputs/outputs that track resources	...	
Outcomes that reflect performance	...	
Applying performance outcomes to operations	...	

### 3.5 Conclusions and Recommendations for Future Research

Snow/ice removal practices of transportation agencies have evolved into current forms due to technology improvements, as well as social and political pressures. As evidenced in the literature review and the survey, not all agencies use performance metrics to measure the performance of their snow removal operations; and a variety of currently used performance measures are not standardized. In this context, establishing performance metrics and service standards for winter highway maintenance operations has been more important for measuring and comparing service levels and justifying budget allocations. As technology advances, it has become more feasible to collect performance-related data, which in turn has increased the demand for snow removal performance measuring.

The findings of survey indicated that restoring safety and mobility consistently remains a priority of nearly all agencies' snow/ice control operations. To achieve this goal, time to established LOS criteria is the most commonly used metric. Maintaining roads safe and passable throughout a storm, providing bare pavement as soon as possible, and setting service by traffic volumes are the top three LOS criteria considered for the snow/ice control.

The increased use of outcome-based measures, such as a friction-based metric, has been noticed in the survey. This trend is likely a result of the rising importance of customer satisfaction and the increased demand for agency's transparency to the public. Many agencies also showed strong interest in the severity index-based performance metric, as it has value in allowing for more accurate comparison of storm-to-storm or season-to-season, which would be useful for long-range budgeting and planning. The cost-method matrix and the timeliness-reliability-effectiveness analysis also showed that most of outcome-based measures have relatively high reliability and timeliness.

For agencies at different levels, performance metrics are generally safe and efficacious for improving winter operations. These metrics can also facilitate the communication and engagement between the public and transportation agencies, which in turn can lead to a more transparent and effective program for snow/ice removal.

Areas for future research:

- Investigations of agency preferences regarding data gathering methods are needed to determine if the effectiveness for performance measurements can be improved.
- Some studies to address snow operation improvement by using a performance metric specifically. Evaluation is required regarding the need for resources and training to assist comparison between a performance metric and conventional LOS.
- Further investigation is required of the role of performance measurements in the snow removal operation, as this may be a cost-effective option. The literature review found that a structured performance based program offered the better benefits.
- The development of methods to investigate long-term outcomes of performance metrics including appropriate comparison groups is required.

- The optimal circumstances for adding a performance metric into the current system of agencies with snow removal operations, including which agencies, for how much resources needed, and in conjunction with what additional training.
- The survey did examine agencies' efforts towards the performance metrics application, however, the examination of which agencies are collecting performance metric data, how agencies are utilizing the data to evaluate their program and make improvements is an important area of potential research.

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## Appendix A: Literature Review

This appendix describes the results of comprehensive literature search on the use of performance measures by transportation agencies for winter highway maintenance activities.

### A.1 Introduction

For several decades, agencies have been performing winter maintenance at some level. For most of this time, these agencies have also been asked to account for their success in doing so. With the onset of widespread attempts to make all operations more efficient, the last decade alone has brought more investigation and investment in documenting program success. As a variety of agencies measure performance, there are a variety of performance measures used as well.

Recent literature has shown that these measures are often inconsistent and quite difficult to apply to assess the success of a winter maintenance program. The most recent comprehensive look at this topic in the U.S. is NCHRP Project 6-17 (Maze et al. 2007). NCHRP 6-17 identified both methods and measures for assessing agency and contractor performance in snow and ice control operations. This research provided a snapshot of how agencies were measuring snow and ice performance (in terms of inputs, outputs, and outcomes) and a framework for future practices; however, there is still considerable need to revisit this issue by assessing needed improvements in data (and those made in recent years), and reviewing guidance on incorporating better cost information on storm severity and method/application costs.

In addition, measures applicable to different roadway classifications, local climates, and storm characteristics have evolved since the publishing of NCHRP 6-17 results. A related challenge is the need to effectively communicate the success of these practices in measuring the performance of snow/ice removal operations.

A comprehensive review of the international state of winter maintenance practices was published in 2015 in the fourth edition of the *Snow and Ice Databook 2014*, compiled by the World Road Association (Permanent International Association of Road Congresses, PIARC) Technical Committee 2.4. Among the 26 countries included in PIARC (2015), performance measurement practices in 10 countries—Belgium, Canada, Czech Republic, Denmark, Estonia, France, Germany, Iceland, Italy and Norway—will be discussed herein. The PIARC (2015) report provides a fairly detailed summary, despite reviewing practices in 26 countries. It represents the most up-to-date summary of international practices.

Another international review of performance measurement techniques (for road management in general, including but not restricted to winter maintenance) was performed in 2012 by the International Transport Forum and compiled by Karlaftis and Kepaptsoglou (2012) at the National Technical University of Athens, Greece. The review surveyed current practices in the US, Canada, Australia, New Zealand and Japan. Because the review covered general road management, there was little specific information on winter maintenance-related performance measurement. The report does mention the metric used by Canada of number of days of snow and/or ice free roads, but there is little detail beyond that.

Individual state DOTs have investigated measurement of snow and ice removal practices. States such as Idaho (Veneziano et al. 2014) and Minnesota have researched success of their own winter maintenance practices. In addition, groups other than Clear Roads, such as the I-80 Winter Operations Coalition and I-95 Corridor Coalition, are looking at innovations and establishing a structure for sharing information and coordinating winter maintenance operations across jurisdictional boundaries.

The following sections summarize published literature regarding performance measurement approaches and terminology (2.2), the application of different metrics and methods at agencies and research institutions around the globe (2.3), challenges faced by some of these agencies while implementing said methods (2.4), innovative technologies that have been used for performance measurement (2.5), and how agencies communicate their performance with the public (2.6).

## **A.2 Objectives of Literature Search**

This literature review will introduce common terminologies associated with current snow removal performance metrics. The research completed since NCHRP Web-Only Document 136 “Performance Measures for Snow and Ice Control Operations” (2007) will be assessed and evaluated. Recent advances by various transportation agencies on snow removal performance metrics will be reviewed as well. Specifically, this review will focus on following aspects:

- Common terminology associated with snow removal performance metrics,
- Performance measuring & reporting systems,
- Evolvement of snow removal performance metrics,
- Guidance to incorporate the best performance measures,
- Needs to communicate performance measures among transportation agencies, and
- Innovative uses of technology for performance measurement.

## **A.3 Approach of Literature Search**

The approach is to conduct a comprehensive literature search, both nationally and internationally, on the use of performance metrics by transportation agencies for winter highway maintenance activities, focusing on the research completed since NCHRP Web-Only Document 136 was published, to identify common terminology and reporting systems. Available literature will be synthesized to document the state of the practice and the state of the art pertinent to winter maintenance performance metrics.

Multiple databases will be used to gather relevant information and data, including: Transportation Research Information Service, Google Scholar, ISI Web of Science, and Washington State University Library. Research conducted in Canada, Europe, and other international sources will be reviewed wherever available, along with the ongoing research and existing documents published by the DOTs, Clear Roads, Pacific Northwest Snow fighters (PNS) Association, university transportation centers (UTCs), Strategic Highway Research Program (SHRP), Federal Highway Administration (FHWA), NCHRP, Airport Cooperative Research Program (ACRP), American Public Works Association (APWA), and American Association of State Highway and Transportation Officials (AASHTO).

Resources that provide a basis or framework for the identification of performance metrics through customer satisfaction surveys are included in this literature review. National conferences, held to discuss performance metrics and road user expectations in general, are reviewed as well. NCHRP syntheses and reports serve as another important resource.

For example, NCHRP Synthesis 238 (Poister 1997) identified the types of performance measures used by state DOTs, with a focus on what is measured and how it is measured. While many of these metrics may not be fully applicable to snow removal operations, they offer ideas for potential alternatives and improvements.

#### **A.4 Snow Removal Performance Measurement**

Snow/ice removal policies and practices have evolved into their current form over the last few decades due to technology improvements and social and political pressures. Current performance measurements adopted by state DOTs for snow/ice control operations are not standardized.

NCHRP Report 551 (Cambridge Systematics et al. 2006) investigated performance measurement for asset management, but their assessment can generally apply to winter maintenance, as well. When developing metrics, the report proposes the following steps:

1. *Examine existing performance metrics:* Are there gaps? What new metrics need to be developed to fill those gaps?
2. *Integrate new performance metrics:* Identify possible enhancements to data collection, analysis and reporting techniques. Involve stakeholders.
3. *Establish performance targets:* Identify long-term and short-term targets.

Karlaftis and Kepaptsoglou (2012), working with information from NCHRP Report 446 (Cambridge Systematics 2000), summarized important properties for effective performance metrics (or indicators), as follows:

- *Relevance:* the metric must be applicable to the planning and budgeting needs of the agency
- *Clarity:* the metric must be clearly defined to avoid misinterpretation by different personnel or agencies
- *Reliability:* the measurement process should be standardized to avoid bias or errors
- *Precision:* the collection of data should be as precise as possible
- *Availability:* the data should be cost-effectively collectable and outcomes should be readily accessible by management and other stakeholders.

As DOTs use different metrics or indicators to measure the performance of snow removal operations in their own regions, it is difficult to benchmark or compare performance between regions. In general, performance metrics are categorized into three groups detailed as follows (Maze et al. 2007; Karlaftis and Kepaptsoglou 2012; and references therein):

**Inputs:**

This category represents resources spent or utilized to perform snow removal operations, including fuel usage, labor hours, machinery or equipment hours, anti-icing materials and so on. Although some inputs can be readily used to calculate the cost of snow removal operations per lane-mile or per storm event, they alone cannot provide enough information to assess the efficiency or effectiveness of snow removal operation.

**Outputs:**

This category quantifies the resulting physical accomplishment from inputs mentioned above. Typically, outputs are quantified in terms of lane miles per unit of time plowed, lane-miles deiced, truck plowing speed, material application rates, payments for winterizing, and other accomplishments. For performance measurement, outputs are more useful than inputs alone, since it shows how well the inputs are converted to outputs to some extent.

**Outcomes:**

Outcomes are generally abstract concepts and measured through indicators, which are able to assess the effectiveness of snow removal operations directly. These concepts include safety improvements, mobility, and user satisfaction. Commonly used indicators are summarized in Table A.4.1. Bare pavement regain time, friction, and user satisfaction survey are popular ones used for performance metrics (Blackburn et al. 2004).

**Table A.4.1: Types of outcome indicators for performance measurements**

	Outcome Indicators
Physical Characteristics	Bare pavement regain time Pavement friction Duration and frequency of closures
Visual Characteristics	Centerline, wheel path bare Loose snow, packed snow cover Thin ice, thick ice cover Path surface conditions: dry, damp, slush, frost, wet
Customer Satisfaction Characteristics	Reduction of crashes Advanced warning time to customers User satisfaction survey

In the United States, bare pavement regain time is used as a common measure for performance of snow removal operations, whereas Sweden, Finland and Japan have been using friction indicator as a common measurement. Furthermore, Japan uses friction (coefficient) as an indicator for reduction of crashes and traffic speed and volumes.

According to PIARC (2015), Belgium, Canada, Czech Republic, Denmark, Estonia, France, Germany, Iceland, Italy, and Norway use a variety of visual metrics, physical measures (depth and width of snow/ice features on the roads), friction measures, and an associated time to reach preset

thresholds to assess performance, as discussed in detail in Section A.3. Some common types of outcome measures were summarized by Bandara et al. (2015) as follows.

*1. Visual characteristics of road condition*

Centerline bare, wheel path bare, loose snow cover, packed snow cover, etc. were used for the visual assessment of road condition. A pavement snow and ice condition (PSIC) table was developed to help the transportation agency determine the performance level of snow removal operations. Michigan DOT has also developed a pavement condition evaluation scale (Fig. A.4.1), which was incorporated in the commercial Dynatest “SURVEY” program.

*2. Roadway friction*

Roadway friction is usually expressed as the coefficient of friction between vehicle tire and pavement. It can be increased by appropriate winter maintenance activities. NCHRP Web Document 136 illustrated three operational uses of friction measuring devices, which can be used as an indicator for performance of snow removal operations (Maze et al. 2007).

Table A.4.2 summarizes the survey responses from different transportation agencies, regarding the outcome based performance measures for snow/ice control operations.

**Table A.4.2: Outcome based performance measures used by different agencies**  
(Bandara et al 2015)

Measure	Approach
Time to reasonable near-normal winter conditions	a. Visual inspection by maintenance personnel (AK, CA, NV, NM, NY) b. Reports from field personnel (IA, CA, NV, NM, NY) c. Visual inspection by law enforcement (NW)
Customer satisfaction	a. Annual sensor at end of season (AK) b. Internet survey (CA)
Travel Speed	a. Automatic traffic recorders (NY, IA)
Time to bare pavement	a. Visual inspection by maintenance personnel (CO, MD, NY, OH, WA, ON) b. Reports from field personnel (CO, MD, MO, NY, OH, WA, ON) c. Visual inspection by law enforcement
Total time of road closure	a. Accounting records of hours closed (CA)
Total time of chain restrictions	a. Records of chain restriction hours (CA, CO)
Time to single bare wheel track	a. Reports from field personnel (IA, KS)
Time to two bare wheel paths	a. Reports from field personnel (KS)
Time to treat critical areas	a. Reports from field personnel (MO)
Friction	a. Testing (OH, ON) b. Establishing friction coefficient (Sweden)

This table indicates that visual pavement conditions are used as a major performance measure used by transportation agencies to gauge their winter maintenance operations.

Bandara et al (2015) also developed a relationship between pavement friction levels and visual pavement condition, which can be used by transportation agencies to predict the safety level of the roadway. This relationship has a great potential to serve as an effective and efficient performance measure.

Surface Condition	Description	Picture
<b>Bare</b>	Bare Pavement	
<b>Centerline Bare (CL Bare)</b>	Entire lane is cleared of snow, ice and slush.	
<b>Wheel Track Bare (WT Bare)</b>	Only wheel tracks are bare, snow/ice/slush in the other areas	
<b>Loose Snow/Slush (Loose Snow)</b>	Loose snow/slush covered	
<b>Snow Covered (Snow)</b>	Entire roadway is covered with packed snow and ice	

**Figure A.4.1 Winter Pavement Condition Evaluation Scale (Bandara et al. 2015)**

Further work needs to be done to incorporate all possible visual characteristics for this relationship.

Direct measurement of friction for performance measurement is done internationally. Finland has built their LOS standards based on friction measurements. Researchers in Japan have built a model linking friction to accidents, and noted that improving pavement friction has a positive impact on traffic safety (Qiu and Nixon 2009, and references therein).

Adams et al. (2014) highlighted that setting performance goals or targets are an effective way to measure success or deficiency in performance. For example, for a given roadway category based on average daily traffic (ADT), a target for bare lane regain time would be set.

A specific example of post-storm bare lane regain targets set per ADT category is given in their Table 29 for Minnesota DOT, which is also found in Neimi (2006) and reproduced below in Table A.4.3. (The customer-driven feedback MnDOT used to establish these outcome targets is covered

in Section A.3.) However, in Adams et al. (2014) and the current project’s survey results, MnDOT reports an update to its super commuter route targets: 0-3 hours. The specific outcome measure is the frequency of achieving bare lane within the set target hours.

**Table A.4.3. Regain time (in hours) performance targets developed for MnDOT based on survey responses for varying road types (by ADT) (Niemi, 2006). Note: Regain time target for super commuter routes is now 0-3 hours.**

Roadway Classification	ADT	Regain Time (Hours)
Super Commuter	>30,000	1 - 3
Urban Commuter	>10,100	2 – 5
Rural Commuter	>2,000	4 – 9
Primary	>800	6 – 12
Secondary	<800	9 - 36

The Idaho Transportation Department (ITD) identified a goal to minimize the amount of time that ice is bonded to the pavement. Therefore, ITD developed a winter performance index (WPI) that measures the duration of ice per unit of storm severity. First, storm severity is calculated using wind speed, surface precipitation accumulation and road surface temperature—data that are gathered from road weather information system environmental sensing stations (RWIS-ESS) located throughout Idaho. Ice duration is defined as “the amount of time grip, or friction, falls below 0.6 (on a scale of 0 to 1, with 1 being optimal friction)” (Jensen and Bala 2012).

The WPI is calculated real-time and then provided to maintenance managers to allow for storm response assessment immediately following events. Jensen and Bala (2012) stated that “this metric allows for accurate evaluation of different treatment strategies and maintenance operations.” Figure A.4.2 shows the WPI legend. Note that the lower the index value, the more effective the treatment. The goal for this metric is a WPI rating of 0.25 for interstates and 0.45 for regional routes.

Performance Index Legend	
0.00	Successfully Treated
0.00-0.30	Significantly Accelerated Grip Recovery
0.31-0.49	Some Success at Grip Recovery
0.50-0.69	Very Little Success at Deicing
0.70+	Limited Maintenance or No Deicer Success
	Observation Data Missing or Temp. Below Threshold.

**Figure A.4.2 Idaho Transportation Department’s WPI Legend (Spoor 2013)**

Jensen and Bala (2012) and Spoor (2013) also discuss the Winter Mobility Index (WMI), which is derived using the percentage of time road conditions do not impede mobility during a storm (i.e., time during which the grip value is above 0.60). Since development of these measures, winter storm mobility in each Idaho district has improved.

With the data available, ITD was able to match the treatment to the event. This led to the creation of a dashboard for winter storm mobility by district, which shows the percent of time mobility was not significantly impeded during winter storms.

Based on this finding, MnDOT changed their indicator to “Bare Lane Indicator,” which is the time from the end of the event until bare lane is achieved. Table A.4.3 showed developed bare lane regain time performance targets based on this research.

Maintenance performance and public interest are intrinsically linked, and, therefore, many DOTs choose to use customer satisfaction as a performance metric. Transparency with the public (i.e., communicating performance through online “scorecards” or reports) is one way agencies hold themselves accountable to the public (more details in Section A.6), though many DOTs also gather feedback directly from the public through surveys (Yurek et al. 2012).

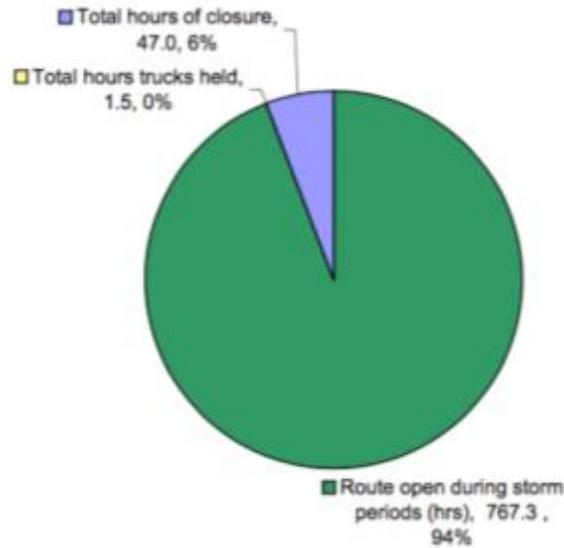
Customer-driven benchmarking is “a process used to identify, assess, and implement best practices of operationally-relevant organizations that have been shown to provide the highest levels of customer-oriented outcomes relative to the services used” (Niemi 2006). Section A.3 documents some of the ways in which customer feedback has been used by agencies, and ways in which this feedback has ultimately altered measurement methodology itself.

## **A.5 Applications of Snow Removal Performance Measurements**

This section presents different evaluation methods for snow removal performance, by using measurements from the three aforementioned categories: inputs, outputs and outcomes.

California Department of Transportation (Caltrans) developed Snow and Ice Levels of Service (SNOW LOS) in 2004. SNOW LOS is a statewide pilot program to measure the effectiveness of the department’s snow removal operations on high traffic volume routes. A high emphasis on mobility was incorporated to develop SNOW LOS methodology. The main rating element is the percentage of time a route is available to traffic during storm periods from November through April (Caltrans 2009).

Figure A.5.1 illustrates the percentage of Route 80 closure hours for SNOW LOS measurement.



**Figure A.5.1 District 3, Route 80 Snow and Ice Level of Service (Caltrans 2009)**

Zwahlen et al. (2006) at Ohio University have tried to categorize the level of service for snow removal operations by comparing surface traffic speed levels during a storm with the average dry surface speed. Table A.5.1 shows the different levels of service related to different speed levels.

**Table A.5.1. LOS Categories by Ohio University (Zwahlen et al. 2006)**

Level of Service	Adequate	Slightly inadequate	Moderately inadequate	Inadequate	Highly inadequate	Extremely inadequate
% of Dry Surface Speed	76–100%	68–75%	60–67%	51–59%	42–50%	< 41%

Lee et al. (2008), at University of Wisconsin, Madison, made an effort to quantify snow removal operation performance by measuring traffic-flow data. A regression model was developed by calculating speed recovery time as a function of maximum speed reduction, time to maximum speed reduction, snow depth, etc. LOS for snow removal operation will be categorized based on the speed recovery time.

$$\text{Speed Recovery Duration} = 9.68 + 9.926 \cdot \text{MSRPCENT} - 0.086 \cdot \text{StoS2MSR} + 0.493 \cdot \text{crew delayed} - 0.222 \cdot \text{snow depth}$$

Where:

MSR = Maximum speed reduction,

StoS2SD = Time lag to speed drop after snow storm starts

StoS2MSR = Time to MSR after snow storm starts

Crew delayed = Time lag to deploy maintenance crew after snow storm starts

Snow depth = snow precipitation.

Kwon et al. (2012), at University of Minnesota, Duluth, have made a further effort to estimate speed recovery duration from traffic flow data. Traffic speed, flow rate and density data were used in the process. Speed-change patterns, which are V-type, U-type, and Wide types, were identified as well. Then road condition recovery time can be associated with speed recovery patterns. This study will facilitate an automatic process to identify the speed change and the road condition recovered times and incorporate this process into TICAS (Traffic Information and Condition Analysis System).

Usman et al. (2010, University of Waterloo and McGill University, in partnership with the Ministry of Transportation of Ontario) developed an approach using traffic and safety for maintenance performance measurement. They developed a model that integrates weather, road surface conditions, traffic and maintenance, and related those elements to accidents. The ultimate application for performance measurement would be a more inclusive method that incorporates traffic and safety into maintenance performance.

The International City/County Management Association ([ICMA](#)) has developed pseudo-performance measures for snow and ice removal in comparative performance measurement. ICMA’s measure is simply per capita snow and ice removal expenditures.

Cuelho et al. (2010), at the Western Transportation Institute in Montana, developed guidelines for optimal snow and ice removal operations, which depend on the effective temperature and application rate of chemicals. “The lowest effective temperature for a deicer is defined as the temperature at which the deicer will ‘melt’ a reasonable amount of ice within a reasonable amount of time” (Cuelho et al. 2010). Effective temperature and application rate will serve as important part of performance measurement.

Three groups of performance measurement methods have been developed as well (Hintz et al. 2002).

*Performance Measure 1: Efficiency*

Efficiency is a ratio of the actual expenditures of snow removal to the number of lane-miles operated and the amount of snow precipitation. The result is cost efficiency.

$$\frac{\text{Expenditures}}{(\text{lane miles}) \times (\text{inches of snow precipitation})}$$

*Performance Measure 2: Effectiveness*

Effectiveness measures the quality of snow removal operations. The results are an overall quality rating from zero to one. The quality rating for each area in the equation should be standardized for consistency.

$$\frac{\sum (\text{lane miles} \times \text{quality rating})}{\text{Total lane miles}}$$

*Performance Measure 3: Cost-Effectiveness*

Cost-effectiveness is calculated by dividing *Performance Measure 1* by *Performance Measure 2*. The resulting units are dollars, weighted for quality.

To help establish reasonable LOS guidelines for ITD, a recent study (Veneziano et al. 2014) surveyed transportation agencies in northern climates, asking them to rank their maintenance goals. The results are shown in Table A.5.2.

**Table A.5.2 Maintenance Goal Rankings by Northern States (Veneziano et al 2014)**

	1	2	3	4	5	Rating Average	Rating Count
	Percentage/(Number of Responses)						
<b>Safety</b>	<b>86.1</b>	5.6	0.0	0.0	8.3	1.39	36
	<b>(31)</b>	(2)	(0)	(0)	(3)		
<b>Mobility</b>	<b>52.8</b>	33.3	5.6	5.6	2.8	1.72	36
	<b>(19)</b>	(12)	(2)	(2)	(1)		
<b>Reduced Impact to the Environment</b>	2.8	27.8	<b>45.7</b>	22.2	2.8	2.94	36
	(1)	(10)	<b>(16)</b>	(8)	(1)		
<b>Reduced Corrosion Impact to Infrastructure, Equipment, Vehicles, etc.</b>	2.8	19.4	<b>41.7</b>	30.6	5.6	3.17	36
	(1)	(7)	<b>(15)</b>	(11)	(2)		
<b>Other</b>	6.7	20.0	13.3	0.0	<b>60.9</b>	3.87	15
	(1)	(3)	(2)	(0)	<b>(9)</b>		

*Note: Numbers in parentheses (#) indicates the number of respondent agencies assigning a particular rank. BOLD denotes highest responses/percentage.*

Table A.5.2 reveals that safety and mobility are the two main goals of winter maintenance agencies; as such, the performance measures the agencies use tend to aim at achieving these two goals.

Indiana DOT uses vehicle speed, constituting a subjective LOS, to assess performance of winter operations (McCullough et al. 2013). LOS grade by speed category is shown in Table A.5.3. They are careful to point out that their method describes performance from a pavement condition (which contributes to speeds) perspective, and can therefore be subjective. *Storm impact period* is the duration of the slowing of speeds during a storm as a result of the storm. The period is defined by speeds being 55 mph or less on interstates with 70-mph posted limits. They also calculate a *storm index* (severity) using the following inputs: storm type, temperature, early-storm behavior, during-storm wind, post-storm temperature, and post-storm wind.

As stated in the previous section, customer feedback is an increasing method for assessing maintenance performance. Yurek et al. (2012) summarized methodologies used at a few State DOTs, as listed in the following paragraphs (note: Yurek et al.’s review is not specific to winter maintenance).

**Table A.5.3 Indiana DOT’s LOS grades based on measured interstate speeds**  
(adopted from McCollough et al. 2013)

Traffic speed (70 mph posted)	LOS grade
55+	Very good
45-55	Good
35-45	Fair
25-35	Poor
<25	Very poor

Minnesota DOT (MnDOT) employs full-time market research personnel and considers customer input as an integral part of their stewardship goals. Customer surveys and focus groups have served to adjust the agency’s snow and ice performance targets. For example, one significant change that resulted from the inclusion of public input is that the focus of MnDOT’s snow and ice performance has shifted from output-based measures (e.g., hours spent on snow removal) to outcomes (e.g., time to bare lanes).

More specifically, the outcomes were honed to reflect interest from the public: establishing bare lanes as soon as possible was more important to the public than establishing bare pavement across the whole width of the road. Niemi (2006) also reported that customers rated bare lane—a condition where the road is bare between the wheel paths but has snow both on centerline and edgeline—nearly as high as they rate completely bare.

Many different methods are used to gather public feedback (Yurek et al. 2012): mailed paper surveys, phone surveys, and email-based surveys. These methods offer a controlled dataset on which analysis can be performed. While most DOTs have permanently accessible web forms the public can use to provide feedback, this method provides an uncontrolled, low-resolution, and more biased dataset on which it is much less suitable to performing statistical analysis.

Formal surveys also give the agency the opportunity to educate the public through clarification and explanation, allowing for the most informed and (potentially) least biased feedback. For example, Utah DOT and Washington State DOT being their surveys by explaining the difference between state and local routes in the respondent’s area. This is done as an effort to ensure that public feedback refers to DOT maintenance activities only (Yurek et al. 2012).

The following paragraphs overview performance measurement in 11 countries as reported by PIARC (2015). PIARC (2015) also notes that some of the countries that share borders are working toward standardizing LOS definitions and performance goals across borders, though the private and government structures of transportation agencies between countries can vary much more drastically than agency differences between states in the US.

One major difference between the US and other countries in the application of performance assessment is that many other countries use performance measurement to gauge how contracted maintenance companies are reimbursed for their services (rather than reimbursing based on work completed; Karlaftis and Kepaptsoglou 2012).

The Flemish Road Authority in Belgium strives to minimize the ratio of salt usage to winter severity. The inputs to their ratio calculation are: quantity of salt spread, area of road treated, number of nights during which road temperature was below 0°C (32°F) and dew point was greater, and the number of nights during which winter showers or snow fell on an icy surface. GPS-based automatic vehicle location (AVL) and spreader controls are used to track the trucks and the material they use.

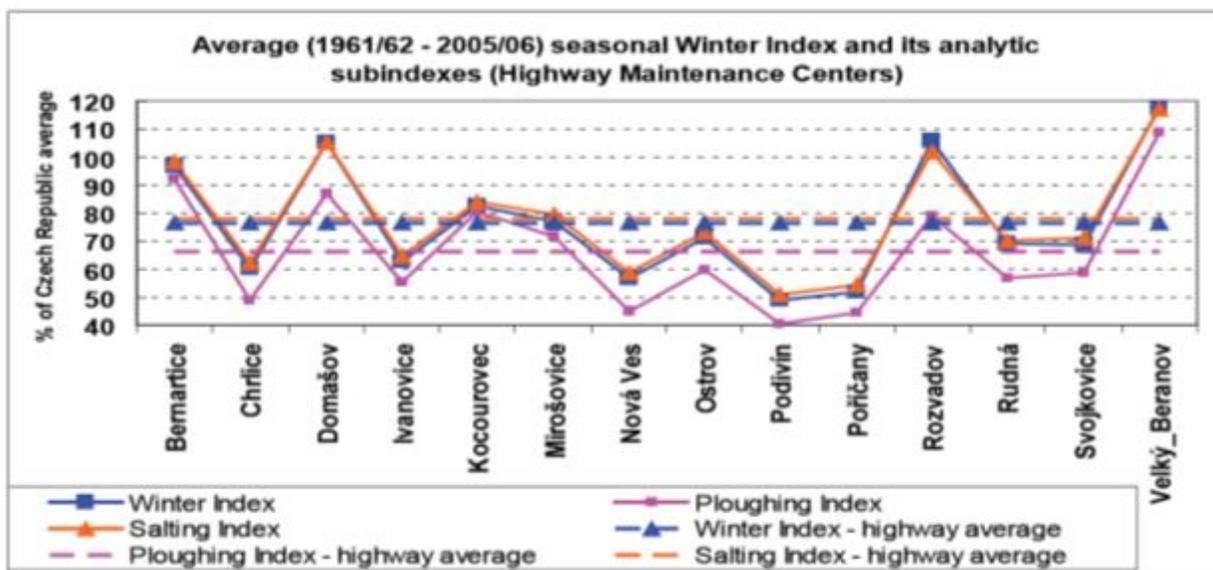
Canadian performance goals are based on time to a set level of service, defined differently for different road classifications. See Table A.5.4 for details.

**Table A.5.4 LOS Goals in Canada** (adapted from PIARC 2015)

Road Classification	Expressways	Arterial highways	Connector roads	Local roads
Surface Condition	Bare pavement	Bare pavement	Bare centerline	Snow-packed with abrasives
Max Time to LOS	4-12 hrs after end of storm	12 hrs after end of storm	12 hrs after end of storm	12-14 hrs after end of storm

In the Czech Republic, the cost expended for winter maintenance is compared to a winter weather index calculated for each territory.

Figure A.5.2 graphically shows calculated winter index and plowing and salting indices (measures of cost expenditure) per territory and averaged over the country. The comparison of these two metrics (weather and cost) provides a measure of performance per territory for use by road managers and contractors alike.



**Figure A.5.2 Graphical representation of performance measurement indices used in the Czech Republic** (adopted from PIARC 2015)

The Danish Road Directorate uses a salt index to gauge the severity of a winter and relates it to the winter maintenance performed. Inputs to the index include environmental conditions—such as road temperature, dew point temperature, and their relation to one another—and the amount of time or number of times certain environmental thresholds are reached. As in Canada (Table A.5.4), Denmark classifies its roads and sets a maximum time to reach a given condition rating for each road classification. Table A.5.5 shows Denmark’s performance standards.

**Table A.5.5 Danish Road Directorate’s desired duration of road conditions**  
(adopted from PIARC 2015)

Class	Desired duration of Road Conditions below the Service Objectives
State roads	Slippery roads without snow:
	<ul style="list-style-type: none"> <li>• Rime frost                    0 hours</li> <li>• Ice                                0 hours</li> </ul>
	After snowfall:
	<ul style="list-style-type: none"> <li>• Slush                            2 hours</li> <li>• Light snow                    2 hours</li> <li>• Compacted snow            0 hours</li> </ul>
Other roads	After blown snow:
	<ul style="list-style-type: none"> <li>• Driven snow                 2 hours</li> <li>• Blocked                        0 hours</li> </ul>
	Slippery roads without snow:
	<ul style="list-style-type: none"> <li>• Rime frost                    2 hours</li> <li>• Ice                                2 hours</li> </ul>
	After snowfall:
	<ul style="list-style-type: none"> <li>• Slush                            4 hours</li> <li>• Light snow                    4 hours</li> <li>• Compacted snow            2 hours</li> </ul>
	After blown snow:
	<ul style="list-style-type: none"> <li>• Driven snow                 4 hours</li> <li>• Blocked                        0 hours</li> </ul>

The Estonian Road Administration classifies its roads based on ADT, and measures performance based on maximum time required to meet set LOSs. LOS is visually described in Figure A.5.3, but specific quantitative thresholds were created for each. That is, thresholds were established for the following, specific to each LOS: allowed depth of loose snow, allowed depth of slush (mix of salt and snow), width between snow mounds, and allowed depth of ruts/unevenness in packed snow.

For example, LOS 3 is defined as: wheel tracks free of snow and ice; and its quantitative thresholds are: <3 cm of loose snow, <2 cm of slush depth, whole driveway and shoulders free of snow mounds, and <2 cm depth of ruts (wheel tracks). Set maximum time to reach each LOS varies based on road class, and is different for different maintenance activities: snow and slush removal, de-icing/anti-skid treatment, and salt-snow mix removal.



**Figure A.5.3 LOS 1-3 in Estonia (LOS 4 is bare pavement; adopted from PIARC 2015)**

France defines LOS by the presence of ice or snow, a minimum allowed condition and a maximum restoration time to that minimum condition. The French Road Directorate uses the following measures to assess performance: salt consumption, cost per kilometer, number of man-hours for winter maintenance, and public user satisfaction. France also posts the location of its plow trucks online using AVL.

The Federal Highway Research Institute in Germany developed a winter index in order to compare weather severity to snow and ice control, as with many other countries listed here. In Germany, roads are classified based on specific criteria: category (federal freeway, secondary road, residential, etc.), traffic volume (ADT), special traffic (school bus routes, rescue routes, etc.), and accident-prone areas (curves, bridges, shade, etc.). Time to bare pavement, salt consumption, and cost expenditures are the predominant performance metrics.

The Icelandic Road Administration (ICERA) uses the following metrics for assessing performance: service aims, LOS, timing of actions, maximum snow depth/road surface evenness, friction, and visibility at intersections/leveling of snowbanks.

Figure A.5.4 shows service categories used by ICERA. Service category 1 requires a bare pavement strategy. Service categories 2-4 allow for a certain amount of snow and ice build-up.



**Figure A.5.4 Iceland’s winter service categories and performance standards.**  
(adopted from PIARC, 2015)

The following table shows required service to categories 1 and 2.

**Table A.5.6 Service requirements to category 1 and 2 roads in Iceland** (from PIARC, 2015)

Summary of Winter Service Quality Standards		Service Class	
		1	2
Service hours	In town	24 / 7 service	06:00 - 22:30
	60 km from town		08:15 - 22:00
	120 km from town		10:30 - 21:30
Critical snow depth for service		2 cm	4 cm
After snowfall, ploughing		2 hours	3 hours
After road closure, snow removal is completed within		-	3 hours
Max. service cycle duration		2 hours	
Max. service route pr. vehicle		50 km	
Maximum snow depth		5 cm	12 cm
Maximum track depth		1 cm	2 cm
Min. friction coefficient	Generally	$\mu > 0.25$	$\mu > 0.15$
	Curves and slopes	$\mu > 0.25$	$\mu > 0.25$

Italy calculates a snow removal index, which is a ratio between performance and expected minimum value of performance. Here, performance is defined as the number of roads closed to traffic for more than 12 hours (non-exceptional cases). Threshold index levels are set and penalties applied if unmet.

Norway has classified its roads into winter maintenance-specific classes (A-E) based on general approved road conditions, from bare road surface (A) to compacted snow and ice/friction down to 0.20 acceptable (E). Detailed performance standards were set for each. As examples, Classes B and C are shown in Tables A.5.7 a and b, respectively. Notice that the metrics used are road condition, friction, thickness and unevenness of snow/ice, maximum time for snow removal, maximum time for de-icing, and time to approved road condition.

**Table A.5.7a. Performance objectives for Winter Maintenance Class B roads in Norway**  
(from PIARC, 2015)

Method for friction improvement	De-icing with chemicals, When de-icing is not possible, sand should be used.
Approved road condition	
Road condition	Bare road surface– wet or dry in wheel tracks. Compacted snow and ice surface between wheel tracks accepted during limited time periods, loose snow less than 1 cm.
Friction - general	Higher than 0,25
Friction – special road sections	Higher than 0,30
Snow/Ice-surface: Thickness Unevenness	Less than 2,0 cm Less than 1,5 cm
Resource input at weather event	
Maximal cyclus-time for snow removal	2 hours
Maximal cyclus-time for de-icing/ gritting	2 hours
Time to reestablish approved road condition	In wheel tracks: 2,5-5 hours Road as a whole: 1-5 days

**Table A.5.7b. Performance objectives for Winter Maintenance Class C roads in Norway**  
(from PIARC, 2015)

Method for friction improvement	Sand De-icing chemicals during light snowfall or mild periods
Approved road condition	
Road condition	Bare road surface – wet or dry during mild weather - compacted snow and ice surface during cold periods, loose snow less than 2 cm
Friction - general	Higher than 0,25
Friction – special road sections	Higher than 0,30
Snow/ice-surface: Thickness Unevenness	Less than 2,0 cm Less than 1,5 cm
Resource input at weather event	
Maximal cyclus-time for snow removal	2,5 hours
Maximal cyclus-time for de-icing/ gritting	3 hours
Time to reestablish approved road condition	3 hours

The application of performance measures in snow and ice control operations has significant impact, not only on meeting an agency’s mission and directives, but also on the safety and mobility of travelers and various sustainability metrics (economic, societal and environmental, and infrastructure implications).

In light of these multiple dimensions of snow and ice control operations, Task 2 of this project will categorize the different performance measures available, evaluate them for their suitability for winter maintenance applications, and identify the potential measures that should be implemented. This will be done using the information obtained during the literature review and agency survey under Task 1.

The approach taken in completing this task will consist of first categorizing the different performance metrics that are identified. At a high level, the performance metrics should at a minimum be accurate, timely, reliable, consistent, affordable to implement, and easily understood. Beyond this, snow and ice control performance metrics under consideration can be grouped into three categories, as detailed in Section A.2, above: *inputs* such as labor hours and materials used, *outputs* such as lane miles cleared or *outcomes* such as level of service and time to regain bare pavement.

Each metric will be assigned to one or more of these categories for further evaluation. However, as NCHRP Project 6-17, “Performance Measures for Snow and Ice Control Operations” (Maze et al., 2007) noted, inputs and outputs are good tools for managing operations given their

measurement of amounts (labor, material, costs), but they do not directly measure outcomes such as sustainability, safety, operational, or societal impacts. Consequently, outcome measures take on a greater importance when evaluating the different performance metrics available.

In a recent study (Veneziano et al. 2014), it was clear that safety and mobility were the top goals of agencies; with acknowledgement that reducing environmental and corrosion impacts were also priorities. The agencies that used LOS or other measures reported using different approaches. These include:

- Time to complete maintenance following a storm (ranging from 4 - 48 hours),
- Providing bare pavement conditions as soon as possible,
- Meeting political and/or customer expectations,
- Route type or classifications,
- Maintaining roads as safe and passable throughout a storm,
- Using observed travel speeds,
- Setting service based on traffic volumes,
- Prioritizing corridors, and
- Measured friction levels.

In some cases, agencies used different objectives, metrics or combinations of those listed. Collectively, agencies appear to use those metrics that are prioritized in their locale for any number of reasons, including (but not limited to) political and customer feedback and expectations.

For respondents whose agency did not use LOS or other metrics to establish how a road was maintained, responses generally indicated that these agencies do in fact employ a standard for winter maintenance. In these cases, time to clear a class of roads, clearing a road until it is deemed safe, and the use of maintenance standards based on length of route, number of lanes, and traffic, could be considered the agency's performance metrics.

There is an ongoing NCHRP Project (14-34) that aims to update NCHRP Document 136, "Performance Measures for Snow and Ice Control Operations" (NCHRP Project 6-17), and to develop a "Guide for Performance Measures in Snow and Ice Control Operations." This project (Clear Roads 14-05: Snow Removal Performance Metrics), is a parallel effort more narrowly-focused on snow removal, and will inform NCHRP 14-34.

## **A.6 Challenges in Implementing Snow Removal Performance Metrics**

Performance metrics are not universally used by U.S transportation agencies. Although performance or pseudo-performance measurements have been studied and adopted by some transportation agencies, there are still a large amount of agencies lacking systematic means of snow removal performance evaluation. The following paragraphs describe various methods that have been adopted by DOTs and coalitions (not already mentioned herein).

The [North/West Passage](#) program focuses on the development of a multi-state project to coordinate Intelligent Transportation System (ITS) deployments along Interstates 90 and 94 from Wisconsin to Washington State. One of the current issues associated with planning and programming for the

North/West Passage is lack of corridor-oriented performance metrics (North/West Passage Updated Issues 2013).

The Milwaukee Department of Public Works (DPW), responsible for plowing all city streets, plows from curb to curb and operates under a “bare pavement” policy. Currently, DPM has no means of objectively measuring the efficiency and effectiveness of its snow removal program.

Some other transportation agencies, like the I-80 Winter Operation Coalition and I-95 Corridor Coalition, track a few input or output measures, such as lane-miles plowed. However, they lack a performance-based metric relating cost to performance.

Maze et al. (2007) summarized the reason why performance measurement has not been widely adopted: Generally, U.S. transportation agencies have historically set static (as opposed to variable) standards, which make it difficult or impossible to incorporate performance measurements as variables for financial and condition evaluations.

Most agencies employ a hierarchy of routes when prioritizing winter maintenance operations; classifying routes by traffic volumes, functional classification, or another measure. It is also cautioned that a WSI is needed so that maintenance agencies can compare winters from year to year and district to district to identify best performers and areas for improvement. The WSI is often incorporated into the performance measures, e.g., bare pavements regain time and average cost per lane mile per event.

CTC & Associates (2009) compiled a review of performance measurement practices by state DOTs for the Wisconsin DOT. The review included identification of general performance measurement principles and their application in research, as well as experiences in applying measures. They also completed a survey of state practices for winter maintenance LOS and performance measures.

Respondents indicated their agency used ADT (Iowa, New York), corridor significance (Missouri, Wisconsin), bare pavement (Kansas, Maryland), or route classification (Interstate versus lower priority; Maine, Minnesota) as classification measures.

Often, the challenges of implementing performance measurement are related to the cost of collecting the data. Hardware, instrumentation, and software can be expensive; but they are usually also utilized for general operations. Therefore, the benefits of these technologies are realized in many other ways. Customer satisfaction, however, is one technique that is used exclusively for measuring performance, and its methodology can be costly (although, feedback from the public is viewed by many DOTs as worth the investment).

For example, Missouri DOT conducts a yearly public phone survey at a price of approximately \$200,000 per year (Yurek et al. 2012). Because of the exclusive cost, not all agencies are able to regularly maintain this method of performance measurement. Yurek et al. (2012) reported that Kansas DOT, for example, suspended customer surveys due to budgetary constraints.

Other challenges with customer satisfaction is that the results can be easily biased by external influences. For example, before suspending its customer survey program, Kansas DOT learned that the media play a significant role in how the public views performance (Yurek et al. 2012). When local news promoted an upcoming winter storm as major, but the storm was minor from a mitigation perspective (say, a large amount of easily-plowable snow), the public is more likely to rate the DOT's performance highly.

Unfortunately, the opposite can also occur, in which a storm billed as minor to the public, can be very difficult to mitigate, thus driving down customer satisfaction. These external influences should be noted when the results are evaluated, as they inform the context of the feedback received.

Similarly, and also from discussions with Kansas DOT, Yurek et al. (2012) notes that the public is not always aware of the factors that trigger certain maintenance activities, or which routes are under state versus local jurisdiction. Thus, customer satisfaction should be used among a number of other quantitative measures of performance, and not the sole driver of maintenance budget allocations.

## **A.7 Innovative Technology for Performance Measuring and Reporting**

With increased utilization of information technology and information collecting systems in maintenance operations, it has become more possible to collect performance-related data easily, which in turn has increased the demand for snow removal performance measuring and reporting systems. The following paragraphs summarize innovations that have contributed to technologically-based performance measurement.

Mobile-based weather and pavement sensors have great potential to enhance the collection of performance-related data. AVL and related technologies are already able to track plow trucks and their material usage, and a rich AVL database has been established in recent years (both nationally and internationally). Mobile weather sensing will allow overlays of weather and pavement conditions with a truck's locations and control actions.

Vehicle-based sensors are already able to collect almost all desired atmospheric and pavement parameters (including, for the latter, friction and salinity), and then communicate that data at a high (seconds to minutes) temporal resolution. DOTs are gradually adopting these technologies for use in operations and for performance measurement.

Older technology (such as webcams and RWIS) is still in use, and greater bandwidths have allowed for enhanced data collection. Webcams [either roadside or mounted on plow trucks (Iowa DOT 2014)] view highways and provide visually-based performance information. Despite the surge of mobile sensors, stationary RWIS-ESS remain critical elements of atmospheric and pavement data collection.

RWIS-ESS are sited to World Meteorological Organization standards, the sensors are meticulously maintained and calibrated, and the data are quality controlled and archived; as such, they serve an important ground-truthing function for mobile sensors. These roadside technologies are widely used and trusted for performance management worldwide.

Because mobile observations will greatly enhance the resolution of environmental data collected along the roads, they will greatly improve the calculation of storm severity indices. Agencies have taken a number of approaches to calculating severity indices for winter storms (see Farr and Sturges 2012, and references therein). The severity index distills a storm's characteristics—precipitation amount, duration, intensity, type, etc.—into a single value, enabling the direct comparison of one storm to another. From this index, an agency can compare, for example, material usage across similarly severe storms and from maintenance shed to maintenance shed.

Friction has traditionally been measured using a locked-wheel, skid-resistance device attached to maintenance vehicles (Qiu and Nixon 2009). However, cutting-edge mobile technology has offered a smaller, sleeker way to measure friction. Externally-mounted, road-viewing sensors optically measure the road surface state from which a friction coefficient can be derived.

Alternatively, data transmitted from a vehicle's controller area network (CAN) bus can return information on wheel slippage and acceleration changes. In-car information can also be used to detect other safety parameters, which may be useful when accidents are used as a performance metric. These technologies are not yet widely in use for routine performance measurement.

Vonderohe et al. (2006) reported on “the development, implementation, and installation of a GIS application for assessing performance of winter highway applications” at Wisconsin DOT. The software, called “Wiscplow,” accepts data recorded from winter maintenance vehicles during operations and combines it with spatial data representing roadways and vehicle patrol sections. Analysts can then select among a number of performance measures and decision management tools for outputs from the system. Outputs are categorized according to labor, equipment, materials, and map displays that indicate vehicle routes and data collected along the way.

## **A.8 Communicating Performance with the Public**

Many agencies (e.g., Wisconsin DOT, Iowa DOT, ITD, etc.) share their winter maintenance performance with the public via website interfaces (“dashboards”) or reports that state the DOT's maintenance goals and summarize success at meeting those goals. Most dashboards display performance outcomes from past seasons, so that the public can see trends. A winter severity index is also a typical part of the display, as it is a key input to the performance calculations and helps the public understand what contributes to improvements or declines in performance.

Most DOTs are upfront about a decline in performance, why it occurred (usually related to winter severity) and what is being done to improve. The following paragraphs describe a few DOT's public dashboards.

In 2012, Wisconsin DOT launched a public-facing dashboard to improve communication and engagement with the public regarding performance. The dashboard, called “[MAPSS](http://www.mapss.wi.gov) (Mobility, Accountability, Preservation, Safety, Service) Performance Improvement Program” ([www.mapss.wi.gov](http://www.mapss.wi.gov)) shares a number of key performance outcomes, and explains the results so the public can understand why, for example, performance may have dropped. The predominant outcome the DOT shares with the public is time to bare pavement.

Iowa DOT has a public-facing winter maintenance performance website (available: [www.iowadot.gov/performance/winter\\_operations.html](http://www.iowadot.gov/performance/winter_operations.html)). There are a number of metrics displayed visually on the site. Key metrics are cost (labor, equipment, materials) and time to bare pavement for category A, B and C roads (which are interstates, other major highways and rural, low-volume roads, respectively).

Minnesota DOT shares its annual performance with the public via its “At a Glance” report (available: <http://www.dot.state.mn.us/maintenance/>), within which it shares measures based on weather, materials, costs/performance and labor. One performance target identified here is the frequency of achieving bare lane after winter event: 70%. Otherwise, performance is comparable from year to year.

Missouri DOT discusses some of its snow removal performance measures in its “Tracker” report (Missouri DOT 2013), which examines a wide range of departmental performance measures. For example, through December 2012 (covering the October - December period), continuous routes (major highway) required 3.5 hours to reach a clear condition following a storm, while non-continuous (low volume highways) routes required 5.3 hours. The report also highlights the total snow removal costs per lane mile for the state.

Australia and New Zealand’s association of road transport and traffic agencies (Austroads) disseminates performance measurement results via their National Performance Indicators website (<http://algin.net/austroads/site/index.asp?id=5>). Despite the fact that snow/ice control metrics are not included explicitly, the website offers a useful example of publicly-accessible graphics that display the relative success of transport agencies in meeting certain targets. The measures are standardized across each state, allowing for easy direct comparison in performance from state to state.

## Appendix B: Summary of Agency Responses

### B.1 Progression in Metrics

Descriptive responses are listed by agency in the [Individual Agency Responses](#) section below. Of those responding, the following 13 agencies reported that they had not established formalized performance metrics (those marked with “\*” indicated that they are in the process of establishing them):

- Alberta\*
- Arizona
- City of Omaha
- Denmark
- Finland
- Illinois
- Massachusetts\*
- Nevada\*
- Otter Tail County, MN
- Pennsylvania\*
- Slovenia\*
- Virginia
- West Virginia

The following 14 agencies reported that their existing metrics are currently in flux; i.e., either they are working on changing their metrics or are adding new metrics:

- Colorado
- Connecticut
- Iowa
- Kansas
- Maine
- Michigan
- North Dakota
- Scotland
- South Dakota
- Utah
- Vermont
- Washington
- Wisconsin
- Wyoming

Five (5) agencies specified interest in adding speed-based metrics (including, for example, time to regain normal speed and average speed reduction) or using new ways of gathering speed data (such as using cell phones as vehicle probes). Five (5) agencies specified interest in pursuing friction-based metrics, specifically utilizing instrumentation.

Severity index-based performance measurement (or at least performance contextualization) is of relatively strong interest. Four (4) agencies noted that they are working on improving their existing index, and nine (9) are currently working on (or desire to begin) developing one. Moving toward outcome-based measurement was a general theme noted by many responding agencies.

## B.2 Winter Severity Index

The table below lists the agencies that reported currently using a severity index (either incorporated or not incorporated into their performance measurement techniques) or that reported not using a severity index, but investigating it for their agency. Details on each agency’s index can be found in the [Individual Agency Responses](#) chapter.

**Table B.2.1 Agency Currently Using (or Investigating) Some Form of a Severity Index**

<b>Yes, and incorporated into performance measurement</b>	<b>Yes, but not (yet) incorporated into performance measurement</b>	<b>No, but are currently working on or are interested in developing one</b>
Idaho	Alberta	Colorado
Maine*	Denmark	Connecticut
New Hampshire	Finland	Missouri
Ohio	Iowa	Ontario
Sweden	Kansas*	Scotland
Utah*	Massachusetts	Slovenia
Wisconsin	Michigan	Tennessee
	Middelfart Municipality, Denmark	Vermont
	Minnesota	Wyoming
	Pennsylvania	
	South Dakota*	
	Washington	

*\*These agencies are working on improvements to the index they currently use (or how they use it).*

## B.3 Methods and Costs of Gathering and Analyzing Performance Data

The following agencies (as listed in the subsection above, “Overall Performance Measurement Results”) do not formally measure performance (or are in the process of developing new measures) and thus did not have current data for this question:

- Alberta
- Arizona
- City of Omaha
- Colorado
- Massachusetts
- Nevada
- Otter Tail County, MN
- Pennsylvania

- Connecticut
- Denmark
- Finland
- Illinois
- Slovenia
- South Dakota
- Virginia
- West Virginia

The following agencies did not provide an answer to the cost question:

- California
- City of West Des Moines
- Maryland
- New York State
- Sweden

The following agencies reported not knowing or not tracking cost data:

- City of Farmington Hills, MI
- Maine (costs currently unknown; working on new way to use speed data to track performance)
- Minnesota
- Montana (performance measurement process is not formalized)
- Nebraska (practices are currently too new to know costs; see Nebraska subsection for details on methodology)
- Norway
- Scotland (performance measurement is integrated into regular operations, so no additional cost)
- Texas
- Wyoming (though currently working on developing new metrics, Wyoming DOT manually reports road conditions and metrics as part of normal operations, facilitated, in part, by a new reporting application developed in 2015; there is no additional cost for making these reports during normal operations)

**Table B.3.1(a) Summary of Agencies Reporting Methods and Costs for Gathering and Analyzing Performance Measurement Data - Part 1**

<b>Agency</b>	<b>Method</b>	<b>Cost</b>
<a href="#">Alaska</a>	Software system that tracks winter operations costs; QA data collected by contractor	Cost of software, minimal time required to extract reports, QA contract is \$220k/year
<a href="#">Delaware</a>	Manual observation/reporting	Performance metrics are included in normal reporting practices, so costs are deemed “not significant.”
<a href="#">Denmark</a>	Software that tracks spreader data and RWIS data.	Costs are included in operations.
<a href="#">Idaho</a>	RWIS instrumentation	“Approximately \$5,000 per year per [RWIS] site on maintenance, data collection and communication”
<a href="#">Iowa</a>	Manual observation/reporting; software computes averages and percentages automatically	Costs were involved in developing techniques, but are now included in normal personnel tasks and reporting practices, and so thus can be hard to quantify: “Some time was invested in creating the performance computation programs but are automatic now. Crews also must spend time after each storm to report these items at each garage.”
<a href="#">Kansas</a>	Road condition reporting system software	Cost would have occurred when software was developed. “No cost involved as it is part of our road condition reporting system and is being done anyway.”
<a href="#">Michigan</a>	Manual determination of end of storm; software (RITIS) computes speed data; customer surveys in rural regions	Cost of software; man hours used by personnel distributing and analyzing surveys
<a href="#">Middelfart Municipality, Denmark</a>	Software that tracks winter operations data, and instrumentation (SOBO-20) that measures salt on roadways	Municipality uses software owned by the Danish Road Directorate. Data is automatically tracked. Cost were not listed.
<a href="#">Missouri</a>	Manual entry of data into software	Primarily, the cost is included in “the time spent by the field maintenance employees entering their data into our ‘winter event database.’” After which analysis is automatic. Cost would have been associated with developing the software, too.

**Table B.3.1(b) Summary of Agencies Reporting Methods and Costs for Gathering and Analyzing Performance Measurement Data - Part 2**

<a href="#">New Hampshire</a>	RWIS instrumentation and other weather data; weekly salt reports	Response: “Took a couple of staff days to combine and QC the data for last winter.” Opportunity to reduce costs by automating part of the process using RWIS.
<a href="#">North Dakota</a>	Cost of operations <i>is</i> a performance metric. Software tracks material and equipment usage.	The costs would be that of the software; otherwise, the cost of measuring performance is not tracked.
<a href="#">Norway</a>	Friction, snow and ice thickness measurements and shift report.	No cost analyses
<a href="#">Ohio</a>	RWIS for weather data, INRIX for speed data	Costs are included in maintaining statewide RWIS and paying vendor (currently, INRIX) for speed data.
<a href="#">Ontario</a>	Manual reports for every highway segment at the end of each storm	Costs are “included in lump sum long-term Area Maintenance Contracts. Contract bids are not broken down by function in this manner.”
<a href="#">Oregon</a>	Manual observation/reporting	No additional cost since reporting is part of normal personnel tasks.
<a href="#">Sweden</a>	Weather station system	No cost analyses
<a href="#">Tennessee</a>	Manual observation of conditions; material usage reported manually	Costs are minimal, as reporting is part of personnel tasks.
<a href="#">Utah</a>	RWIS instrumentation and software	All RWIS were upgraded with instrumentation needed for performance-based index; development of algorithm has been done in-house (man hours); estimated total expenditure so far for new index: \$500k.
<a href="#">Vermont</a>	Current: manual reporting of material usage. Upcoming: AVL will track usage	“AVL costs are approximately \$1,500 per truck with a monthly fee of \$40 per truck. We have 250 trucks and 25 spares that do not have AVL currently.”
<a href="#">Washington</a>	Manual reporting	Costs included in personnel man hours and are thus considered insignificant. A new (and likely more expensive) way to track metrics is being investigated.
<a href="#">Wisconsin</a>	County departments submit weekly reports	Tabulation and calculation is automated; thus, other than implementation of the program, costs are currently negligible.

In summary,

- Most agencies report that tracking performance has become a routine part of their personnel's jobs, and so the cost is included in man hours.
- In some cases, reporting has become automatic (through instrumentation or software), and so the costs were realized initially when the technique was developed and implemented into the agency's technology.
- When AVL software is used for data collection, there is an initial installation cost per truck and there is often a recurring fee for running and communicating with the device.
- Those agencies which use RWIS data as part of their performance measurement include a portion of the costs of maintaining, collecting data from and communicating with the RWIS sites as part of the costs of performance measurement, whether or not the portion of RWIS function that is utilized for performance measurement explicitly constitutes a line item in the budget (versus being wrapped up into other maintenance-related functions of RWIS). One exception is when RWIS are updated specifically to obtain performance-related data (such as friction).
- For agencies that use maintenance contractors, the contractor is often required to report performance data as part of their contractual duties with no additional costs incurred by the agency. See Alberta and Ontario Ministries of Transportation and the Norwegian Public Roads Administration in Appendix for examples of performance-based contracts.

The table above does not specify the methods used for gathering data for traffic speed or friction metrics. For speed-based metrics, respondents report using instrumentation (in-pavement devices or radar-based sensors) or data from third-party companies. Automated road weather information system (RWIS) instrumentation was the predominant method for gathering friction data.

For both metrics (speeds and friction), partnership with traffic operations or weather operations (internal or external groups) was mentioned as an important aspect of acquiring each dataset.

#### **B.4 Performance Measurement by Geographic Region**

This section provides a summary of the agency responses stratified by geographic regions. Overall, there is no significant trend from a geographic perspective on the best practices for performance measurement.

**Southern states (AZ, TX, TN, VA, MD):** Texas and Tennessee both use input-type metrics (material usage and level of effort). Texas only recently developed a statewide snow & ice plan. Maryland uses time to bare pavement. Arizona and Virginia do not use performance measurement.

**Northeast states (DE, CT, ME, MA, NH, NY, VT, PA, WV):** A wide variety of performance metrics are used, including: time to bare; cost/mile – labor, materials, equipment; friction/severity index; material usage. Massachusetts, Pennsylvania and West Virginia do not use performance measurement.

**Intermountain (WY, UT, ALB, NV, MT, ID, CO):** Time to passable roads, time to bare, level of effort, friction/severity index (Idaho; Colorado is in progress). Alberta & Nevada have none.

**Upper Midwest (SD, ONT, OH, ND, MN, MI, WI, Otter Tail Co, Farmington Hill):** Time to bare/wet, time to normal speeds or LOS condition, overall cost, frequency of meeting bare lane target, and customer satisfaction. Customer satisfaction seems to be more prevalent in the upper Midwest.

**Central Midwest (MO, NE, Omaha, KS, IA, West Des Moines, IL):** Time to bare or mostly clear, total cost, time to normal speed, percent of road segments of a particular class returned to normal within its specified time, measured grip/friction (WDM). Illinois has none.

**Pacific Northwest (WA, OR, CA, AK):** Washington is looking at speed recovery and friction. Oregon uses time to LOS, time at chain restrictions, and duration of road closures. Alaska uses time to LOS and cost per lane mile, as well as percent of system meeting LOS. Similar to Oregon and Alaska, California also uses time to LOS. LOS is different in each state.

**Europe (Denmark, Middelfart Municipality, Finland, Scotland, Slovenia, Norway, Oslo, Sweden):** Contractor-based performance (e.g., response time) in many European countries. Scotland is interested in using friction; Norway does use friction and time to LOS condition. Most countries use something like an acceptable amount of time to bare or acceptable thickness of ice or snow on the road surface. Slovenia and Finland do not officially track performance. Sweden measures the snow removal performance by the time to achieve bare pavement, which is determined by friction and amount of snow on the road.

## Appendix C: Individual Agency Responses

This appendix summarizes agency responses. Where applicable, subheadings include: LOS, Performance Measurement, Severity Index, Method & Cost, and Other Notes. The words “In Progress” were added when an agency indicated it was in the process of altering its methodology in some way.

### Alaska DOT&PF

#### *LOS*

Route priority is set by traffic volumes. Alaska state government’s funding is based on oil revenues. With oil prices down, the department may be forced to alter their LOS based on what they can afford to provide.

#### *Performance Measurement*

Alaska DOT & Public Facilities tracks (1) percent of system meeting LOS, (2) time to return to LOS, and (3) cost per lane mile.

#### *Method & Cost*

A Maintenance Management System tracks operations data to compute cost, and extracting a report from the system takes a matter of minutes. Quality assurance (QA) data are collected by a contractor at a cost of \$220,000 per year.

### Alberta MOT

#### *LOS*

From Alberta Transportation Highway Maintenance Guidelines and Level of Service Manual (2000, [http://www.transportation.alberta.ca/Content/docType34/Production/los\\_manual.pdf](http://www.transportation.alberta.ca/Content/docType34/Production/los_manual.pdf)). Following is a direct transcription from p8:

**Table C.1 – Winter Level of Service (Rural Highways)**

Class of Highway	Traffic Volume (AADT)	Maximum Reaction Time• (hrs)	Maximum Time to Good Winter Driving Conditions•• (hrs)	Typical reaction Time (hrs)
A	> 15,000	2	6	1
B	7,000 – 15,000	4	6	1
C	5,000 – 7,000	4	8	2
D	2,000 – 5,000	4	8	2
E	1,000 – 2,000	6	12	3
F	500 – 1,000	8	12	3
G	100 – 500	12	18	4
H	< 100	16	24	5

- Maximum time allowable for equipment to have commenced work from the time of a 3cm accumulation. This value represents the maximum time that will be required to respond after an average winter storm. Normally, equipment will begin work during most storm events and as a result most roads are cleared faster than the maximum time indicated.
- Good winter driving conditions exist when snow and ice have been removed from the driving lanes and excessive loose snow has been removed from the shoulders and centerline of highway. Short sections of ice and packed snow are acceptable and can be expected within the driving lanes between the wheel paths, as well as on centerline.

An average winter snowstorm is defined as one in which snowfall amounts range between 3 and 8 centimeters, the air temperature is lower than -10°C, the wind velocity is less than 15 kilometers per hour and the road surface is frozen. EXEMPTIONS TO THE ABOVE TABLE - Predefined “hotspots” will require a quicker response time. Hotspots are locations that have been identified as special feature areas within the maintenance contract.

#### *Performance Measurement*

*In progress:* While Alberta Transportation does not currently have a performance metric, they are working on developing one “doing trials with pavement friction (mobile road condition sensors) and have tried remote cell probe data for traffic speed monitoring on a network level, but don't have firm enough results to propose a metric” (quote from survey response). “We're starting our 2nd winter of trials on Luft and Vaisala mobile pavement condition sensors; early results are that we can set a reasonable 'grip number' that both machines give for ‘chemical wet’ conditions as a winter performance goal.”

#### *Severity Index*

*In progress:* From survey response: “We have just introduced a WSI (pilot projects in 2013/14 and 2014/15), and haven't incorporated it into our performance monitoring yet.”

### **Arizona DOT**

#### *LOS*

LOS is based on maintaining safe and passable roadways and on traffic volumes. Performance is not measured, but AZDOT does have “a great deal of interest” in doing so. AZDOT reports using mobile technologies for greater accuracy regarding application and measurement of chemicals.

### **Care Enterprises (Private)**

This company works for several small property management firms in semi-rural Colorado, and predominantly maintains parking lots. LOS is based on cleanliness of parking lot when business opens. They measure performance in the following manner (from their survey response): “Performance metric 1: Did we meet our LOS this storm? Metric 2: Did we hear anything from the customer—positive or negative? Metric 3: Did we do it at or close to our allocated cost for the job?”

## **California DOT**

### *LOS*

California Department of Transportation (Caltrans) sets service levels based on traffic volume. Their stated LOS goals are to meet political and/or customer expectations and to maintain roads as safe and passable throughout a storm. As stated in the District 3 Snow Removal Operations Plan (2009/10, <http://www.dot.ca.gov/dist3/departments/mtce/documents/SnowRemovalOps.pdf>), Caltrans' goal is to "keep the motoring public moving through the snow areas limiting the necessity of tire chains or excessive delays, while...maintaining the safety of our employees and customers."

### *Performance Measurement*

Caltrans measures time to achieve established LOS after a storm. For example, total hours of chains versus non-chain, total hours of road closure, and total hours trucks held. No further responses provided.

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## **City of Farmington Hills, Michigan**

### *LOS*

From survey response: "City of Farmington Hills has a policy to keep all Major Routes open, including Bus Routes as manpower is present. The goal for the abovementioned is achieved mostly from 4am thru 11pm on most events."

### *Performance Measurement*

Farmington Hills evaluates how the next storm will impact their area, so they can better budget resource usage for current tasks. (Note: This is not a performance tracking technique, per se, but it does help them to ensure improved performance and optimized efficiency.) In addition, Farmington Hills uses mobile tablets to track events.

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## **City of Omaha**

### *LOS*

From survey response: "Arterial and collector streets return to normal speeds within 24 hours of the onset of accumulation." This is measured through manual observation. Performance is not otherwise formally tracked, though vehicle-based GPS has allowed for tracking individual plow operator performance.

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## **City of Oslo**

### *LOS*

The City of Oslo, Norway's Agency for Urban Environment is responsible for maintenance within the city. The LOS goals are to meet political and/or customer expectations and to maintain safe, passable roads throughout a storm.

LOS is also set using the following priority levels:

1. Primary roads with streetcars
2. Other primary roads
3. Residential roads where there are service routes of buses or where there are steep slopes
4. Other residential roads
5. Parking spaces

Each priority level has a set time when plowing must start.

#### *Performance Measurement*

Performance is measured by completeness of plowing (i.e., percentage of the road on which plowing has occurred) at the specified time.

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### **City of West Des Moines**

#### *LOS*

Meet political and/or customer expectations, maintain roads as safe and passable throughout a storm, set service based on traffic volumes.

#### *Performance Measurement*

Time to achieve established LOS following a storm and measured grip or friction levels.

No further responses provided.

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### **Colorado DOT**

#### *LOS*

Provide bare pavement as soon as possible.

#### *Performance Measurement*

Time to achieve established LOS.

*In Progress:* Colorado DOT is working to develop a measure based on friction, as well as a storm severity index and winter performance index. *Method:* “Currently, data is collected through maintenance work orders. We are deploying additional friction sensors statewide on our 108 RWIS stations. Also, working on developing mobile sensors on snowplows with weather cloud.”

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### **Connecticut DOT**

#### *LOS*

LOS based on providing bare pavement as soon as possible, and maintaining roads as safe and passable throughout a storm.

The survey response details LOS goals per roadway class (“...” added to decrease text):

- Class 1 – Limited Access Highways – Includes interstates, parkways and expressways with corresponding ramps. ...Multi-truck echelon plowing and material applications; applications are made as necessary for reasonably safe travel and prior to rush hour periods. ...Desired cycle time of two hours with a goal to have lanes cleared to bare and wet pavement within four hours following a winter event.
- Class 2 – Primary Routes – Includes major and minor collector highways. ...Two-truck echelons; application on centerline with one-wheel path of traction in either direction; lanes scraped down to near bare pavement; ...desired cycle time three hours with a goal to have lanes cleared to bare and wet pavement 4-6 hours after a winter event.
- Class 3 – Secondary / Miscellaneous Routes – Includes low-volume, state-maintained roadways. ...One assigned plow; application on centerline as needed; ...cycle time may exceed three hours; goal is to have the lanes cleared to bare and wet pavement within six hours following a winter weather event.

#### *Performance Measurement*

Time to achieve established LOS following a storm, and time to recover normal traffic speed.

*In Progress:* Connecticut DOT is working on developing/updating their performance metrics. They are “evaluating AVL/GPS technologies to enhance [the] ability to track and measure performance.”

#### *Winter Severity Index*

*In Progress:* Connecticut DOT has plans to develop a winter severity index in the future.

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### **Delaware DOT**

#### *LOS*

Provide bare pavement as soon as possible, meet political and/or customer expectations, maintain roads as safe and passable throughout a storm, and set service based on traffic volumes.

#### *Performance Measurement*

Time to achieve LOS. Pilot programs are evaluating the use of AVL to better monitor field operations.

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### **Danish Road Directorate**

#### *LOS*

Denmark’s Road Directorate requires contractors to provide bare pavement as soon as possible and to maintain roads as safe and passable throughout a storm.

#### *Performance Measurement*

They measure time to achieve established LOS and time to recover normal traffic speeds.

### *Severity Index*

A salt index is used to define the severity of a winter related to winter maintenance. It is formulated in the following manner:

$$V_i = \text{SUM}(1 \text{ October}-1 \text{ May}) V_{\text{day}}, \text{ where } V_{\text{day}} = a \cdot (10b + 0.1c + 7f + 18g) + 0.3a$$

- a: Days with road temperature below  $+0.5 \text{ C}^\circ$
- b: Number of times the road temperature is below  $0 \text{ C}^\circ$  while the road temperature is below the dewpoint temperature for a minimum period of 3 hours and with an interval of at least 12 hours
- c: Number of times the road temperature drops below  $0 \text{ C}^\circ$  of at least  $+0.5 \text{ C}^\circ$  to  $-0.5 \text{ C}^\circ$
- f: If within a day measured precipitation falls while temperatures are below the freezing point for the minimum following times: 30 minutes,  $f = 1$ ; 90 min,  $f = 3$ ; 270 min,  $f = 9$ ; 420 min,  $f = 12$
- g: When the road temperature falls below the freezing point and there has been precipitation over the past 3 hours (according to at least three logs),  $g = 1$ .

### *Method & Cost*

Most spreaders are equipped with GPS and data collection. Speed, dosage, spreading width, etc. are gathered by software and analyzed. Cost included equipment and installation, broken down by route. The Road Directorate already had the software in place for operational purposes.

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## **Denmark AIBAN Vinterservice**

### *LOS*

Provide bare pavement as soon as possible and to maintain roads as safe and passable throughout a storm.

### *Performance Measurement*

Time to achieve established LOS following a storm.

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## **Finnish Road Administration**

### *LOS*

LOS priority is set based on traffic volumes, importance of route, and geometry of route (for example, a dangerous curve requiring more attention in winter). Customer needs are a significant part of service levels. The Finnish Road Authority sets LOS goals to maintain safe and passable routes throughout the winter. Achieving bare pavement is not a specific goal. Rather, within cost restraints, service levels for higher priority routes are to maintain “moderate winter road conditions,” allowing for reasonable slipperiness, and asking road users to drive more carefully and prepare for delays. Service levels for lower priority routes are to maintain “tolerable winter conditions,” allowing for passable roads and even greater delays. These LOSs are to be reached, while striving to lessen environmental impact and reduce abrupt boundaries in road condition between jurisdictions.

### *Performance Measurement*

According to survey response, performance is not officially tracked; however, "winter road maintenance is successful when the actual quality corresponds to the ordered quality. This requires a sufficiently efficient and well-designed quality assurance system." Still, maintenance costs are tracked for budgetary purposes, and are compared year to year, weighted by a winter severity index.

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### **Hy-tech Property Services**

(The client(s) of this company is/are unknown.) Their LOS is to provide bare pavement as soon as possible, and their performance metric is time to achieve LOS.

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### **Idaho Transportation Department**

#### *LOS*

LOS is based on a **Storm Index**. Direct quote from survey response:

- The map identifies levels of winter maintenance service for those routes on the State Highway System not covered by a separate local maintenance agreement. These standards represent the minimum travel conditions when general area-wide weather events are of such duration and intensity as to demand full deployment of Department resources.
- **Storm Index is calculated as ice duration per unit of storm severity. It is not the intent of this policy to provide bare roads during winter travel.**
- **INTERSTATE AND STATEWIDE CORRIDORS:** During the storm event: Remove snow and ice continually to keep primary lanes open to traffic; providing a reasonable surface on which to operate. Deploy maintenance forces in an effort to **achieve a Storm Index of 0.25**. Following the storm event: Remaining lanes and shoulders will be cleared during regularly scheduled work shifts.
- **REGIONAL CORRIDORS:** During the storm event: Remove snow and ice during regularly scheduled work shifts to keep roads open to traffic. The primary goal will be to treat snow or ice covered areas on steep grades, sharp curves, bridge decks, intersections, known high accident locations, etc. Deploy maintenance forces in an effort to **achieve a Storm Index of 0.45**. Following the storm event: Snowpack need not be removed until thawing conditions exist, or the pack becomes so thick as to constitute a traffic hazard. Remove the pack and clear the road surface during regularly scheduled working hours.
- **DISTRICT CORRIDORS:** During the storm event: The primary goal will be to provide a passable roadway. Otherwise, resources should be directed to Statewide and Regional corridors. Following the storm event: When resources are not committed to Statewide and Regional corridors, remove excess snow and ice from the road surface during regular working hours. These routes may be posted to indicate limited maintenance, and they may be closed for extended periods of time.

*Performance Measurement*

Two performance metrics: **storm index** (ice duration in relation to storm severity) and **mobility index** (measures ice reduction/elimination when water is present and pavement temperature is below freezing).

From Literature Review: A **winter performance index** (WPI) is also calculated. It rates treatment effectiveness (relative to storm severity) as recovery to safe grip. For more detail on each of these indices, see Method & Cost subsection below.

*Severity Index*

From survey response: “We evaluate wind speed, precipitation amount and surface temperature to derive an index number that describes the storm severity.”

*Method & Cost*

From survey response: All data is gathered via our Road Weather Information System (RWIS) consisting of Vaisala non-invasive and atmospheric sensors. We spend approximately \$5,000/year/site on maintenance, data collection and communication.” From Literature Review: ITD developed a winter performance index (WPI) that measures the duration of ice per unit of storm severity (Jensen and Bala, 2012; Spoor, 2013). First, storm severity is calculated using wind speed, surface precipitation accumulation and road surface temperature—data that are gathered from RWIS-ESS located throughout Idaho. **Ice duration** is defined as “the amount of time grip, or friction, falls below 0.6 (on a scale of 0 to 1, with 1 being optimal friction)” (Jensen and Bala, 2012). The WPI is calculated real-time and then provided to maintenance managers to allow for storm response assessment immediately following events. The authors stated that “this metric allows for accurate evaluation of different treatment strategies and maintenance operations” (Jensen and Bala, 2012). The figure below shows the WPI legend. Note that the lower the index value, the more effective the treatment. The goal for this metric is a WPI rating of 0.25 for interstates and 0.45 for regional routes.

0.00	Successfully Treated
0.00-0.30	Significantly Accelerated Grip Recovery
0.31-0.49	Some Success at Grip Recovery
0.50-0.69	Very Little Success at Deicing
0.70+	Limited Maintenance or No Deicer Success
	Observation Data Missing or Temp. Below Threshold.

**Idaho Transportation Department’s WPI Legend (Source: Spoor, 2013)**

Jensen and Bala (2012) and Spoor (2013) also discuss the Winter Mobility Index (WMI), which is derived using the percentage of time road conditions do not impede mobility during a storm (i.e., time during which the grip value is above 0.60). Since development of these measures, winter storm mobility in each Idaho district has improved. With the data available, ITD was able to match the treatment to the event. This led to the creation of a dashboard for winter storm mobility by

district, which shows the percent of time mobility was not significantly impeded during winter storms.

#### *Other Notes*

Idaho evaluated its performance measurement technique and found that “since implementation approximately 4 years ago, performance has improved almost 300% while costs have declined approximately 30%.” ITD also reports revising their metrics and LOS on an annual basis. *In Progress*: “We are currently engaged in equipping all snowplow trucks with AVL/MDC in an effort to better understand the efforts related to the outcomes that derive the metrics. We anticipate as we have better data in regard to effort, we will see additional efficiencies in regard to cost reduction.”

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### **Illinois DOT**

#### *LOS*

LOS based on **traffic volume**. From survey response:

- 3,000 < ADT, Attain CODE 3 immediately, CODE 1 as soon as possible.
- 1,000 < ADT < 3,000, Attain CODE 6 immediately, CODE 1 as soon as possible.
- ADT < 1,000, Attain CODE 6 immediately, CODE 4 as soon as possible, CODE 1 after all other higher ADT roads are at CODE 1.

#### *Performance Measurement*

None.

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### **Iowa DOT**

#### *LOS*

LOS is based on 3-tier classification of road type. From survey response:

- A= interstates. Must be returned to normal road condition within 24 hours after end of storm
- B = multi-lane highways and major 2-lanes. Must be returned to normal road condition within 24 hours after end of storm
- C = low volume 2-lane highways. Must have one bare wheel-track within 24 hours after end of storm and returned to normal within 3 days following a storm

#### *Performance Measurement*

Survey response: “‘*Official*’ performance metric is **percentage of road segments of a particular class returned to normal within its specified time**. Must be 99% for A and B roads, and 98% for C roads” (see LOS designations above). “‘*Unofficial*’ performance metric is **average time to normal following a storm and average time to normal after crew deployment** -- both for a particular road class within a particular area.”

*In Progress*: Iowa DOT is also “*working on a traffic-speed based performance metric* -- Average time below expected speed, Average speed reduction from expected, and % of time below posted speed limit. *None in operational mode yet.*”

## *Severity Index*

Iowa DOT has 4 severity indices (from personal communication with T. Greenfield, August 2016):

1. The “General Winter Index” has been in use for about 11 years. It is calculated using weather information reported in the crew records—duration and frequency of events, the type of events, and the worst case pavement temperature and wind speed during those events. It started as a year-end metric for every garage location, and reported to the field along with their other LEM totals. It was a way for the DOT to help answer some of the ‘yeah-but...’ statements regarding why some used more labor-equipment-materials (LEM) dollars and others used less. However, since the value was calculated at the end of the season—a time they cannot do much with the results since the season is over—the district managers would have to remember to watch any outliers through the next winter. The DOT also used the index for some early studies of salt use trends across the state.

A few years ago, the DOT started reporting the index as a year-to-date vs. statewide average on their public performance page to help create some context regarding their use and performance ([http://www.iowadot.gov/performance/winter\\_operations.html](http://www.iowadot.gov/performance/winter_operations.html)). This page is updated monthly.

2. The “Salt Use Index” was created in 2011 for estimating a location’s salt use based on weather. One of the problems with the old general index was that while it followed salt, it didn’t do as well in some scenarios. For example, a bad blizzard could close roads and keep the DOT plowing for days—rightly ranking high on the general index—but in reality, should be a relatively low salt user because it was too cold and windy. For this very specific purpose of salt, the DOT codified their existing Salt Use Chart, which is a longstanding policy and guidance document that the field had been trained to. It is designed to be kept in the plow’s visor for easy reference. The chart links precipitation type and intensity with pavement temperature.

This is very much an index although most people don’t think of it as such. It works well, because, if one knows a bit about a garage’s miles, one can create an estimated tonnage. This is exactly how it is used. It is the driver for the Salt Dashboard that started in FY12.

The Salt Dashboard updates daily on information from the day before. It uses RWIS for pavement temperature and the crew reports for precipitation start, end, and type. It analyzes the storm type and temperature information on a 10-minute cycle, and has a few additional logic portions to handle cleanup and off-the-chart events like blowing snow. As such, there is no one formula; it is governed by a set of logic loops to decide how much salt to give for a certain 10-minute period. Those periods are added up for daily totals, which can be further summarized as necessary.

This is a heavily used index/program and does modify salting decisions. Since it is linked to the garages’ miles and LOS information, it also can account for variations there (which can be bigger than weather-related differences) and allows for easy cross-garage comparisons of salt use. This index can explain about 80% of the variation between

garages' average yearly salt use. Since it updates daily, course corrections are possible if one sees oneself going into the red.

3. The "Hour Use Index" was also created in 2011 for the same reason as the salt index. It is much simpler, however, since crew hours are less related to temperature or storm type as they are related to the duration of storms (except for blowing snow, which is always an outlier). All the data are reported by the crews regarding storm start, end, and type.
4. The "Traffic Index" was developed to estimate traffic speeds for the purpose of performance measurement, but Iowa DOT is working on getting it into operation (and out of the experimental phase). It links weather data from RWIS and crew reports to traffic speeds. It is described here: <http://onlinepubs.trb.org/onlinepubs/circulars/ec162.pdf#page=199>. (See page 187)

#### *Method & Cost*

Survey response: "Storm start and stop time, storm type, and time to normal and time to wheel path are required reporting items for maintenance crews. Time to normal is based on a visual indication by the crew. Computer reports/programs compute the time-after-precip averages and percentages automatically."

Costs are "hard to quantify. Some time was invested in creating the performance computation programs but are automatic now. Crews also must spend time after each storm to report these items at each garage."

In summary, Iowa's costs were mainly expended when techniques and software were developed. Now data collection is automatic and routine, so costs are wrapped into normal tasks and personnel practices.

#### *Other Notes*

*In Progress:* Iowa DOT is working on adding traffic-based metrics and is investigating changes to their LOS Guidelines. New technology better enabling traffic measurement (sensors and Inrix data) has become more available. They report that "unofficial" performance goals balance public complaints, mobility, and safety, in the context of available resources.

The following statements, from communication with T. Greenfield (August 2016), address how performance measurement results have been used or made an impact to maintenance operations:

The salt dashboard is viewed regularly by the field, and personnel will do their best to stay within range while still keeping their expected service. This has led to measureable changes in Iowa DOT's statewide use over the years. However, it is viewed more as a resource management tool than a performance measurement tool.

Otherwise, the public site link above is where the performance metrics end up. Some managers may look at it, but the main driver is likely their own feel for the expectations and how well they think they are being met.

Something that is not a ‘performance measurement system’ by design but may kind of be one is our 511 road condition reports. This is a during-storm update for travelers, but most garages hate to be the last one with not-normal conditions, or worse conditions than their neighbors. This web map probably gets a lot of people thinking about their effectiveness even though that is not its intention.

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## **Kansas DOT**

### *LOS*

LOS is based on **traffic volume** classification:

- Routes > 3000 AADT: All lanes will have bare/wet wheel paths with intermittent bare pavement
- Routes 1000 - 3000 AADT: All lane will have intermittent bare/wet wheel paths
- Routes < 1000 AADT: One-wheel path in each lane will have intermittent bare/wet wheel paths

### *Performance Measurement*

**Time to achieve established LOS** (see above for LOS designations) was used before, but no longer used. Currently using **Length of time that road meets LOS** and **Length of event** from time road drops below normal till when it returns to normal.

### *Severity Index*

Kansas DOT does have a severity index, but it does not consider wind, and so the respondent noted they are looking into a better one.

### *Other Notes*

Kansas DOT performed an evaluation of their measurement methods and found they were not a good reflection of performance. They are looking for new measures to use.

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## **Maine DOT**

### *LOS*

LOS is based on classifying roads and measuring their **average speeds** and/or cycle times. From survey response:

- P1: Interstate. South of Exit 197 both travel and passing lanes and north of Exit 197 the travel lane will normally be clear within 3 daylight hours after a storm. Maximum recommended travel speeds during a storm will normally be 45 mph but may be less during extraordinary events.
- P1: Non-Interstate. Travel lanes will normally be clear within 3 daylight hours after the storm. Maximum recommended travel speeds will be 40 mph during a normal storm, may be less during extraordinary events.
- P2: Travel lanes will be clear within 8 daylight hours after the storm. Maximum recommended travel speeds will be 35-40 mph during a normal storm, may be less during extraordinary events.

- P3: Travel lanes will be clear within 24 hours after the storm. Maximum recommended travel speeds will be 35-40 mph during a normal storm, may be less during extraordinary events.
- P4 & P5: Travel lanes will be clear within 30 hours after the storm. Maximum recommended travel speeds will be 35 mph during a normal storm, may be less during extraordinary events.

#### *Performance Measurement*

Maine tracks “**cost per mile of each crew**, broken down by materials, labor and equipment, **against the number of storms incurred**” (from survey response). *In Progress*: Maine is investigating “how to track and measure the **length of speed reduction** during and following storms on any corridors that generate enough traffic to support that type of measure.”

#### *Severity Index*

Maine DOT currently relates winters to a **storm count**, but does not calculate an index based on weather elements (due to lack of weather stations). *In Progress*: Respondent intends to look into the Aurora WSI calculator to see if it would be useful in Maine.

#### *Other Notes*

When Maine DOT evaluated their performance measures, they implemented priority corridors and adapted LOS standards to them. The evaluation sought to balance cost, environmental impacts, and customer expectations for mobility. A note on using innovative technology: more available traffic speed data and grip measurement has made metrics based on these data more accessible. However, as with all measurement systems, there are challenges and costs to implementing each. Also, GPS tracking of plow trucks is being done, but it does not currently relate to a performance metric.

### **Maryland SHA**

#### *LOS*

From survey response: “**Time to bare pavement** measure of 4 hours from the end of precipitation. This is on our primary roadways and bare pavement is defined as **no remaining snow or ice in any portion** of the traveled roadway.”

#### *Performance Measurement*

Metric is **time to LOS** (bare pavement).

### **Massachusetts DOT**

#### *LOS*

From survey response: “**Pavement surface free of snow and ice from shoulder to shoulder** for major interstates as soon as possible. The secondary highways clean shoulder to shoulder after the interstates.”

### *Performance Measurement*

In Progress: Massachusetts DOT is working toward establishing metrics now.

### *Severity Index*

Massachusetts DOT uses an index that compares year to year and area to area.

### *Other Notes*

In Progress: “We are moving forward with an expansion of a ‘drive by download system’ for salt spreaders. The program will expand across the state as improved technology becomes available.”

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## **Michigan DOT**

### *LOS*

Michigan DOT’s Winter Maintenance Guidelines designate corridor priority based on traffic volumes and other considerations, such as tourism routes, border crossings, commercial traffic, the location of intermodal hubs (e.g., airports or carpool lots), etc. Two priority levels exist (paraphrased from 2009 Winter Operations Guidelines):

- Priority 1: Orange Route. Goal is to **provide bare pavement** across entire width, using overtime until goal is met.
- Priority 2: Blue Routes. Goal is to **provide one bare wheel track**, using overtime until goal is met. Full-width bare pavement is to be attained without using overtime.

### *Performance Measurement*

Each region in Michigan measures performance. **Time to regain normal speeds** is used in the more populated regions, and **customer surveys** are used to measure performance in the more rural regions. The objective of the former is to regain normal speed within 2 hours after the end of a storm.

*In Progress:* An interview with Justin Droste (MDOT) revealed that their maintenance division is switching to performance-based maintenance, in which outcomes are tracked rather than time and materials. This has not yet been specifically or formally applied to winter maintenance, but Mr. Droste believes it is going in that direction.

### *Severity Index*

*In Progress:* MDOT is in the beginning stages of using a severity index, but it is not yet tied to performance metrics.

### *Method & Cost*

In order to calculate time from end of storm to normal traffic speeds, MDOT maintenance personnel determine time that the end of the storm occurred, and RITIS software determines the time at which traffic returned to normal speeds. There are a few rules by which the metric is determined:

- If another storm begins within 2 hours, the events are combined.
- Traffic data is based on 10-minute average data from RITIS.

- If the segment consists of several TMC's, the average speed and average historical speed is calculated.
- Whenever the average speed rises to within 5 mph of average historical speed for at least one hour, normal operations have been regained.

The methods used by personnel to determine end-of-storm time are not specified. The above method occurs in the more populated regions of Michigan. The more rural regions distribute customer satisfaction surveys, by which they measure performance. The costs of these methods are for the software and for the man hours used to distribute and analyze the surveys.

## **Middelfart Municipality, Denmark**

### *LOS*

LOS is based on providing bare pavement and maintaining safe, passable roadways. From survey response: “Middelfart Municipality LOS criteria for 110 km of highways is **never slippery roads from ice**. Snow will be removed continually during storm event and before the storm and during the storm there will be salting with brine every 6 hours.”

### *Performance Measurement*

Metric is **time to LOS** (bare pavement). According to their calculations for severity index, Middelfart also tracks **salt usage**, **snow plow hours** and **traffic accidents** during slippery conditions. See below.

### *Severity Index*

Rather than calculating a storm or winter severity index based on weather and pavement conditions, AIBAN Vinterservice reports that for Middelfart Municipality, they track salt usage (ton/km), snow plow hours (per every 50 km) and traffic accidents with slippery roads (per every 100 km). “The index has been used to compare with different routes and winter strategies in another agency” (from survey response).

### *Method & Cost*

Software called Vinterman tracks all operations during winter. (Vinterman is an IT system that supports winter operations. It manages data for contractors, schedules, and routes and documents all activities and statistics. It sends data to vintertrafic.dk, which is a sort of traveler information website for the Danish Road Directorate—Vejdirektoratet. Vinterman is owned by Vejdirektoratet, and is used by Denmark's municipalities.) The municipalities participate in a Vinterman working group, but it is unclear what other costs would be associated with the usage of the software.

Respondent did note that the data gathering system is not perfect, and sometimes data is missing. The SOBO-20 instrument is used to detect salt concentration on the road surface. It helps to determine whether there is enough residual salt to warrant not salting prior to an event. It is not used to measure performance.

## Minnesota DOT

### LOS

Provide “bare pavement” conditions as soon as possible, meet political and/or customer expectations, maintain roads as safe and passable throughout a storm, and set service based on traffic volumes.

### Performance Measurement

From survey response:

- MnDOT developed its current snow and ice removal performance measure/operational guidelines through **customer satisfaction surveys**. Two factors included in the survey were level of importance of snow and ice removal and level of satisfaction with MnDOT's current operational guidelines.
- Our roadways are classified into 5 route classifications based on AADT [(i.e., **traffic volumes**)] and a **bare lane regain time** has been established for each. Our official performance measure is the "**frequency of meeting bare lane target**" or the percentage of events within the target range set for each maintenance route by designated classification. Target range is set between 55 - 70 percent.

From literature review, MnDOT's ADT categories and associated target regain times are (Niemi, 2006):

Roadway Classification	ADT	Regain Time (Hours)
Super Commuter	>30,000	1 - 3
Urban Commuter	>10,100	2 - 5
Rural Commuter	>2,000	4 - 9
Primary	>800	6 - 12
Secondary	<800	9 - 36

Survey respondent noted that super commuter route target was changed to 0-3 hours shortly after the publication of Niemi, 2006.

### Severity Index

Winter index is used to compare severity in each districts. From survey response: “We have recently created a winter response index (WRI) which incorporates additional weather variables and can be used to see how we responded to a winter event. Our goal is to be able to compare how we responded and analyze this against how MDSS recommended we respond. There are many more uses for the WRI.”

### Other Notes

MnDOT trains its plow operators yearly, including bare lane training, which aids in tracking performance. MnDOT is a significant user of MDSS. “We have developed extensive reports [using MDSS] to assist with tracking and measuring performance.”

*In Progress:* “There is also research being studied by UMD to look at a traffic speed correlation with our existing performance measure.”

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## Missouri DOT

### *LOS*

LOS based on providing “mostly clear” rather than “bare” pavement. From survey response:

- Continuous Operations Routes: These routes include all major highways, minor highways with 2,500 AADT or greater **traffic volumes** and other urban and community routes designated by the district in consultation with the Maintenance Division. This also includes all designated incident bypass routes.
- The objective is to have all lanes on these routes restored to a **near normal condition** as soon as practical after the end of the storm. To achieve this objective, plowing and/or application of snow and ice control treatments on an as needed basis on these designated routes, 24 hours per day throughout the storm, will be necessary. Interstates and other higher AADT routes will be plowed and treated first. The use of anti-icing methods is appropriate for continuous operations routes.
- Non-Continuous Operations Routes: All other state highways not included in the Continuous Operations Routes.
- The objective is to have these routes open to two-way traffic and treated with salt and/or abrasives on hills, curves, intersections and other areas as needed. It is allowable for these routes to be plowed and the surface remain partly covered or covered when snow and ice operations are suspended. 24-hour per day coverage may be appropriate until the objective has been met. These routes should be prioritized by traffic volume. Reasonable efforts will be made to ensure that all roads have received some level of attention prior to morning and evening rush hours.

### *Performance Measurement*

Performance metric is the **average time (in hours) to meet LOS**, described above. **Total cost of winter operations** and **fleet incidents** during winter operations are also tracked.

### *Severity Index*

In Progress: Missouri is exploring a severity index.

### *Other Notes*

“In 2010 we adjusted our LOS objective on our continuous operations routes to be mostly clear or near normal rather than clear. We have also twice since 2010, reviewed practice and emphasized meeting LOS objectives on non-continuous operations routes instead of exceeding these objectives.” Annual customer survey includes a question about snow removal. 80% of respondents are satisfied or very satisfied with snow removal efforts.

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## Montana DT

### *LOS*

From survey response (“...” added to decrease text; see spreadsheet for full text response): The objective of the Winter Maintenance Guidelines is to provide a uniform service between maintenance areas and better allocation of resources. Six levels of service have been established. Factors considered when establishing the level of service for a specific route were as follows:

- Safety
- Average Daily Traffic (ADT)
- Commuter routes
- School bus routes
- Availability of alternate routes
- Public interest and concern
- Potential economic impact
- Consequence of not providing higher level of service
- Available resources.

Note: If the Area Maintenance Bureau Chief and/or District Administrator has justification why a roadway should receive a different level of service from the guidelines indicate, a letter of justification will be sent to the Area Maintenance Bureau Chief if the change could result in a budget overrun. An example would be a high-volume route or frontage road like in the Billings or Missoula areas.

Plowing, sanding and chemical anti-icing and de-icing will be accomplished as follows:

- Level I (Urban): All MDT-maintained roadways generally within or adjacent to a 3 mile radius to towns or cities with an **average daily traffic (ADT)** greater than 5000 per day. Snow plowing and anti-icing/de-icing operations may be continuous throughout the storm. ... The **primary objective will be to keep at least one travel lane in each direction open** to traffic and to **provide intermittently bare pavement as soon as possible**. ...
- Level I-A: All interstate and other MDT-maintained roadways with **ADT** of greater than 3000 vehicles per day. Snow plowing and sanding/de-icing operations may be continuous throughout the storm. These routes are eligible to receive up to 19 hours per day coverage...at the discretion of the Area Maintenance Chief. The primary objective is to **keep the roadway open to traffic** and provide an **intermittent bare pavement surface in the main driving lane as soon as possible**. ...
- Level III: All MDT-maintained roadway with an **ADT** of 200-1000 vehicles per day. When staffing and equipment is available, snow plowing and sanding operations will typically be conducted during the storm to keep the driving lane passable. These routes are eligible to receive up to 15 hours per day coverage...at the discretion of the Area Maintenance Chief. ... **Snow packed and/or icy surfaces are acceptable** for Level III roadways. ...
- Level IV: All MDT-maintained roadways with **ADT** of less than 200 vehicles per day. When staffing and equipment is not being used to clear other roadways, snow removal operations may be conducted. Winter maintenance activities will be accomplished during regularly scheduled working hours. **These roadways may be closed for an extended period of time until resources are available to plow the traveled way**. ...
- Level V: Seasonal Roadways. These roadways will receive no scheduled winter maintenance activities. These will generally be roadways that are of a seasonal nature or designated a non-maintained route. These routes should be posted to indicate no winter maintenance.



### *Performance Measurement*

Montana Department of Transportation “only measures **level of effort** at this point” (from survey response).

### *Other Notes*

Notes on legislative influences: Legislature has pushed MDT to reduce chloride usage. Current LOS was considered too high in many places around the state.

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## **Nebraska DOR**

### *LOS*

Nebraska Department of Roads is “in the process of finalizing our LOS for winter operations” (from survey response). Currently, they endeavor to maintain safe, passable roadways throughout a storm.

### *Performance Measurement*

Nebraska DOR tracks **time to return to safe operating speed** once the storm has moved out of designated areas.

### *Method & Cost*

First, event timeline is identified “by a collaboration between local weather outlets and NDOR staff.” Then, NDOR's Traffic Division staff “determine the average speed during a specified timeframe during the event.” Time is tracked from the end of the event until an analysis of speed data shows a particular segment returned to a safe operating speed (i.e., 65 mph on interstates). The practice is currently too new to know its cost.

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## **Nevada DOT**

### *LOS*

LOS based on traffic volumes, providing bare pavement, meeting political expectations, and maintaining safe and passable roads. Survey response (“...” added to decrease text):

- LEVEL OF SERVICE A: Snow will be removed continuously, and anti-icing and de-icing techniques and abrasive mixtures will be used as needed during the storm event to keep the roads open for traffic and provide a good surface on which to operate. ...
- LEVEL OF SERVICE B: This level is the same as Level A except when personnel and equipment are not sufficient to maintain Level A service for both Level A and B routes, and then Level A routes will take precedence. ...
- LEVEL OF SERVICE C: Snow should be removed during the storm to keep roads open for traffic. Snow pack left by truck plows will be removed as soon as conditions (e.g., weather and workload) permit. ...
- LEVEL OF SERVICE D: Snow should be removed only during scheduled shifts except some routes may be plowed on overtime when the District Engineer determines there is sufficient reason for plowing. ...
- LEVEL OF SERVICE E: These routes are allowed to close during the winter...

*Performance Measurement*

*In Progress:* Performance metrics are currently being investigated.

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**New Hampshire DOT**

*LOS*

LOS based on providing bare pavement and maintaining safe, passable roadways. This is accomplished by measuring grip and calculating a weather severity index. (See performance metrics for New Hampshire in next section.)

*Performance Measurement*

Performance metrics are based on **maintaining friction** and **weather severity**. For interstates, the goal is to maintain a grip of 0.60 for 50% of the storm duration, based on a weather severity of 30. The history behind this: “We for years reported on the time to bare lanes after a storm. Found we were far exceeding our required LOS however that was due to higher public expectations. We changed then to grip during a storm due to the public not willing to wait until the storm was complete to regain the roadway. This change has been in the last 2 years as more grip sensors have been deployed.”

*Severity Index*

From survey response: “We currently use the Vaisala WSI that is computed out of the Idaho work when we are looking at % time grip of >0.60 is achieved during the storm. The salt usage performance measure that we have compares against the WSI that was developed from the NCHRP H-350.”

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**New York State DOT**

*LOS:*

Provide bare pavement (goal within 2 hours after a storm), maintain roads as safe and passable throughout a storm, and set service based on traffic volumes. Performance metrics: Time to achieve established LOS following a storm. No further responses provided.

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**North Dakota DOT**

*LOS*

LOS classification is based on traffic volume. Goals are to meet political/customer expectations and maintain safe, passable roadways. The table below is from an NDDOT policy document (source: NDDOT; unknown document title). “Cleared” lanes mean “all plowable snow and ice is removed,” but “compacted snow or ice could still remain” (so not necessarily “bare” pavement).

Classification	Desired Recovery Time	Desired Pavement Condition	Desired Coverage	
			Days/Week	Hours/Day
Urban Areas Level 1	1 - 3 hrs.	All lanes/ramps interchanges cleared	7 days/week	18 hrs/day 4 am - 10 pm local time
Rural Interstate Level 2	2 - 6 hrs.	All lanes/ramps interchanges cleared	7 days/week	14 hrs/day 5 am - 7 pm local time
Interregional System Level 3	2 - 8 hrs.	All lanes cleared	7 days/week	14 hrs/day 5 am - 7 pm local time
State Corridor Level 4	3 - 10 hrs.	All lanes cleared	7 days/week	14 hrs/day 5 am - 7 pm local time
District Corridor Level 5	6 - 12 hrs.	All lanes cleared	7 days/week	10 hrs/day 7 am - 5 pm local time
District Collector Level 6	8 - 24 hrs.	All lanes cleared	7 days/week	10 hrs/day 7 am - 5 pm local time

*Performance Measurement*

From survey response: “Currently **overall cost** as well as **material usage verses MDSS recommended actions** have been put together for our districts. We have also used **customer satisfaction.**” *In Progress:* “A speed service indicator is being proposed.”

**Norwegian Public Roads Administration**

*LOS*

From the survey response: Service levels are set based on traffic volumes; goals are to meet political expectations and to maintain safe, passable roads throughout a storm. Bare pavement is either wet or dry, and compacted snow or ice between wheel tracks is acceptable during limited time periods.

As discussed in the Literature Review (Section A.5), Norway has classified its roads into winter maintenance-specific classes (A-E), and has set allowances for road conditions on each: from bare road surface (A) to compacted snow and ice, with friction down to 0.20 acceptable (E).

*Performance Measurement*

From the survey response: Norway measures time to established LOS, measured grip/friction, thickness of ice and max snow depth. The objectives for performance in each category vary per road class. As stated in PIARC, 2015, the data used for performance evaluation are **road condition, friction, thickness and unevenness of snow/ice, maximum time for snow removal, maximum time for de-icing, and time to approved road condition.** Examples of performance objectives for all classes can be found in PIARC, 2015.

### *Method & Cost*

Cycle time is found using AVL. Regain time is normally measured using RWIS instrumentation (T. Vaa, August 2016, personal communication).

The Norwegian Public Roads Administration uses contractors for maintenance work. From personal communication with T. Vaa (August 2016): “The contractor is expected to have a system with self-documentation. When it gets a discussion about if standards are met or not, the road owner normally will present data from [their] own observations. The documentation is often based on photos and a yardstick except for friction where we use approved measurement devices. The performance measures are laid down in the contract and [the contractors] are subject to sanctions if they are not met.

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## **Ohio DOT**

### *LOS*

LOS is based on a combination of weather and speed data (from RWIS and INRIX, respectively).

### *Performance Measurement*

At Ohio DOT, performance is graded using a program combining weather and traffic data (as mentioned above). The program is called SNIPE: SNow and Ice Performance Evaluator. The goal is to “return travel speeds to within 10 mph of the expected speed within 2 hours of a snow event on all priority routes,” and performance is measured by **the time it takes to achieve that goal**, which is ODOT’s LOS. Note that “expected” speed, not posted speed is the goal. A weather event is considered to have occurred only when speeds drop on a portion of roads. ODOT prioritized their speed-based outcome by considering what was most important for the motoring public (“Justifying winter ops spending,” *Public Works Magazine*, April 2014).

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## **Ontario MOT**

### *LOS*

LOS is based on providing bare pavement, and roads are prioritized by traffic volumes. See below.

### *Performance Measurement*

Time to achieve established LOS is MTO’s performance metric.

Contracted crews must meet “Bare Pavement Regain Time standards in at least 90% of the storms in each Contract Area” (from survey response). “The standard timeframe to restore bare pavement varies depending on winter traffic volume and highway type” (from “How We Measure Performance;” available: <http://www.mto.gov.on.ca/english/ontario-511/area-maintenance-contractors.shtml#measure>).

**Table C.2 The timeframe for each class of highway is:**

Class	Bare Pavement Standard
1	Bare pavement within eight hours of the end of a winter storm, e.g. Highway 401, Queen Elizabeth Way, Highway 11 four-lane sections
2	Bare pavement within 16 hours of the end of a winter storm, e.g. Highway 17, Trans-Canada Highway in Ontario
3	Bare pavement within 24 hours of the end of a winter storm, e.g. Highway 35
4	Centre bare pavement within 24 hours of the end of a winter storm; fully bare pavement when conditions permit, e.g. Highway 516. Centre bare means a 2.5m strip in the middle of the road.
5	Snow packed driving surface within 24 hours of the end of a winter storm. Excess snow is plowed off and sand is applied where required to improve friction.

*Severity Index*

In Progress: A severity index is in development.

*Method & Cost*

Method, from survey response:

The Bare Pavement Performance metrics are reported to the Ministry by the Area Maintenance Contractor for every highway reporting segment at the end of each winter storm. There are 20 separate Area Maintenance Contracts across the province and each one has many reporting segments covering each of the 5 Winter Highway Classes. Ministry staff audit a sample of the reports (and others provided by the Contractor) using defined procedures to ensure that the information provided is accurate. The standard requires that Bare Pavement Regain Time standards are met in at least 90% of the storms in each Contract Area.

Costs are “included in lump sum long-term Area Maintenance Contracts. Contract bids are not broken down by function in this manner” (from survey response).

*Other Notes*

Notes on using innovative technology: “RWIS cameras provide a remote check on road conditions. AVL allows real-time tracking and a detailed archive of past activities to check that contractor equipment was deployed in a timely manner and that appropriate materials were used.”

**Oregon DOT**

*LOS*

Oregon DOT classifies its roadways into 5 designations based on **traffic volumes**, and sets snow and ice control goals for each. Included goals are to **provide bare pavement** as soon as possible, and to **maintain roads as safe and passable** throughout a storm.

### *Performance Measurement*

Oregon DOT measures **time to achieve LOS**, length of **time chain restrictions is active**, and length of **time a road is closed due to winter weather**.

### *Other Notes*

*In Progress:* “We are working on a telematics pilot that is evaluating the feasibility of automatic data collection on winter maintenance vehicles to track application of sand, deicer, and plowing events.”

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## **Otter Tail County, MN**

### *LOS*

LOS depends on working within staffing levels and budget. In line with political/customer expectations, the goals are to “achieve bare wheel tracks,” which may be accomplished during overtime hours, while completing the “remaining storm cleanup on regular hours.” Performance is not measured.

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## **Pennsylvania DOT**

### *LOS*

LOS is based on maintaining safe, passable roads, classified into 6 conditions: 1=dry to 6=impassable. Performance measurement is *In Progress*: Pennsylvania DOT is currently developing new performance metrics.

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## **Transport Scotland**

### *LOS*

Transport Scotland’s LOS is based on providing bare pavement, meeting customer expectation, and maintaining safe, passable roadways. From survey response:

In general terms, customer expectation is that the roads should **run bare of snow and ice throughout the winter period; which is unrealistic in relation to snow**. However, we fully expect that roads are **clear of ice throughout the winter period**. ...

*In Progress:* Transport Scotland is considering using grip as an LOS criterion. From survey response:

Transport Scotland trialed the use of Idaho Transportation Department (ITD) Storm Performance Index last winter to explore the potential use of ‘grip’ as part of our winter service. It is our aim to investigate the outputs from the ITD index in quantifying the economic benefits of investing in winter service.

### *Performance Measurement*

From survey response: To measure how well our Operating Companies (maintenance contractors) carry out their winter duties their performance is monitored monthly during the winter period using one Performance Indicator (PI). This combines and averages the data below:

- Treatment times;
- Response times; and
- Successful electronic data logger downloads.

In Progress: As mentioned above, Transport Scotland is considering using grip as a new way to measure performance. From survey response, regarding Transport Scotland's weather station network (currently consisting of 156 stations): "recent developments have included conversion of 8 sites to non-invasive sensors and addition of present weather detectors. This will assist with our research into 'grip.'"

### *Severity Index*

*In Progress:* Transport Scotland is investigating an index based on grip.

### *Method & Cost*

Cost for measuring performance is not specifically tracked.

### *Other Notes*

A significant event in 2010 led to a high volume of public feedback and reassessment of performance measurement.

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## **Slovenia DARS d.d.**

Slovenia's Družba za avtoceste v Republiki Sloveniji (DARS d.d.) is a private company responsible for maintaining the expressways in the country. The remaining "main" and "regional" roads are maintained by the Slovenian Infrastructure Agency, and local roads are maintained by communities. Only DARS d.d. practices are reflected here.

LOS: Provide bare pavement and meet political expectations. Performance is not tracked, but an evaluation will be performed in 2016 that will work toward establishing measures. Idaho TD's index and MDSS were both cited as consideration for DARS d.d. performance measurement system.

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## **South Dakota DOT**

### *LOS:*

Meet political/customer expectations and maintain safe, passable roadways "when practical." More specifically, LOS is based on providing a driving surface that is 80% clear of snow and ice in a given time frame.

*Performance metrics:*

Time to achieve established LOS and time to recover normal traffic speed.

*In Progress:* SD DOT is currently working on a severity index. No further responses provided.

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## **Swedish Transport Administration**

*LOS*

Sweden has set 5 LOS classes of roads based on traffic volumes. Each class has an assigned threshold for friction and amount of snow allowed on the road. LOS priority is to achieve bare pavement.

*Performance Measurement*

The measure is time to achieve bare pavement, which is determined by friction and amount of snow on the road. RWIS pavement condition observations (friction and road snow data) are used to track this time. Performance measures are used to ensure LOS is being met and to regulate their contractors' cost.

*Severity Index*

The Swedish Transport Administration uses a winter index which accounts for number of days with snow of different intensities and days with low friction measured on the road surface.

*Method & Cost*

RWIS instrumentation is used to measure friction and road snow. Time to reach bare pavement is thus drawn from the instrumentation data. The RWIS are placed at critical areas of the network, and the results are either used per area or are aggregated nationwide.

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## **Tennessee DOT**

*LOS*

From survey response:

Our forces work continually throughout the storm event to provide the **best riding surface possible** for traffic to operate on. TDOT has a **bare pavement policy** and all forces work until the **lanes and paved shoulders are clear of snow and ice**.

*Performance Measurement*

Tennessee DOT tracks **time to achieve LOS, time to recover normal traffic speed, and material usage** during events.

*Method & Cost*

From survey response: "Counties and districts report [material] usage through a MMS system... Costs are minimal when collecting the information." Personnel at headquarters evaluate the data from the database.

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## Texas DOT

Texas just completed its first statewide snow and ice plan.

### *LOS*

Roadways are classified based on a combination of commerce transport and traffic volumes. The 4 roadway classifications are:

- Tier I: “roadways/corridors that could impact interstate commerce. These are mostly interstate and other high-traffic corridors.”
- Tier II: roadways “that are important locally. Examples would include loops, US highways, etc.”
- Tier III: roadways “that may get pre-treatment on bridges and will get deicing after Tier I and II roadways are open.”
- Tier IV: “most likely will not get pre-treatment and would be the lowest priority for de-icing.”

Each district sets their own LOS based on the availability of resources (equipment).

### *Performance Measurement*

Texas DOT tracks **level of effort**, and goals are set at the district level. TDOT only recently completed a snow and ice plan.

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## Utah DOT

### *LOS*

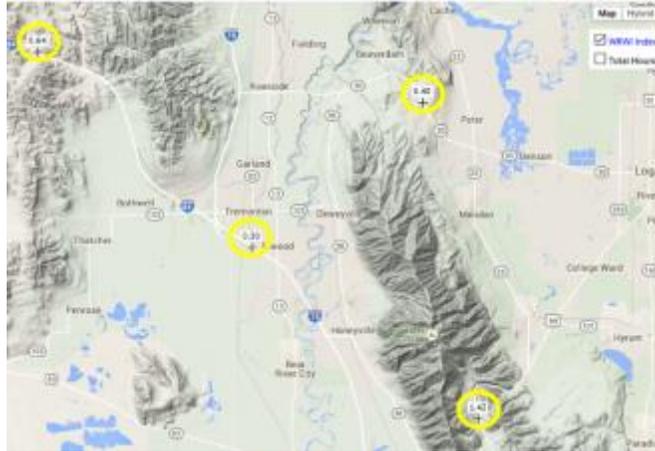
Provide bare pavement as soon as possible, meet political and/or customer expectations, maintain roads as safe and passable throughout a storm, and set service based on traffic volumes.

### *Performance Measurement*

Time to achieve established LOS following a storm and (upcoming) measured friction levels. *In Progress:* See below for a soon-to-be-operational “Snow and Ice Performance Measure” which is based on a severity index which uses weather and road surface conditions.

### *Severity Index*

Previous version: The Winter Road Weather Index (WRWI), shown in screenshot below. (*Note: this is not a publicly-accessible website and should be kept internal to this team pending UDOT permission.*) The yellow circles denote the RWIS locations at which the WRWI is computed.



In Progress: In development, and soon to be operational is the Snow and Ice Performance Measure. Quoted directly from email communication with Cody Oppermann and Jeff Williams at UDOT:

- The Snow and Ice Performance Measure basically subtracts the road condition element out of the Winter Road Weather Index and compares it to the resulting "Storm Intensity Index (SII)". In the simplest of terms, based on Central Maintenance's definition of 1"/hr being the max that they can keep up with, if the weather conditions are worse than about 1"/hr, then they are either performing acceptably (slushy) or exceptionally (wet). If it is not snowing, then plows are not meeting expectations when the roads are snow covered. And when the SII is less than 1 (about 1"/hr at 32 degrees) and greater than 0.25 (about 0.25"/hr at 32 degrees), then if the roads are snow covered, conditions are unacceptable; slushy = acceptable; wet = exceptional.
- Tallying up those conditions for each observation throughout a storm yields an "unacceptable" percentage that Central Maintenance can use to evaluate resource allocation, etc., but no plans have been made based off this data and we are technically still pulling in data to evaluate as well as still upgrading the RWIS.
- The new website illustrating the performance measure should be ready sometime within the next couple months.

## Vermont Agency of Transportation

### LOS

LOS is dependent upon a 4-level classification of roads, based upon traffic volume, and subject to having a certain fraction of a lane bare within certain time requirements. From survey response:

- Orange (High Volume/Interstate and Limited Access highways): Full width bare as soon as practical following storm.
- Blue (high volume State Highways): Full width bare as soon as practical following storm.
- Green (medium volume State highways): Full width bare pavement as soon as practical next working day following the storm.
- Yellow (lower volume State Highways): 1/3 bare pavement as soon as practical next working day following the storm.

### *Performance Measurement*

Time to achieve LOS. *In Progress:* VTrans also tracks material usage, with hopes to relate this to storm severity in the future.

### *Severity Index*

VTrans reports wanting to adopt a winter severity index. The desire is to compare storm-to-storm and year-to-year material usage based on storm-specific or annual winter severity.

### *Method & Cost*

Currently, maintenance supervisors input usage data into a database, and software tabulates the data and compares it to previous storms or years. *In Progress:* Two efforts are currently in the works: implementing a winter severity index and deploying AVL on all plow trucks, which will capture data that is currently reported manually. Once a winter severity index is implemented at VTrans, they “will begin using [it] to compare like storms and yearly severity versus materials used. [They] will have AVL/GPS in all plow trucks starting this year, so [they] can monitor the usage via web-based information.” “AVL costs are approximately \$1,500 per truck with a monthly fee of \$40 per truck. [There are] 250 trucks and 25 spares that do not have AVL currently” (from survey response).

*In Progress:* On using technological innovations: We have begun using RWIS to verify road conditions and grip where available. We also have AVL and have used the RWIS grip and AVL materials application rates to show our employees and supervisors the results of the efforts and to validate materials application rates. With more technologies we have additional validation means and methods that will be incorporated.

### *Other Notes*

Public feedback has been a driving factor in revising performance measurement. Vtrans continues to outreach to the public for educational purposes. “Political pressures have been received for the past for increased LOS, which were discussed with the Governor’s office, Secretary of Transportation and the legislature. We have given costs that would be expected for the increased LOS.”

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## Virginia DOT

### *LOS*

LOS is based on **prioritizing routes** (4 priority designations plus Snow Emergency Routes) and **attaining bare pavement or passable conditions**, depending upon the route priority. From survey response: Levels of Service for Various Amounts of Accumulation:

- Priority 1 Routes should be kept free of ice and snow so that traffic can proceed in safety without severe delays, except during periods of heavy falling or drifting snow and ice storms.
- Priority 2-4 routes will receive attention as soon as practical in accordance with the Levels of Service described below. In most cases, this can be accomplished within 24 hours on hard surfaced roads, but variances are allowed based on severity of the storm...
  - Priority 2 Routes should be kept free of ice and snow or covered with abrasives so that traffic can proceed safely without severe delays as soon as possible.

- Priority 3 Routes should be plowed or have the intersections and curves covered with abrasives as soon as possible...
- Priority 4 Routes should be made passable by appropriately equipped vehicle as soon as possible after treatment of Priority 1-3 Routes to minimize severe delays.  
\*Note: The term “passable condition” indicates that the routes have been plowed and/or treated.
- Snow Emergency Routes: When routes in the State Highway System are designated snow routes by the governing body of a county or town in accordance with Section 46.2-1302 of the Code of Virginia, the Department shall erect necessary signs designating these snow emergency routes.

*Performance Measurement*

None are tracked.

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**Washington State DOT**

*LOS*

LOS is based on **achieving bare pavement** with different time and resource allowances depending upon the roadway class (5 levels).

*Performance Measurement*

Currently, **pavement condition** is the sole performance metric. *In Progress:* WSDOT is currently reevaluating how to measure performance. From survey response: “We are leaning toward an evaluation of traffic speed recovery and/or friction.”

*Severity Index*

A “frost index” is used to help WSDOT compare expenses, but it is not a part of performance measurement.

*Method & Cost*

Currently, operators manually report road conditions at the end of each shift, “such as: -Bare Pavement -Patches of frost, ice, slush -Wheel tracks bare -50% of roadway with compact -Entire roadway with compact” (from survey response). “The cost is currently insignificant, however...we fully expect that the new [method] will be more expensive and time consuming, but also provide more consistent data.”

On technology: “AVL provided an initial method to perform data evaluations through the controller data input devise. Currently we are using iPads to collect roadway feature data as well as tie work activities to those features. Also, iPads are now used to enter snow and ice LOS.”

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## **West Virginia DOT**

### *LOS*

West Virginia DOT sets its service levels based on traffic volumes.

### *Performance Measurement*

WVDOT does not use performance measures.

No further responses were provided.

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## **Wisconsin DOT**

### *LOS*

LOS is based on maintaining roads as safe and passable throughout a storm, providing bare pavement (to a lesser degree), meeting political/customer expectations, and setting service based on traffic volumes. Five categories of roadway are identified (classified by volume), and maintenance allowances vary per category, as described in a January 2012 Wisconsin DOT document located here: <http://wisconsin.gov/Documents/doing-bus/local-gov/hwy-mnt/mntc-manual/chapter06/06-15-01.pdf>.

Attaining and maintaining “passable roadways” are a significant part of the LOS goals. The document states:

A “passable roadway” is defined as a roadway surface that is free from drifts, snow ridges, and as much ice and snow pack as is practical and can be traveled safely at reasonable speeds. A passable roadway should not be confused with a "dry pavement" or "bare pavement" which is essentially free of all ice, snow, and any free moisture from shoulder to shoulder. This "dry/bare pavement" condition may not exist until the weather conditions improve to the point where this pavement condition can be provided.

### *Performance Measurement*

Performance measurement is largely based on the fraction of the time the road is returned to bare/wet within a certain timeframe. Wisconsin DOT reports maintenance performance to the public using the MAPSS (Mobility, Accountability, Preservation, Safety, Service) Performance Scorecard (<http://wisconsin.gov/Pages/about-wisdot/performance/mapss/goalmobility.aspx>). “Percentage to bare-wet within a specific time period after a storm” is specified within the Mobility Scorecard. A winter severity index is included in the evaluation of performance, in order to place performance in context with the seasonal severity. Preservation, Safety and Service also contain maintenance performance evaluation.

### *Severity Index*

Wisconsin DOT does use a severity index. Details were not provided in the survey response, but details were gathered from a July 29<sup>th</sup> TRB webinar and personal communication with Mike Adams, road weather contractor for WisDOT.

WisDOT calculates WSI in each county using manually reported weather factors: number of snow events (SE), number of freezing rain events (FR), total snow amount (AMT), total storm duration (DUR), and number of incidents (INC). WSI is calculated using the following method (from internal WisDOT document, available through Mike Adams):

$$RAW\ INDEX(I) = 10 \times \frac{SE}{63} + 5.9 \times \frac{FR}{21} + 8.5 \times \frac{AMT}{314} + 9.4 \times \frac{DUR}{1125} + 9.2 \times \frac{INC}{50}$$

The values are then normalized for ease of understanding. When average annual WSI is compared to total salt use per lane mile over that season, the two values are well correlated, suggesting that the index reflects reality. Because the weather factors are reported manually, they are subjective in nature. Mike Adams reports that they are starting to use a new MDSS-based index, which uses objective data. He did not say when the old method would be swapped with the new method.

#### *Method & Cost*

From survey response: “Weekly storm reports are submitted by county highway departments after every event.” The performance tabulation is automated, and the ongoing costs are therefore negligible.

*In Progress:* Respondent reports that WisDOT is in the process of evaluating additional, new metrics.

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## **Wyoming DOT**

### *LOS:*

Maintain roads as safe and passable throughout a storm.

### *Performance measurement:*

Currently, Wyoming DOT tracks **time to achieve LOS**. *In Progress:* Wyoming DOT is working to establish new performance metrics.

### *Method & Cost*

Wyoming DOT developed a new application that allows maintenance personnel to report pertinent information, including truck hours, man hours, the amount of salt/sand used in tons, the amount of liquid used in gallons, the amount of ice slicer used in tons, visibility estimates, road temperature estimates and snow accumulation estimates. Some of this information will also be able to be collected automatically by WYDOT through existing systems in the vehicle.

### *Severity Index*

Their index is *In Progress:* Wyoming DOT is interested in using a winter severity index as part of their new performance measurement methods.

## **Other Agencies: From Literature Review**

This section supplements the information gathered through the survey by overviewing performance measurement practices at another US agency (Indiana DOT<sup>1</sup>) and six European agencies (current as of 2014<sup>2</sup>): Belgium, Czech Republic, Estonia, France, Germany and Norway.

### Indiana (from literature review)

Indiana DOT uses **vehicle speed**, constituting a **subjective LOS**, to assess performance of winter operations.<sup>1</sup> LOS grade by speed category is shown in Table C.3. They are careful to point out that their method describes **performance from a pavement condition (which contributes to speeds) perspective**, and can therefore be subjective. *Storm impact period* is the duration of the slowing of speeds during a storm as a result of the storm. The period is defined by speeds being 55 mph or less on interstates with 70-mph posted limits. They also calculate a *storm index* (severity) using the following inputs: storm type, temperature, early-storm behavior, during-storm wind, post-storm temperature, and post-storm wind.

**Table C.3 Indiana DOT's LOS grads based on measured interstate speeds**  
(McCullough et al., 2013)

Traffic speed (70 mph posted)	LOS grade
55+	Very good
45-55	Good
35-45	Fair
25-35	Poor
<25	Very poor

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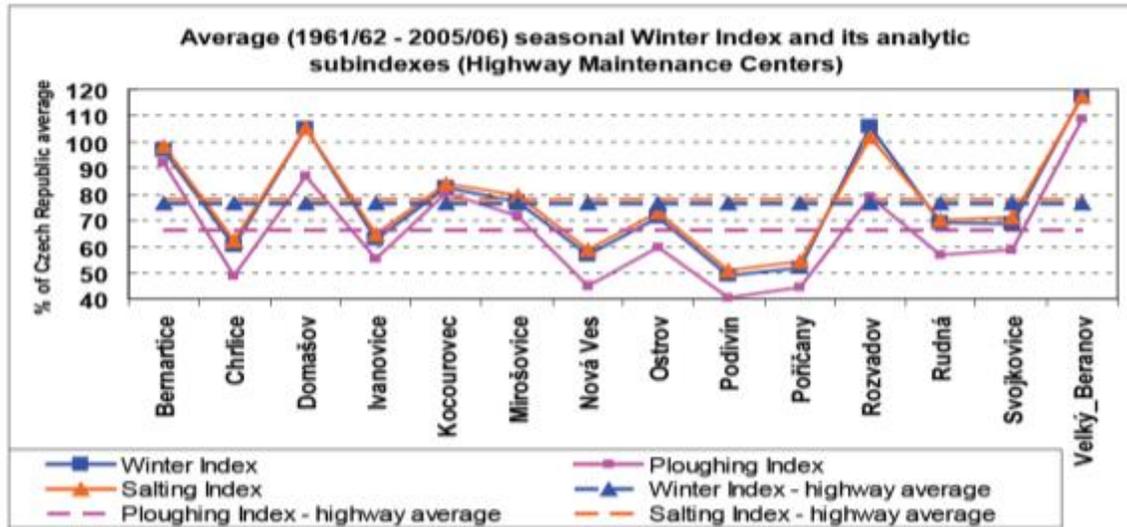
### Belgium (from literature review)

The Flemish Road Authority in Belgium strives to **minimize the ratio of salt usage to winter severity**. The inputs to their ratio calculation are: **quantity of salt** spread, **area of road** treated, **number of nights during which road temperature was below 0°C (32°F) and dew point was greater**, and the **number of nights during which winter showers or snow fell on an icy surface**. GPS-based AVL and spreader controls are used to track the trucks and the material they use.

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### Czech Republic (from literature review)

In the Czech Republic, the **cost expended** for winter maintenance is compared to a **winter weather index** calculated for each territory. Winter index and plowing and salting indices (measures of cost expenditure) are calculated per territory and averaged over the country. See figure below. The comparison of these two metrics (weather and cost) provides a measure of performance per territory for use by road managers and contractors alike.



Graphical representation of performance measurement indices used in the Czech Republic. (PIARC, 2015)

### Estonia (from literature review)

The Estonian Road Administration classifies its roads based on average daily traffic (ADT), and measures performance based on **maximum time required to meet set LOSs**. Set maximum time to reach each LOS **varies based on road class**, and is **different for different maintenance activities**: snow and slush removal, de-icing/anti-skid treatment, and salt-snow mix removal. LOS is visually and quantitatively described. That is, the following quantitative thresholds were established for each LOS: **allowed depth of loose snow**, **allowed depth of slush** (mix of salt and snow), **width between snow mounds**, and **allowed depth of ruts/unevenness in packed snow**. For example, LOS 3 is defined as: wheel tracks free of snow and ice (visual); and its quantitative thresholds are: <3 cm of loose snow, <2 cm of slush depth, whole driveway and shoulders free of snow mounds, and <2 cm depth of ruts (wheel tracks).

### France (from literature review)

France defines LOS by the presence of ice or snow, a minimum allowed condition and a maximum restoration time to that minimum condition. The French Road Directorate uses the following measures to assess performance: **salt consumption**, **cost per kilometer**, number of **man-hours** for winter maintenance, and **public user satisfaction**. France also posts the location of its plow trucks online using AVL.

### Germany (from literature review)

The Federal Highway Research Institute in Germany developed a **winter index** in order to compare weather severity to snow and ice control. In Germany, roads are classified based on

specific criteria: category (federal freeway, secondary road, residential, etc.), traffic volume (ADT), special traffic (school bus routes, rescue routes, etc.), and accident-prone areas (curves, bridges, shade, etc.). **Time to bare pavement, salt consumption and cost expenditures** are the predominant performance metrics.

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### **Norway (from literature review)**

Norway has classified its roads into winter maintenance-specific classes (A-E) based on general approved road conditions, from bare road surface (A) to compacted snow and ice/friction down to 0.20 acceptable (E). Detailed performance standards were set for each. As examples, Classes B and C are shown in the Table A.5.7. Notice that the metrics used are road condition, friction, thickness and unevenness of snow/ice, maximum time for snow removal, maximum time for de-icing, and time to approved road condition.

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research for winter highway maintenance

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