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Performance Measures for Snow and Ice Control Operations

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ABSTRACT

Under the NCHRP 06-17 project, the research team surveyed snow and ice control organizations in the United States, Canada, Europe, and Asia to determine the current trends in performance measurement. The team also inquired about the methods used in developing these programs in order to determine a practical, user friendly method to assist snow and ice control managers in developing a performance measurement system that uses traditional and nontraditional performance indicators and measurement issues. To achieve the project objectives, the researchers issued a survey to snow and ice control agencies throughout North America, Europe, and Asia to obtain data of the performance indicators and measures used, if any, by these agencies. The identified performance indicators and measures were then categorized, defined, and assessed for their usefulness. A process was then developed to assist snow and ice control operations managers in preparing a customer-focused, environmentally friendly performance measurement program.

SUMMARY

The issue of performance measurement for snow and ice control has been a topic of much interest. Developing meaningful data for snow and ice control has produced a variety of responses and differing goals and objectives. However, a rigorous process that the snow and ice control industry can use to determine the most appropriate performance measures and indicators has been lacking.

Research was needed to examine current trends and issues and develop a process that can be used by snow and ice control agencies to prepare a performance measurement system that is sensitive to organizational and public needs as well as environmental concerns. This process would provide a context, or framework, to select and apply appropriate performance indicators and measures that are integral to snow and ice control decision-making. The research would also analyze the different dimensions along which an agency's performance could be defined, measured, and interpreted based on an agency's goals and objectives.

Under the NCHRP 6-17 project, the research team surveyed snow and ice control organization in the United States, Canada, Europe, and Asia, to determine the current trends in performance measurement. The team also inquired about the methods used in developing these programs in order to determine a practical, user-friendly method to assist snow and ice control managers in developing a performance measurement system that uses traditional and nontraditional performance indicators. The plan provides a list of options of performance indicators and measures, and explains how to incorporate the indicators and measures in the decision making process to monitor and improve snow and ice control operations.

One method to incorporate the use of performance measures for snow and ice control operations is a "toolbox" developed by the research team. This toolbox was designed for managers to use to evaluate relevant performance measures for snow and ice control operations and assist them in their decision making process.

To achieve the project objectives, the researchers first reviewed pertinent literature and research findings in the area of performance measurement systems. Next, a survey was issued to snow and ice control agencies throughout North America, Asia, and Europe to obtain data of the performance indicators and measures used, if any, by these agencies. These performance indicators and measures were then categorized by functional type and were fully defined. An assessment of the usefulness of each was prepared. The research team then summarized the theory and practice of the performance measurement. The performance measures were then identified by their key aspects and identifying performance indicators and measures that may have applicability in snow and ice control operations. A process was then developed to assist snow and ice control operations managers in preparing a customer focused, environmental friendly performance measurement program.

CHAPTER 1. INTRODUCTION TO NCHRP 06-17

The purpose of this research is to identify and assess the measures used to evaluate the performance of winter maintenance activities (snow and ice removal from roadways) and to recommend the most promising measures for further development. The research was conducted in two parts. The first part entailed a comprehensive review of performance measures that have been and are currently being used by transportation agencies. This work was accomplished through a thorough review of the literature and a survey of dozens of agencies with winter maintenance responsibilities. In the second part, the performance measures that offered the most promise were identified. In other words, these were measures with the most potential to be applied economically to a roadway network and provide reliable, repeatable, and comparable measures of performance. These most promising measures were then recommended for further development and use by highway agencies.

1.1. Performance Measurement

For many transportation agencies, performance measurement has become a critical issue in the last five to ten years. Such that transportation agencies often attempt to tie strategic direction and agency mission to performance measures. As Osborne and Gaebler, 1992, state in their popular book *Reinventing Government*, “If you don’t measure results, you can’t tell success from failure. If you can’t see success, you can’t reward it. If you can’t reward success you are probably rewarding failure. If you can’t see success, you can’t learn from it. If you can’t recognize failure, you can’t correct it. If you can demonstrate results, you can win public support.”

Performance measurement is one component of a larger “quality in government services” movement. The growing emphasis on performance measurement by transportation agencies has not been sufficiently considered because there was no such need to measure performance but also due to two factors:

1. Transportation agencies have historically focused on standards and specification for physical conditions or level of service (LOS). Generally, transportation agencies have defined the LOS or conditions of a facility based on static standards. Only recently, through asset management application, have these agencies begun to treat LOS and conditions as a variable against which other financial and condition considerations can be balanced.
2. The recent expansion of information technology and the ability to collect information that would have been too costly or impossible to collect in the past has made the collection of performance-related data possible. In addition, the public and public policy makers’ expectation for performance information has grown as they become accustomed to having information at their fingertips. Thus, the growing ability to provide more performance information has driven the demand for collecting and reporting more performance information.

Winter maintenance of roadways is a core and critical business element of many state transportation agencies, and because it is a core business, it needs to be managed. For such management, the performance of winter maintenance must be measured.

1.2. Measurement of Winter Maintenance Performance

Although winter maintenance is a critical activity, there are no standard methods for measuring performance for either agency programs or those performed by contractors. The lack of standard measures also makes it difficult to effectively manage and control winter maintenance activities and subsequently impossible to benchmark and make comparisons both between and within maintenance programs. Measuring the performance of winter maintenance makes it possible to make intelligent management trade-offs between agency costs and user costs.

The agency costs of winter maintenance are quite significant. The direct costs have been estimated to be at least \$1.5 billion per year in the United States alone (NCHRP 5-26). On the user cost side, it is difficult to determine the safety and mobility problems as a result of either not performing winter maintenance or not performing winter maintenance effectively. However, it has been shown that during snow storms of 0.2 inches of snowfall per hour or more that crash rates (crashes per million vehicle miles) on the Iowa rural freeway system increase by 13 times and increase even more during severe storm (low visibility and high winds) events. Failure to remove snow and ice would only continue to extend these high crash rates beyond the end the storm. Through performance measurement, a winter maintenance manager can control and direct winter maintenance to make the best use of available resources and to reduce potential user costs of travel.

Agencies currently measure winter maintenance performance from one or more of three basic perspectives:

- **Inputs.** Input measures represent the resources spent or utilized to perform snow and ice control operations. These resources include fuel usage, labor hours, machinery or equipment hours, and units of anti-icing materials or abrasives. The level of inputs is directly proportional to agency costs and, therefore, they most easily and most commonly are measured by transportation agencies. Because inputs are applied at the beginning of the winter maintenance process, they are unable to help management assess the efficiency, quality, and effectiveness of winter maintenance.
- **Outputs.** Outputs quantify the resulting physical accomplishment of work performed using resources in winter maintenance. Outputs might include the lane-miles plowed or sanded, the number of lane-miles to which deicing materials were applied, lane-miles of anti-icing brine applied, and other accomplishments of the maintenance process in units of work. Outputs are generally more useful than inputs alone because inputs and output together can help to define the efficiency of winter maintenance operations by determining what level of input was or will be required to achieve a level of output. These measures may also be based on time and storm event.

- **Outcomes.** Outcomes generally attempt to assess the effectiveness of the winter maintenance activity, very often from the perspective of the user or customer. Outcomes are inherently more difficult to measure. A desired outcome of winter maintenance might include the improvement of safety, mobility, and/or user satisfaction. Safety, mobility, and user satisfaction are abstract concepts and, therefore, are measured through indicators known to be related to the desired outcome. For example, safety might be measured through pavement friction or through the reduction in number of crashes.

Other known outcome measures include bare pavement regain time, duration and frequency of closures, advanced warning time to customers, and customer satisfaction indicated by customer satisfaction surveys. Although conceptually it may appear simple to measure outcomes, the measurement methods are generally complex. For example, while the number of crashes during and following a storm can be quickly (within a week) identified through a centralized crash record data base, crashes alone do not indicate the relative risk of having a crash. Crash risk is measure by crashes per vehicle miles traveled (VMT), a measure of exposure. Estimating VMT during and immediately following a winter storm may be possible for managed urban freeway systems but difficult to measure reliably for rural network of highways.

1.3. Methods for Measuring Winter Maintenance Performance

Friction has become a very attractive performance measure for snow and ice removal. Sweden and Finland have been measuring friction for over 10 years. Japan also correlates friction with crashes and traffic speed and volumes (PIARC 2005). However, there are different methods for measuring friction. For example, several different types of friction measuring devices can be mounted under winter maintenance trucks or towed by a supervisor's vehicle. Once a technology has been selected, decisions have to be made regarding the number of friction reporting devices and the frequency of measures required to understand the snow and ice control performance across a network of roadways.

In the U.S., a common measure for performance of winter maintenance is time to bare pavement. The Minnesota Department of Transportation (Mn/DOT), for example, measures the time to reach bare pavement throughout the state's trunk highway system and has set different levels of satisfactory performance depending on the level of traffic on the route. These levels were set based on significant stakeholder input. In Minnesota, more heavily traveled routes have shorter time to bare pavement goals. Underlying Mn/DOT's performance measurement are standards for identifying when the pavement is bare, data collection and entry techniques, and quality assurance methodologies.

In general, to allow comparisons across jurisdictions or between jurisdictions, a common reliable, and repeatable performance measure must be identified together with a specific methodology for collecting compiling the relevant data, over the same time frames, and made comparable by normalizing their relative severity (e.g., it is meaningless to compare a performance when a blizzard takes placed in one jurisdiction while another only experiences light snow.).

1.4. Putting Winter Maintenance Performance Measurement into Context

When making comparisons between and among jurisdictions, differences in the severity of storms must also be taken into account, because the severity of a storm impacts the performance of winter maintenance. Figure 1 illustrates the relationship between inputs, outputs, outcomes, and the environment. As shown on the top of the figure, some of the environmental inputs. Labor, equipment, and materials inputs for removing snow and ice from the roadway network, are shown on the bottom. The results achieved from these inputs under these environmental conditions are also shown in the figure.

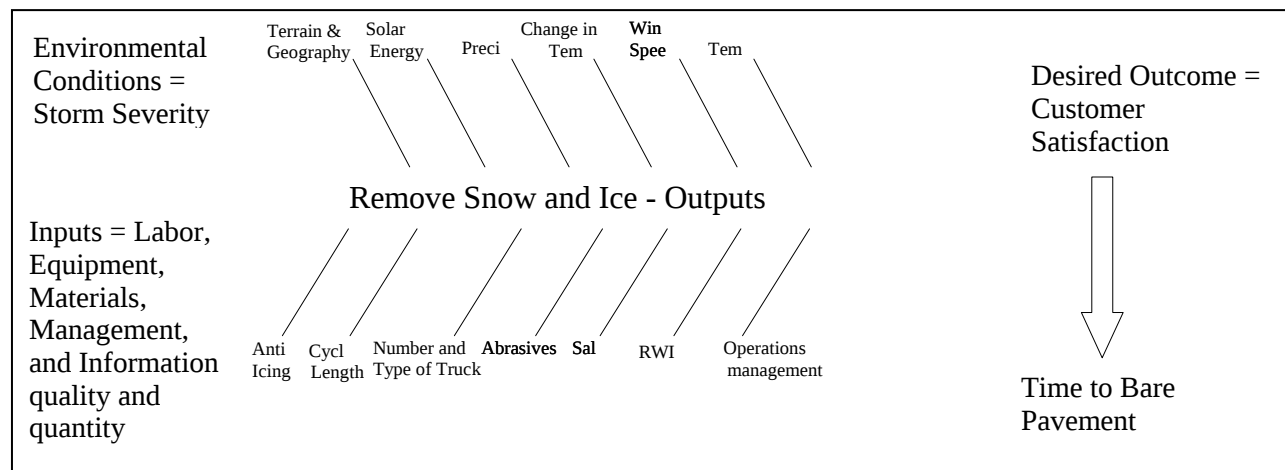


Figure 1. Relationship between inputs, outputs, and outcomes

In this case, satisfying the customer (the road users) was chosen as the desired outcome, and because shorter time to bare pavement reflects higher levels of satisfaction, time to bare pavement is the resulting performance measure. The measurement of time to bare pavement must be supported by a specific data collection methodology.

1.5. Summary of Synthesis Findings and Assessment of Performance Measures

Although a significant amount of published materials deals with different types of performance measures, both in use and theoretical, a limited amount of literature documenting agencies' utilization of performance measures in day-to-day practice. Various instances of research and testing of proposed performance measures were described in literature, but often without implementation or field testing. It appeared that some European countries and Japan are more progressive in terms of developing and implementing winter maintenance performance measures, likely because more snow and ice control operations are contracted to private companies internationally than in the United States.

The survey of winter maintenance personnel was sent to 162 agencies covering the U.S. Snow Belt states, Canadian provinces, northern Europe, and Japan. In all, 43 agencies responded. The responses included agencies that did no snow and ice control performance measurement to those

that incorporated performance measures into their management plans. Most performance measures cited by the respondents are tied to their accounting and management systems. These measures include lane-miles plowed, personnel and/or overtime hours, tons of material used, amounts of equipment deployed, and cost of operations.

Other measures used by some of the respondents include time to bare pavement, time to return to a reasonably near-normal condition, length of road closures, and customer satisfaction. The majority of the measures critical to the respondents' snow and ice control operations focused on public safety and mobility. Obviously, these subjects are central to the role of all transportation agencies, so it makes sense that the measures would focus on them. By maintaining mobility and traffic flow, accidents are reduced and public safety is enhanced.

The survey also found that, while state and local agencies are generally interested in providing the best service to the public, budget and staffing constraints make it difficult for agencies to experiment with new methods or technologies. For example, measures such as friction were identified by only a few agencies and are generally farther from full-scale implementation, especially in the United States.

The survey analysis identified four input measures, five output measures, and 11 outcome measures used by public agencies to measure snow and ice control performance. A complete list of the performance measures identified is provided in Chapter 5. To identify measures and approaches that warrant further study, the following criteria were applied to the measures and approaches:

Measure Criteria

- Does the measure directly measure safety, mobility, or public satisfaction?
- Does the measure improve snow and ice control?
- Is the measure mapped to roadway segments?
- Is the measure reported for garages or districts?
- Is the measure sensitive to storm characteristics?

Approach Criteria

- Is the approach quantitative?
- Is the approach stable across observers?
- Is the technology likely to improve?
- Is a major capital or operational investment required?
- Can the approach be piggybacked on another system to reduce installation costs?

The assessment presented in Chapter 5, determined that outcome measures should be pursued further, the measurement of snow and ice control is to have a role in improving safety and mobility. To help determine the measures and approaches to pursue further, the 11 outcome measures identified in this study were reduced to three basic categories, and two approaches were identified for each measure.

Measure: Degree of clear pavement

- Approach: Manual observation
- Approach: Camera-assisted observation

Measure: Traffic flow

- Approach: Detectors – speed, volume, and occupancy
- Approach: Road closure

Measure: Crash risk

- Approach: Friction (or slipperiness)
- Approach: Reported crashes

Although 15 measures of winter storm severity were found in the literature, none of the responding agencies reported using a storm index to normalize the severity of each storm other than rate of snowfall. Pursuing an operational storm severity index that can be applied to normalize any other measure over time would be desirable. For example, some performance measures may be collected continuously through a storm (e.g., friction or traffic density and speed), while others may be collected following each storm (e.g., time till bare pavement, crashes per storm), and others are calculated per season (e.g., all winter crashes, materials used per year, number of times and duration of road closures); however, winter weather severity indexes are seasonal, resulting in disparity in the time frames of each and, hence, the usefulness of performance measurement.

Seventeen agencies reported using customer satisfaction as a measure of performance.

Satisfaction sets the level of performance that the public expects. The performance measures that were reviewed measure how close winter road maintenance comes to meeting public expectations. Most agencies use a periodic survey to determine public expectations, and some track complaints and 511 calls. Best practices for determining customer satisfaction and linking operational performance to those expectations should be documented, as they are in Chapter 6.

1.6. Conclusions

It is expected that more winter maintenance agencies will adopt performance measurement practices and that the public will continue to expect clear roads and less harm to the environment from snow ice control operations. Technologies such as automated vehicle location (AVL), global positioning systems (GPS), friction meters, road weather information systems (RWIS), among others, will facilitate obtaining the additional data needed to enhance measuring performance. The expanded use of these technologies and their increased production and competition will lead to lower costs. However, both field personnel and management would have to focus more on outcomes when using these technologies.

The objectives selected by each agency can also drive performance measurement by creating targets toward which activities can be directed. In addition to objectives, performance measures need to include a short-term result, an improvement strategy, and hold entities accountable. However, success with performance measurement will require responsive data systems capable of generating timely data.

Performance measurement offers a promise of improved management and improved outcomes. It builds on a long history and extensive experience in techniques to strengthen and improve winter maintenance operations. Developing performance measurement, will lead to more effective winter maintenance programs.

CHAPTER 2. LITERATURE REVIEW

An international literature review of published and in-progress materials related to snow and ice control performance measures was conducted as one of the initial tasks under this research effort. This review involved searches of the Transportation Libraries Catalog, TRIS online, Transportation Research Board in-progress research, and the Internet.

2.1. Summary of Key Points

The literature review revealed that a significant amount of published materials dealt with different types of performance measures, both in-use and theoretical but a limited amount of literature documents agencies' use of performance measures in day-to-day practice. Various instances of research and testing of proposed performance measures were described, but often without implementation or field testing by state or local agencies in the United States. It appeared that some European countries and Japan are more advanced in developing and implementing winter maintenance performance measures, possibly because more snow and ice control operations are contracted to private companies internationally than in the United States.

Also perplexing is the variety of measures that agencies use as winter maintenance performance measures. Measures such as friction are continuously measured, others are measured per storm, and still others are measured per season (e.g., number of road closures). Agencies consider each performance measure collected at varying time intervals and make management decisions based on each interval and have different expectations of their performance measures.

This review discovered the following:

- Three scanning review teams of U.S. officials visited Europe and Japan in 1994, 1998, and 2002, focusing on winter maintenance activities and advanced intelligent transportation systems (ITS) technologies.
- Performance measures can be divided into three general categories: input, output, and outcome measures
- Performance measurement can be collected over several time intervals but are generally measure continuously, storm-by-storm, and season by season, other

- intervals may include week-by-week or month-by-month.
- Known input measures include labor hours, equipment hours, various material units, and expenditures.
 - Known output measures include cost determined by a unit of accomplishment of work performed (e.g., lane-miles plowed or sanded), material application rates, equipping and calibrating trucks, and route characteristics. These measures may also be based on time and storm event.
 - Known outcome measures include bare pavement regain time, friction (skid resistance by coefficient of friction), reduction in crashes, duration and frequency of closures, advanced warning time to customers, and customer satisfaction (indicated by customer satisfaction surveys).
 - A Pavement Snow and Ice Condition (PSIC) chart, as used by some agencies, assists with uniform pavement condition identification by combining traffic flow characteristics and visual observation. (Blackburn, et.al 2004)
 - Various outcome measures can and, are often combined to form an overall Level of Service (LOS) rating for a roadway.
 - Contracts with private sector operators are often written such that reimbursement is based on a combination of input (pay items) and output or outcome measures (with expectations).
 - Innovative technologies installed on winter maintenance vehicles that aid in the collection of data applied to performance measures include AVL, GPS, friction meters, and various sensors of material, equipment, and temperature.
 - Winter weather severity indices have been developed to help quantify the relationship between the severity of winter weather events and roadway condition or safety factors. However, these indexes are generally lacking because their duration of data collection is too long for the making of storm-to-storm decisions.

2.2. Background

Development of Performance Measures in the United States

Several U.S. state transportation agencies are utilizing performance measures or standards for internal assessments or contract monitoring of winter maintenance activities. Performance measures reflect unique characteristics for each agency, such as the following (TransTech Management 2003):

- Agency goals, objectives, and strategies
- Organizational and legislative structures and responsibilities
- Project development processes
- Geography and climate
- Fiscal constraints
- Rural versus urban focus
- Stakeholder concerns

The establishment of goals can lead to identifying potential performance measures specific to an agency's needs. Goals help relate system performance to reflect what a user perceives the system should be achieving. Possible goals for winter maintenance include mobility, quality of life, environmental and resource conservation, safety, operational efficiency, and system condition and performance (Adams et al. 2003). Adams et al. described a process for identifying and developing performance measures:

1. Identify the applications areas for the winter maintenance vehicle data.
2. Form working group of agency personnel responsible for winter maintenance.
3. Identify goals and objectives for each application.
4. Identify the performance measures for the objectives.
5. Formulate the performance measures using winter maintenance vehicle data.
6. Identify and develop analytical tools.

Adams et al. (2003) also described principles to guide selecting performance measures:

- Each measure should be meaningful and appropriate to the needs and concerns of decision makers.
- Each measure reflects specific goals or compliance with guidelines.
- The measures reflect current issues, such as environmental concerns.
- The measures facilitate comparisons among alternative equipment and operational strategies for providing the service.
- The measures facilitate the prediction of future performance trends for planning and budgeting.
- The measures facilitate the asset valuation and depreciation of equipment.
- The measures facilitate comparisons of performance across districts, counties, and patrol sections.

Scanning Review of International Practices

Some international agencies have been using performance measures in winter maintenance operations for many years. In an effort for U.S. agencies to improve efficiency and customer satisfaction, scanning teams were sent abroad to document the process and operations of international winter maintenance agencies. In the past decade, three teams of U.S. transportation experts have traveled overseas to study how other countries handle winter maintenance operations. The first two scans, in 1994 and 1998, primarily focused on maintenance; the third, concluded in 2002, focused on advanced technologies (Pisano 2004).

The first two tours visited European countries and Japan. The scanning tour discovered that Japan and many European countries use a "systems concept" that addresses the vehicle, driver, and the equipment, along with the practices for managing roadway and bridge snow and ice control. The goals for a systems concept include sustaining or improving levels of winter maintenance service with the greatest benefit/cost improvements, increasing the safety of winter driving, and providing an improved level of environmental protection (Smithson 1998).

NCHRP Project 20-7, Task 71, utilized two phases in developing a winter maintenance program. Phase one concentrated on organizing a committee to develop a winter maintenance guide. The second phase established a Snow and Ice Cooperative Program. In 1997, committee members identified ten topics as being of high priority that fit into four broad categories: training, materials applications and specifications, technological advancements, and public relations/communications. The topics of relevance included the development and validation of test methods for anti-icing and deicing materials, the investigation of the use and application of GPS equipment and technology in winter maintenance operations, the measurement of friction on highway pavements during winter activities, and the investigation and evaluation of opportunities for using computerized controls and onboard interactive display services in snow and ice control.

Several European countries are moving toward privatizing winter maintenance operations. Because of the need to define the expected wintertime LOS, agencies are developing methods to evaluate the performance operations (Pisano, 2004). In the 1998 scanning tour which visited France, Switzerland, Norway and Sweden, found that these countries used a bare pavement policy (Smithson 1998). The performance measures are all measurable and are primarily output-based. The policy involves the following features:

1. Maximum deterioration of road conditions tolerated before needed action
2. Minimum LOS conditions before action is ended
3. Time frames for achieving the LOS based on weather conditions

2.3. Types of Performance Measures

A combination of various input, output, and outcome measures may be combined to determine a LOS of the winter maintenance operations. The three categories are discussed further in the following sections.

Input Measures

Input measurements are used to quantify the resources spent on snow and ice control or winter maintenance operations, typically applied to equipment, material, and labor used for winter operations. Quantifying this value is done in terms such as number of trucks, labor-hours, and volume or tonnage of material. During the operation, the number of equipment amounts and labor-hours may be documented. In contracts, the pay items are directly related to time and usage, based on the quantified measures desired (Bourdon 2001).

Output Measures

Output measures quantify physical outputs from the resources that are used in units of work of winter operations. Output specifications primarily deal with defining methods of performing the work and the associated accomplishments. In contract specifications, pay items may be based on route characteristics, storm events, truck operations, truck characteristics, and time (Bourdon, 2001). Cost is one of the most common measures used to establish a performance-based system

established by a unit of accomplishment at the crew level (AASHTO, 1999). Examples of route characteristics include a specified order of plowing roads, development and performance within a plowing network, or number of rounds needed during an event. When compared to time, lane-miles per unit of time sanded or plowed are measured. Truck operations include plowing speed and material application rates. Payments for winterizing, calibrating, and equipping trucks specifically for winter operations are also examples of output-based pay measures.

Outcome Measures

Outcome measures reflect the end result of winter maintenance during and after a storm event, usually as perceived by the motorist. The user of a road typically has expectations on how a road should handle, thus relating the performance of the maintenance to what the motorist feels, sees, and expects in terms of recovery time (Bourdon 2001). The user also wants access and mobility for unrestricted and safe travel.

Outcome measures reflect an agency's success in meeting goals and objectives, typically from the customer's perspective. Common types of outcome measures are (Bourdon, 2001, Blackburn et al. 2004) include the following:

- Bare pavement regain time
- Friction (skid resistance)
- Reduction of crashes
- Duration and frequency of closures
- Advanced warning time to customers,
- Customer satisfaction surveys
- Visual characteristics

The most popular choices are bare pavement regain time, friction testing, and customer satisfaction surveys, which take into account a driver's visual and physical perception of the roadway surface (Blackburn et al. 2004). These outcome measures are discussed in the following subsections.

Visual and Physical Perception of Roadway Surface Conditions

Visual characteristics of road conditions are of greatest concern to the motorists. Road conditions can be assessed by different measurements, visual and physical. Unevenness, rutting, and slippery conditions are concerns of drivers during and after a storm event. Visual characteristics are easily identifiable without physical testing. Different visual roadway characteristics include (Blackburn et al. 2004) the following:

- Centerline bare
- Wheel path bare
- Loose snow covered (percent area and depth)
- Packed snow covered (percent area and depth)

- Bare (percent area)
- Thin ice covered (percent area)
- Thick ice covered (percent area)
- Dry
- Damp
- Slush (percent area and depth)
- Frost
- Wet

A Pavement Snow and Ice Condition (PSIC) table (Blackburn et al. 2004) is developed by using visual characterization of roadway surfaces together with traffic flow and other visual information to identify a level of service of the road. The PSIC table correlates what a driver would perceive the condition of a road to what the driver sees and how the driver feels while driving on the road. The PSIC allows for identifying a distinct condition of the roadway with relevant, useful information to the agency and motorist. The PSIC helps an agency determine what method of maintenance is desired for effective winter maintenance and the instantaneous visual status of measured outcomes. Table 2 shows a sample PSIC table.

Table 1. Sample PSIC table

Conditions	Description
Condition 1	All snow and ice are prevented from bonding and accumulating on the road surface. Bare/wet pavement surface is maintained at all times. Traffic does not experience weather-related delays other than those associated with wet pavement surfaces, reduced visibility, incidents, and "normal" congestion.
Condition 2	Bare/wet pavement surface is the general condition. There are occasional areas having snow or ice accumulations resulting from drifting, sheltering, cold spots, frozen melt-water, etc. Prudent speed reduction and general minor delays are associated with traversing those areas.
Condition 3	Accumulations of loose snow or slush ranging up to (2 in.) are found on the pavement surface. Packed and bonded snow and ice are not present. There are some moderate delays due to a general speed reduction. However, the roads are passable at all times.
Condition 4	The pavement surface has continuous stretches of packed snow with or without loose snow on top of the packed snow or ice. Wheel tracks may range from bare/wet to having up to (1.5 in.) of slush or unpacked snow. On multilane highways, only one lane will exhibit these pavement surface conditions. The use of snow tires is recommended to the public. There is a reduction in traveling speed and moderate delays due to reduced capacity. However, the roads are passable.
Condition 5	The pavement surface is completely covered with packed snow and ice that has been treated with abrasives or abrasive/chemical mixtures. There may be loose snow of up to (2 in.) on top of the packed surface. The use of snow tires is required. Chains and/or four-wheel drive may also be required. Traveling speed is significantly reduced and there are general moderate delays with some incidental severe delays.
Condition 6	The pavement surface is covered with a significant buildup of packed snow and ice that has not been treated with abrasives or abrasives/chemical mixtures. There may be (2 in.) of loose or wind-transported snow on top of the packed surface due to high snowfall rate and/or wind. There may be deep ruts in the packed snow and ice that may have been treated with chemicals, abrasives, or abrasives/chemical mixtures. The use of snow tires is the minimum requirement. Chains and snow tire equipped four-wheel drive are required in these circumstances. Travelers experience severe delays and low travel speeds due to reduced visibility, unplowed loose, or wind-compacted snow, or ruts in the packed snow and ice.
Condition 7	The road is temporarily closed. This may be the result of severe weather (low visibility, etc.) or road conditions (e.g., drifting, excessive unplowed snow, avalanche potential or actuality, glare ice, accidents, vehicles stuck on the road).

A 2001 survey of business owners conducted in Sapporo, Japan, was used to evaluate traffic issues during winter travel. Three highly ranked problems, from a business owner's perspective, were risk of increased traffic accidents, decline in visits to clients for meetings/sale, and increase in time to deliver merchandise. Three relationships were developed based on the responses (Yamamoto et al. 2004):

- “Increased risk of winter accidents” is largely influenced by the skid resistance coefficient of the winter road surface.
- “Increase in time to deliver merchandise” is strongly influenced by reduced traffic capacity from narrowed road width.
- “Decline in visits to clients for meetings or sales” is strongly influenced by both the increased risk of accident and the increased time required traveling to clients. Addressing this issues means improving the coefficient of friction of winter road surface and maintaining the road width.

The five most important indicators of winter road maintenance are road surface conditions (i.e., unevenness, rutting, and slipperiness), road width, sight distance at intersections, pedestrian safety, and provision of traffic congestion information. The top ranked indicators were road width, followed by road surface conditions (Yamamoto et al. 2004).

In the study by Yamamoto et al., outcome indicators were designated as maintained road width and coefficient of friction. For these indicators, quantitative goals, targets of fulfillment rates, and the comparison of the target achievement rates to the actual achievement rates were set as measurements for the outcome.

Bare Pavement Regain Time

Bareness of pavement is a performance measure for winter maintenance used during and after a storm event that is understood by users. Two definitions of bare pavement are acceptable by drivers (Bourdon 2001):

- Bare pavement. Driving lanes are bare with centerline and edge lines showing.
- Bare lanes. Driving lanes bare with centerline and edge lines covered.

Mn/DOT conducted market research in 1994, 1996, and 2000 to determine the pavement conditions at which the public was satisfied. The research indicated that the public felt that the time to obtain an adequate LOS is after a storm was also important. A high public satisfaction was reported at 90% bare lane (Keranen 2002).

The concept of “bare pavement regain time” was originally set by Mn/DOT at 95% of the roadway clear of ice and snow, but was changed to 90% clear of ice and snow in the following combinations (Keranen 2002):

- Ten 50-foot spots per mile
- Two 250-foot spots per mile

- Two mile-long spots per 20 miles
- Two half-mile spots per 10 miles
- Eight quarter-mile spots per 20 miles

In 2001, a study was performed to determine the roadway conditions that motorists would find acceptable for driving to and from work or to other daily appointments (Niemi 2001). The recommendation from this research was that the greatest impact on improving roadway conditions is to first clear two lanes on all road classes before upgrading roadways to fully bare. In the rural Minnesota area, the study recommends clearing four-lane roadways to make the travel way clear, with the centerline covered, with or without the edge lines showing, before upgrading the four-lane roads to fully bare. Within the Minneapolis/St. Paul metro area, interstate highways and four-lane roads should be cleared to two lanes, with centerline and edge lines covered, by 6 a.m., and two-lane roads should be cleared to this condition by 7–9 a.m. for greatest accessibility. In afternoon driving, an improvement over one intermittent wheelpath is desired on two-lane roads, and the interstate highways should be fully bare if possible (Niemi 2001).

Roadway Friction

The Yamamoto et al. study (2004) also found that securing adequate friction to be another important aspect of winter maintenance. The coefficient of friction may be increased with de-icing, anti-icing, and sanding the roadway. Friction testing is a way to measure the effectiveness of this performance. Norway proposed the use of 0.25 as the coefficient of friction threshold when spreading sand on snow packed roads (Al-Qadi et al. 2002).

In the United States, friction meters have been primarily installed on vehicles for testing and research, while some European countries use them in operational applications. Three methods of friction measurements include a model-based approach using climate, traffic, and roadway conditions to predict friction; direct friction measurements by an extra wheel installed on vehicles; or by using traction control systems.

Al-Qadi et al. (2002) suggested four scenarios concerning the methods of friction testing:

1. Friction measurements by a winter maintenance patrol vehicle
2. Friction measurements by winter maintenance snowplow/spreader vehicles
3. Recorded, archived friction measurements by winter maintenance patrol or snowplow/spreader vehicles
4. Recorded, archived, and real-time transmitted friction measurements by winter maintenance patrol or snowplow/spreader vehicles

In the 1998 Nixon study, the author suggests three operational uses of friction measuring devices. First, these devices may be used as a measure of quality, which is beneficial to agencies that need a tool to measure the performance of winter maintenance contractors. Second, friction devices may be used as a source of road user information to inform motorists of hazardous locations of roadways with low friction. Third, friction devices could be used as a means of

controlling chemical application by determining the amount of chemical de-icing to be placed on the roadway.

2.4. Performance-Based Levels of Service

Many performance measures are being tried and related to an overall LOS. According to (Blackburn et al. 2004), the most popular measures are the following:

- Pavement conditions (visual)
- Performance indices relating amount of time pavement is covered in snow/ice to storm total (visual)
- Report cards (customer satisfaction surveys)
- Friction measurements and slipperiness ratings

When relating these measures to LOS in winter maintenance, the primary considerations are cycle time, available material treatments, weather and site conditions, and traffic considerations (Blackburn et al. 2004). Achievable LOS ratings are dependent on the average daily traffic (ADT) volumes of the facility and the capabilities of the agency. Roadway function levels often determine the type of treatment that will be applied to a facility in a specific type of weather event.

Agencies winter maintenance capabilities differ in terms of equipment, labor, and materials used for application. Two timeframes are to be considered when measuring performance-based LOS: within-winter weather event and after-end-of-winter weather event.

Two components compose a within-winter weather event, the amount of loose snow/ice/slush that is allowed to accumulate between plowing cycles and the condition of the ice/pavement interface in terms of bond and packed snow/ice. Often, plowing resource requirements is governed by the amount of loose snow allowed to accumulate on the road surface between plowing cycles (e.g., equipment resources). The plowing production rate is combined with the design snowfall rate to yield a cycle time required to meet an “accumulation” goal. The condition of snow/ice pavement interface in terms of bond or packed snow/ice is a function of pavement temperature, type of treatment, treatment application rate, and cycle time.

The time to achieve particular pavement surface conditions in terms of ice or snow coverage, or PSIC level, is expressed as the after-end-of-winter weather event LOS. Ratings are usually color coded or translated into letter designations A, B, C, D, and F (Blackburn et al. 2004).

2.5. Performance-Based Pay Items in Contracts

Contracts may allow the reimbursement to the contractor is based on the consumption of inputs, production of outputs, or the delivery of outcomes. Many contracts are a blend of inputs (pay items) with output or outcome levels (expectations). Input-based pay items are directly related to time and usage. The unit cost rate may be based on labor hours, equipment hours, or material

used. Output based pay items are related to work accomplishments in units of work performed. Outcome based pay is usually lump sum payments for a season of winter maintenance for a specified location (Bourdon 2001).

2.6. Innovative Use of Technology for Performance Measurement

It is becoming more common for winter maintenance vehicles to be equipped with technology for measuring performance. In Wisconsin, for example, AVL, GPS, material sensors, equipment sensors, and temperature sensors are some of the more advanced technologies that collect data to be used in improving the winter maintenance process and operational methods (Adams et al. 2003). Real-time data of material application rates, location, equipment status, and roadway characteristics allow for instant operational decision making along with post-operational analysis and summaries.

In 1999, the Wisconsin Department of Transportation installed AVL, material usage sensors, front and wing plow status sensors, under-body scraper sensors, and air and pavement temperature sensors to record data as often as every two seconds. Other state DOTs, including Iowa, Michigan, and Minnesota, have worked with Iowa State University and private vendors to equip vehicles with AVL, air and temperature sensors, friction meters, anti-icing and pre-wetting equipment, equipment status sensors, reverse obstacle sensors, and in-vehicle heads-up displays of sensor data (Adams et al. 2003).

The scanning review teams documented many international implementations of sensors. Japan uses ground-view sensors to monitor eight road surface conditions with the eventual goal of being able to adjust chemical applications automatically. Italy uses GPS and AVL technologies to assist with programming variations in chemical application and tracking and billing of materials the spreader has placed (Pisano 2004).

Research is being conducted on the use of automatic traffic recorders to record vehicle speeds to develop speed recovery time as a performance measure (Lee and Ran 2004). This research will combine the average vehicle speed reduction during a winter storm event with storm report data to determine the time needed to regain the normal vehicle speeds.

2.7. Winter Weather Severity Indexes

A roadway weather severity index is used in the road weather community to quantify the relationship between winter weather severity and roadway conditions or safety. Most weather severity indexes provide only measures of relative severity of an entire seasons and this only allows a seasonal comparison of the relative severity of winter. Several winter severity indices developed for general or for specific purposes are described as the following:

Hulme and Modified Hulme Index

Hulme made one of the first attempts to develop a winter index to numerically classify winter severity. A winter was defined as the time between the first of December and the end of March

(Hulme 1982). This index uses three parameters in the winter index computation: the mean daily maximum temperature, the number of days with snow lying at 9:00 a.m., and the number of night ground frosts (Hulme 1982). A constant was also added into the equation to ensure that the weather index averages to zero. The original and modified indices are expressed by the following equations:

$$\text{Winter Index: } WI = 10T - 18.5S - F + 200$$

$$\text{Modified Winter Index: } WI = 10T - (18.5S)^{1/3} - F + C$$

A low index value indicates a severe winter, while a high number indicates a mild winter that can only be used to summarize seasonal weather.

Pennsylvania Department of Transportation Index

Rissel and Scott (1985) developed a winter severity index for the Pennsylvania DOT based on total meteorological data to relate the severity of winters to labor costs to help establish optimum winter staffing patterns and determine staffing cost-effectiveness. The index is presented in the following equation:

$$SI = S + 2M + H + T - (C/2) + R$$

Where:

- (S) is the total inches of snowfall in a period.
- (M) is the number of days with snowfall of 1 to 6 in.
- (H) is number of days with snowfall greater than 6 in.
- (T) is the number of days with a maximum temperature above 32 degrees F and a minimum temperature below 32 degrees F.
- (C) is the number of days with temperatures below 32 degrees F.
- (R) is the total hours in the period when snow or ice occurs.

Strategic Highway Research Program Index

Boselly et al. (1993) developed as part of the Strategic Highway Research Program, SHRP Project-H-350, a winter index that quantitates expression of winter severity. The index is defined by the following four equations:

$$WI = -25.58\sqrt{TI} - 35.68\ln\left(\frac{S}{10} + 1\right) - 99.5\sqrt{\left(\frac{N}{R + 10}\right)} + 50$$

Where:

- TI is the average daily temperature index
- S is the mean daily snowfall
- N is the mean daily values of number of days with air frosts
- R is the temperature range

$$WI = a\sqrt{TI} - b\ln\left(\frac{S}{10} + 1\right) - c\sqrt{\left(\frac{N}{R+10}\right)} + d$$

This is the index expressed in a general form where a, b, c, and d are coefficients that reflect are particular weights and critical values of the parameters in each term, for typical weather conditions encountered at a given location. In this study, the variables were weighted to account for the critically significant level of each parameter to winter maintenance cost.

The Kansas DOT and Mn/DOT have adopted this index, and Ontario has modified the equation to include freezing rain by adding the number of freezing days (McCullouch et al. 2004).

University of Waterloo Index for Ontario Highways on Salt Use

Audrey et al. (2001) conducted a study to assess the suitability of indices developed by Boselly, et al.; Hulme; and Salt Day, which explains the temporal and spatial variability of salt use on highways in Ontario, Canada. The indices were modified to reflect Ontario's climate. The frost term in the SHRP model was replaced with a freezing rain indicator to better represent the variability in monthly salt use. The SHRP model was found best suited for Ontario because it places the most emphasis on snowfall. The adapted model is presented by the following:

$$WI = -25.39\sqrt{TI} - 23.27\ln\left[\frac{S}{10} + 1\right] - 99.5\sqrt{(frz)} + 50$$

Where:

1. TI is the average daily temperature index
2. S is the mean daily snowfall
3. Frz is freezing rain indicator

Knudsen Developed Index in Denmark

Knudsen (1994) developed a winter index in Denmark for every day and county, that considers road temperature, the number of road freezes in a day, snowfall, and presence of snow drift. The index is presented as follows:

$$WI = \sum_{Oct\ 15}^{Apr\ 15} WI_{Day}$$

$$WI_{Day} = x_{freeze} (1 + x_{frost} + x_{refreeze} + x_{snow} + x_{drift})$$

This index did not reveal a relationship between winter maintenance expenditures and index values, but the relationship between the index and salt consumption was $R^2=0.96$ on a seasonal basis.

Indiana Winter Severity Index

McCullouch et al. (2004) developed a winter severity index for the Indiana DOT based on surveys of field crew and employees to identify the weather factors that had the most influence on the snow and ice removal effort. The survey factors were the number of days with temperature and dew point below freezing, the number of days with freezing rain, the number of “snow event days”, and the number of days with drifting snow. To improve correlation within the model, three additional factors were included in the equation. They were snow depth, snow duration, and average temperature.

To account for regional climate differences within the state, separate equations were developed for each zone. The following statewide equation was developed:

$$WI=0.71839*Frost+16.87634*FreezingRain+12.90112*Drifting-0.32281*Snow+25.72981*Snow\ Depth+3.23541*Hour-2.80668*Average\ Temperature$$

Iowa State University/Iowa DOT Index

Carmichael et al. (2004) developed a winter weather index for estimating winter roadway maintenance costs in the Midwest. To relate to winter maintenance costs and weather parameters the index utilized both regression analysis and neural networks for correlation calculations concerning the following:

- Precipitation
- Temperature
- Date
- Wind

To factor in dependent cost variables, operations data were also used. The index is used to judge how well the maintenance personnel performed statewide each winter season by estimating what costs should have been incurred and the amount of hours that should have been used in winter maintenance.

Wisconsin Winter Severity Index

The Winter Severity Index used in Wisconsin to evaluate the counties’ performance on snow and ice removal, is expressed by the following equation (McCullouch et al. 2004):

$$WI = 10 * \frac{SE}{63} + 5.9 * \frac{FR}{21} + 8.5 * \frac{AMT}{314} + 9.4 * \frac{DUR}{1125} + 9.2 * \frac{INC}{50}$$

Where:

1. SE is snow events
2. FR is freezing rain events
3. AMT is snow amount
4. DUR is storm duration
5. INC is incidents (including drifting, cleanup, and frost runs)

Nixon and Qiu Index

Nixon and Qiu (2004) developed a storm severity index based upon that developed by Boselly, et.al., in the SHRP Project H-350, to determine to what extent an individual storm poses difficulty to maintenance activities. This index is unique in that provides a measure of severity for any given storm based on meteorological data. The utility of this index is but one step in the process of creating a quality controlled winter maintenance program. This index provides agencies with storm by information thus; it can be used to measure the performance of a given agency in handling a given storm and as such represents an important part of a quality control process for winter maintenance. The index uses a matrix of possible storms to classify events.

The equation is expressed as follows:

$$SSI = \left[\frac{1}{b} * [(ST * Ti * Wi) + Bi + Tp + Wp - a] \right]^{0.5}$$

Where:

1. ST describes storm type
2. Ti is the in-storm road surface temperature)
3. Wi is the in-storm wind condition
4. Bi is the early storm behavior
5. Tp is the post storm temperature
6. Wp is the post storm wind condition and
7. A and B are parameters to normalize the storm severity index from 0 to 1

Transportation Association of Canada Index

According to its website, the Transportation Association of Canada (2005) is currently developing a winter severity index that will allow the forecasting of the relative harshness of a given winter compared to a base year for each province and territory. The index will be based on

an assessment of other existing indicators used throughout the world and their applicability for use in Canada, while tailored to each jurisdiction.

Washington State Department of Transportation Index

The Washington State Department of Transportation (WSDOT) developed a frost index, which was found to directly relate performance measurement in winter activities. The frost index is a severity index that does not include the snowfall factor and was planned for use to justify an overrun in the snow and ice budget in case of supplemental funding (Perry and Symons 1991).

Strong and Shvetsov Index

Strong and Shvetsov (2005) used data from California, Montana, and Oregon to quantify relationships between winter weather and safety. Linear models were developed for different topographic zones and statewide to predict the cubic root of the crash rate as a function of weather parameters. The models incorporated weather data from National Weather Service stations, crash data within five miles of the weather stations, and annual ADT volumes with monthly adjustment factors.

The Salt Day Indicator

A “salt day indicator” was developed by the Illinois State Water Survey and is being used by the Illinois DOT. The index is a count of a number of days within a month that meet specific criteria for snow removal budget allocations through short-term forecasts (Cohen 1981). The equation is expressed as follows:

$$WI = D_{\text{snow}} + D_{\text{cold}}$$

Where:

D_{snow} = Daily snowfall accumulation is greater than or equal to 0.5 in.

D_{cold} = Number of days where mean daily temperature is between 15° and 30°F

Road Sense Index

The Road Sense Index sponsored by the Insurance Corporation of British Columbia to estimate winter driving risk for the greater Vancouver metropolitan area, by correlating weather parameters with safety. It was intended to alert motorists about hazardous conditions so drivers can adjust their driving behavior (Chen et al. 1994).

Decker Index

This index was to develop a measure of winter maintenance efficiency, accounting by considering labor, equipment and material costs as influenced by storm severity and duration to achieve a specific number of lane-kilometers of given LOS. The index was based on the SHRP equation, and is expressed by the following (Decker et al. 2001):

$$WI = -25.59\sqrt{TI} + -11.50\ln\left(\frac{S}{10} + 1\right) - 99.50\sqrt{\left(\frac{N}{R+10}\right)} + 50$$

CHAPTER 3. WINTER MAINTENANCE MEASURES USED BY HIGHWAY AGENCIES

This chapter identifies and discusses the winter maintenance performance measures used by several states, provinces, cities, and counties. There is a broad range of uses of performance measurement, ranging from not measuring performance of snow and ice control at all to those exercising sophisticated measures of performance of operations. The landscape of performance measurement is wide ranging. While many agencies stated the need for performance measurement, only a few of these have established a formal performance measurement process for their operations. In general, the agencies have focused their efforts on achieving the desired results of effective snow and ice control to meet the demands of the traveling public.

3.1. Survey Results

In this project, a survey was sent to 162 winter maintenance operations personnel including some in other countries. The targeted survey respondents were from local, state, and federal agencies. The respondents were chosen to provide feedback unique to their areas of expertise.

Of the 162 surveys distributed, 43 surveys were completed included responses from state DOTs, four Canadian provinces, one response from Sweden, one from Japan, one from the City of Edmonton AB, and 17 from cities and counties in the U.S. Table 2 lists the agencies that responded to the survey. The responses provided insights into the use of performance measures in winter maintenance operations, particularly in the northern hemisphere regions. The map in Figure 3 indicates the jurisdictions that responded to the survey. The respondents were primarily from the United States and Canada.

The specific responses from the 43 agencies are found in Appendix B, and the findings of the survey are presented in this chapter.

Table 2. Locations responding to the survey

U.S. state agencies responding	U.S. cities/counties responding	Provinces/countries responding
Alaska DOT	Ada County Highway District, ID	Manitoba, Canada
Washington DOT	Detroit, MI, Public Works Department	Ontario, Canada
California (CalTrans)	Minneapolis, MN, Public Works Department	Alberta, Canada
Arizona DOT		Saskatchewan, Canada
New Mexico DOT	Des Moines, IA, Public Works Department	Canadian cities responding
Nevada DOT		
Colorado DOT	Jackson County, MO, Public Works Department	
Kansas DOT	Erie County, NY, Public Works Department	Other countries responding
Nebraska DOR	Indianapolis, IN, Public Works Department	
Iowa DOT	King County, WA	
Missouri DOT	El Paso County, CO, Department of Transportation	Swedish National Road Administration
Wisconsin DOT		Japan
Illinois DOT	Cedar Rapids, IA, Street Department	
Indiana DOT	Mc Henry County, IL, Division of Transportation	
Ohio DOT	Seattle, WA, Department of Transportation	
New York DOT		
New Hampshire DOT		
Maryland SHA		
Minnesota DOT		
	Douglas County, NE	
	West Des Moines, IA	
	Washington County, MN	
	Cook County, IL, Highway Department	
	Cuyahoga County, OH, Engineer's Office	

Performance Measures

The respondents identified the methods used for conducting snow and ice removal operations. As Figure 2 indicates, the majority of respondents, (65%), are using their own staff for snow and ice control. The remaining states or provincial agencies responded that they contract with others

to perform the operations, including private contractors or local agencies to plow selected routes performing all snow and ice control operations. Outsourcing of this work is usually done to reduce expenditures.

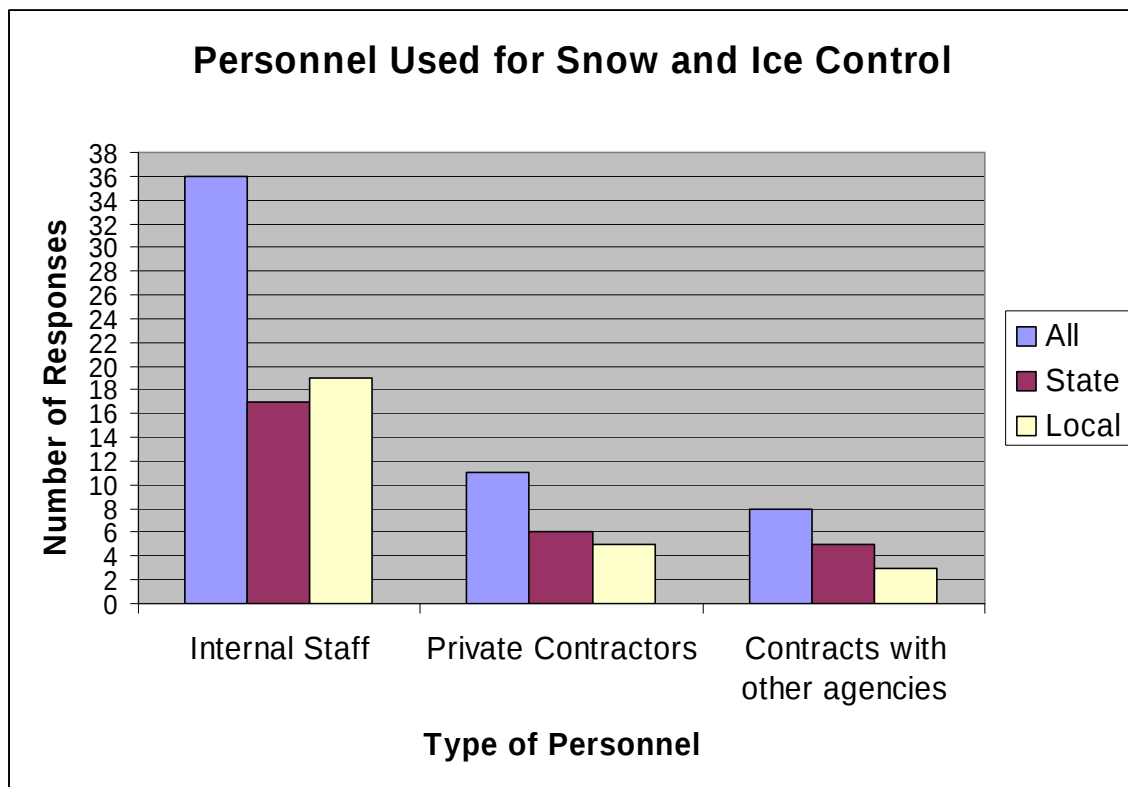


Figure 2. Personnel used for snow and ice control

The respondents who stated that they contracted out snow and ice control were asked if an evaluation of the contractors' performance was in place. In most instances, the contracting agency evaluates the contractors' performance to ensure that the contractor is meeting its obligations. However, four respondents indicated that they do not evaluate contractors' performance. Evaluating contractor's performance helps in to meeting the traveling public's expectations for clearing the roads in a reasonable amount of time. One example is evaluating the contractor's performance is the Virginia DOT (see Figure 3). VDOT has the contractor specify, as much as possible, the measurable outcome to be achieved. VDOT also requires contractors to prepare their own Snow and Ice Plan as to what resources will be used and how they will be used to achieve that outcome. Finally, VDOT require that the contractor's Snow and Ice Plan be approved by the owner-agency prior to the contract award.

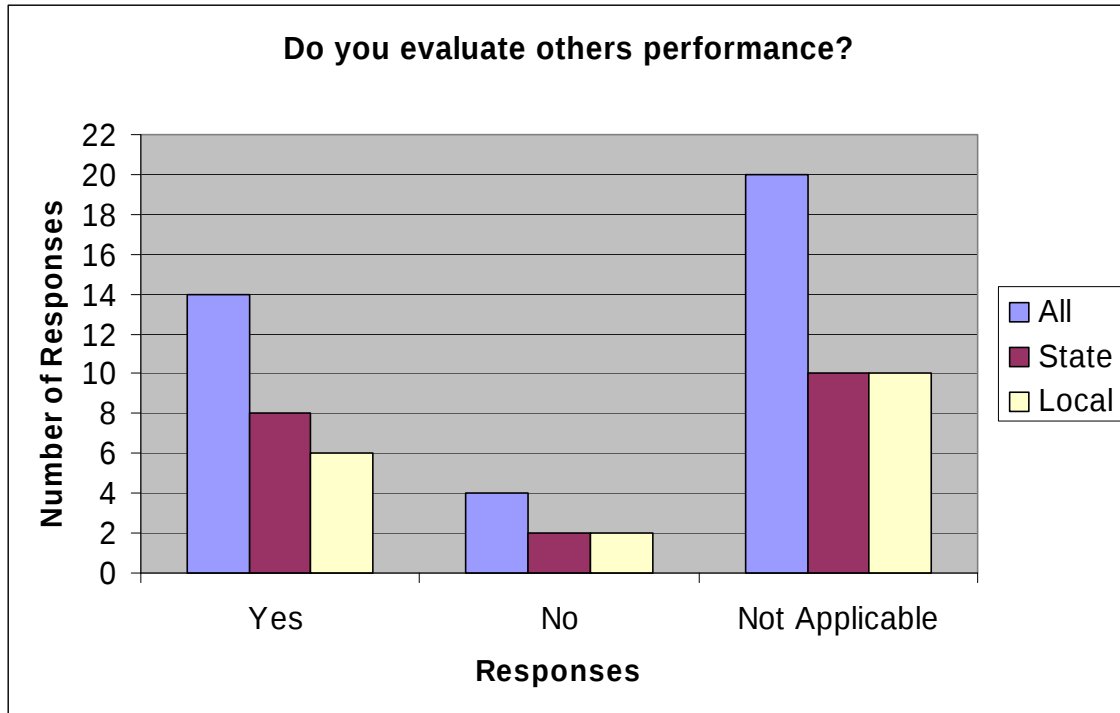


Figure 3. Evaluation of performance

The responding agencies described the relationship of contractor performance to the payment for work done. In eight instances, the contractor's performance is linked to payment, as indicated in Figure 4. However, in 11 cases, no formal method to tie the contractor's performance to payment was reported.

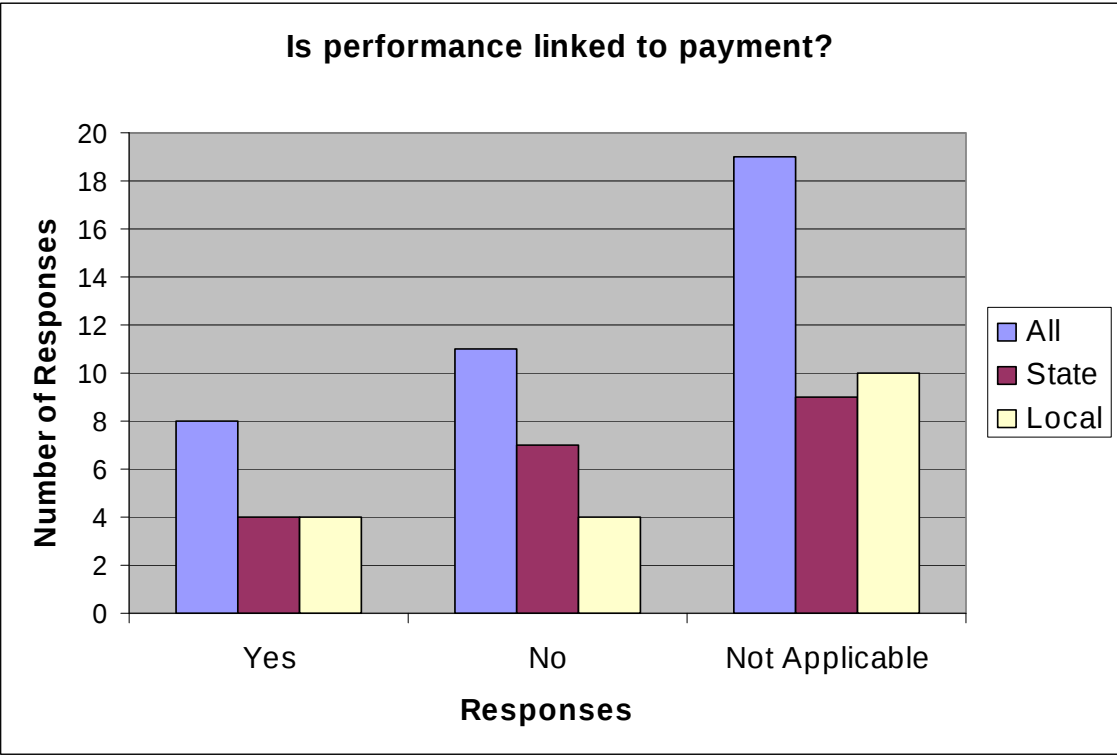


Figure 4. Performance and payment

Thirty-three agencies, including 16 state and provincial agencies and 17 local agencies reported that they measure performance in snow and ice control operations. Figure 5 indicates the performance measures used by the respondents.

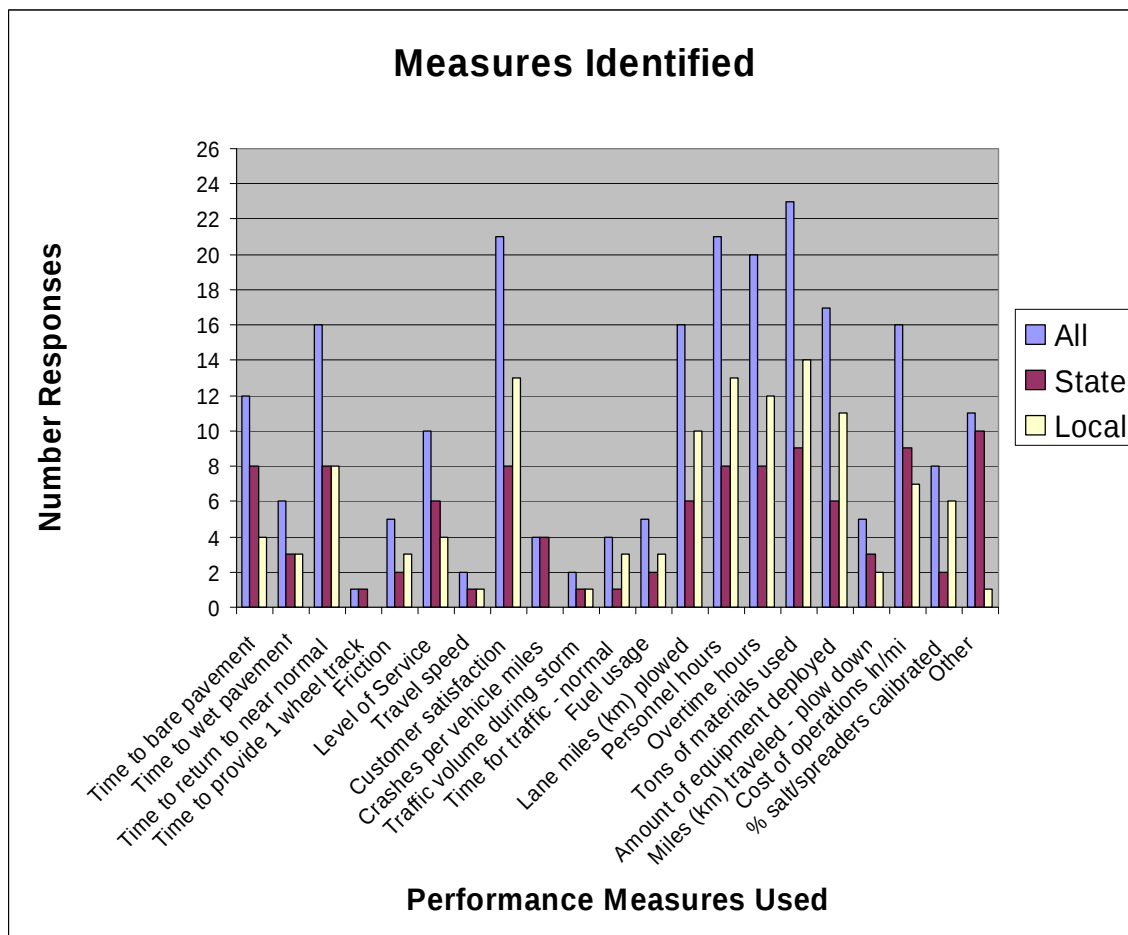


Figure 5. Performance measures used by various agencies

A number of the measures identified are traditional measures that are being tracked, primarily for budget purposes. However, four agencies are experimenting with other measures such as friction measuring devices, road closures, snow depth, and number of times tire chains are required. The following “traditional” measures often cited by local agencies and also by state agencies:

- Fuel usage
- Lane-miles plowed
- Personnel hours
- Overtime hours
- Amount of equipment deployed

Other popular measures cited by all levels of agencies are:

- Time to bare pavement
- Time to return to near-normal conditions
- LOS (mobility)
- Customer satisfaction

Of the agencies using friction as measure, Sweden has the most advanced system of incorporating friction measurement into a performance measurement. The friction coefficient is determined in accordance with the Swedish National Road Administration (SNRA) methods and specifications, and “trigger” values are used to determine those areas where the friction is less than adequate and additional treatment is required. The Ohio DOT is also experimenting with using friction as a measurement, but at this point using friction is still in the testing phase.

The survey sought information on how the agency decides which items to measure in snow and ice control operations. Statewide guidelines, committee input, and budget decision processes were the most common responses. State and provincial agencies, frequently indicated that statewide guidelines, plans, and policies shape the performance measurements. These plans may be made by committee with local input, but the states seem to strive toward a statewide standard of performance measurement. Specific responses from the states included the following:

- Statewide winter operations teams recommend measures, with management approval.
- Measured items chosen using existing guidelines and evolving technology.
- Data are used that were already being captured (road condition information).
- Measured as stated in the agency’s policy and procedure manual.
- Performance measures on bare pavement, material usage, and cost of operations are detailed in the business plan, which is developed by senior managers. Performance measures for hired equipment are determined by the Statewide Maintenance Quality Council, which is composed of district and statewide maintenance managers.

Local agencies use of performance measures is budget driven. Local agencies seem to use traditional, i.e., tried and true, measurements that are required for maintenance management systems. Local agencies select performance measures with consideration to the following:

- Resources and safety
- Customer indicators and fiscal barriers
- Budget planned versus actual cost for snow and ice; the standard cost per mile versus actual cost per mile
- Materials, personnel, and amount of equipment used
- Maintenance management systems outcomes
- Decision by department commissioner

Several agencies indicated that they measured inputs and outputs, but have not established any formal performance measurement process. The input and output measures were tracked for budgetary reasons; some measures were simply tracked because they “have been historically tracked” or were to be input into the management system. Many of the agencies are attempting to

determine the important items that should be measured and how to determine their effectiveness, and also how to meet the increasing expectations of the public for bare pavement.

Responding agencies also identified safety and mobility of the traveling public as the most critical to snow and ice control operations. Twenty-five of the responding agencies indicated pavement condition or public safety as most critical to their snow and ice control operations. The amount of time to return the pavement to “normal” driving conditions and to minimize traffic delays were the focus of the responding agencies. Snow and ice control operations relate to customer satisfaction, which was mentioned by ten agencies; therefore, agencies at all levels are striving to strike a balance between the public’s expectation of clear roads and budget constraints.

Most agencies stated that targets are set annually, usually after the snow and ice season, and the review of how operations were performed. Some agencies established targets more frequently. For example, Iowa DOT stated that it sets targets or objectives quarterly; El Paso County, Colorado, establishes its objectives semiannually; the Ohio DOT sets its objectives as an ongoing process, the Missouri DOT sets its performance objectives on an “as deemed necessary” basis. Sweden, which hires contractors for its snow and ice control operations, set performance objectives any time changes are made in the contract or in the operating rules. Typically, a contract is set for five years. Figure 6 describes the frequency target setting reported by the responding agencies.

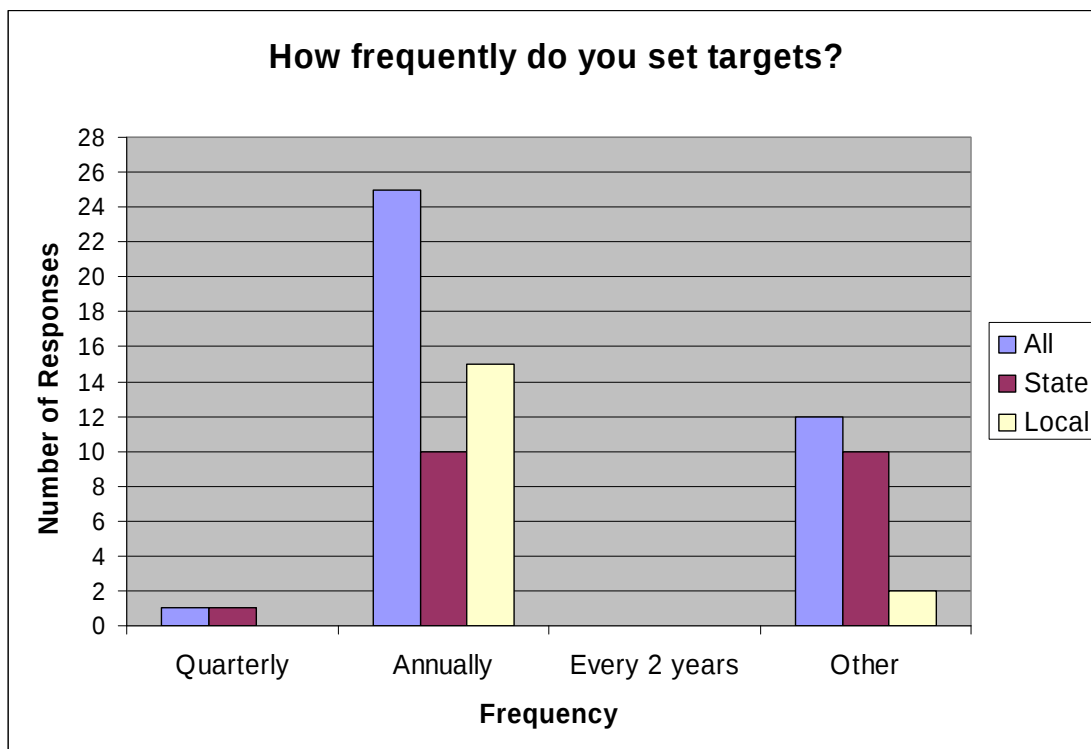


Figure 6. The frequency with which targets are set

Providing mobility for the traveling public was cited 25 times by the respondents and ensuring safety for the traveling public was cited 18 times by the respondents as one of the most important objectives for snow and ice control operations. Other objectives cited by the respondents included efficient use of resources, meeting customer satisfaction, and protecting the environment.

Measures and Performance Level

While many input measures are tracked, usually for budgetary purposes, specific performance levels are often not established. However, some agencies have established performance measures and performance levels to ensure proper measurement. Table 3 indicates a sample of measures and performance levels indicated by the respondents.

Table 3. Performance measures and performance levels

Measure	Performance Level
Time to wet or dry condition; safe travel way for category I routes	As soon as possible after end of storm bare/wet wheel paths
Time to clean up in urban areas after storm event stops	18 hours
Monitor police and public observational/calls	Minimal complaints/calls
Bare Pavement	Reaching wet or dry pavement within 8 hrs of the ending of frozen precipitation
Salt	Annual usage
On high volume roadways, return roads to reasonable, near normal conditions within 24 hours	95%
Follow Maintenance Best Practices (circuit time) contract equipment complement	Meets theoretical circuit time
Safety	Crash rates
Time to bare pavement	depends on ADT
Friction	Friction value
Time to wet or dry condition	As soon as possible after end of storm
Costs	Budget levels
Snow depth	Centimeters

The respondents indicated that roadways with higher ADT receive priority for treatment and specific measures and performance levels are established for the higher volume roads. The time frame to achieve the target for the lower traffic volume roads is longer. As Figure 7 illustrates, most of the data are obtained through observation, either through field observations or from maintenance workers or law enforcement personnel. Some local agencies use closed circuit television cameras from the freeway management systems. Post-processing of information is conducted by some states, in that they obtain data from accounting records to measure how the agency performed.

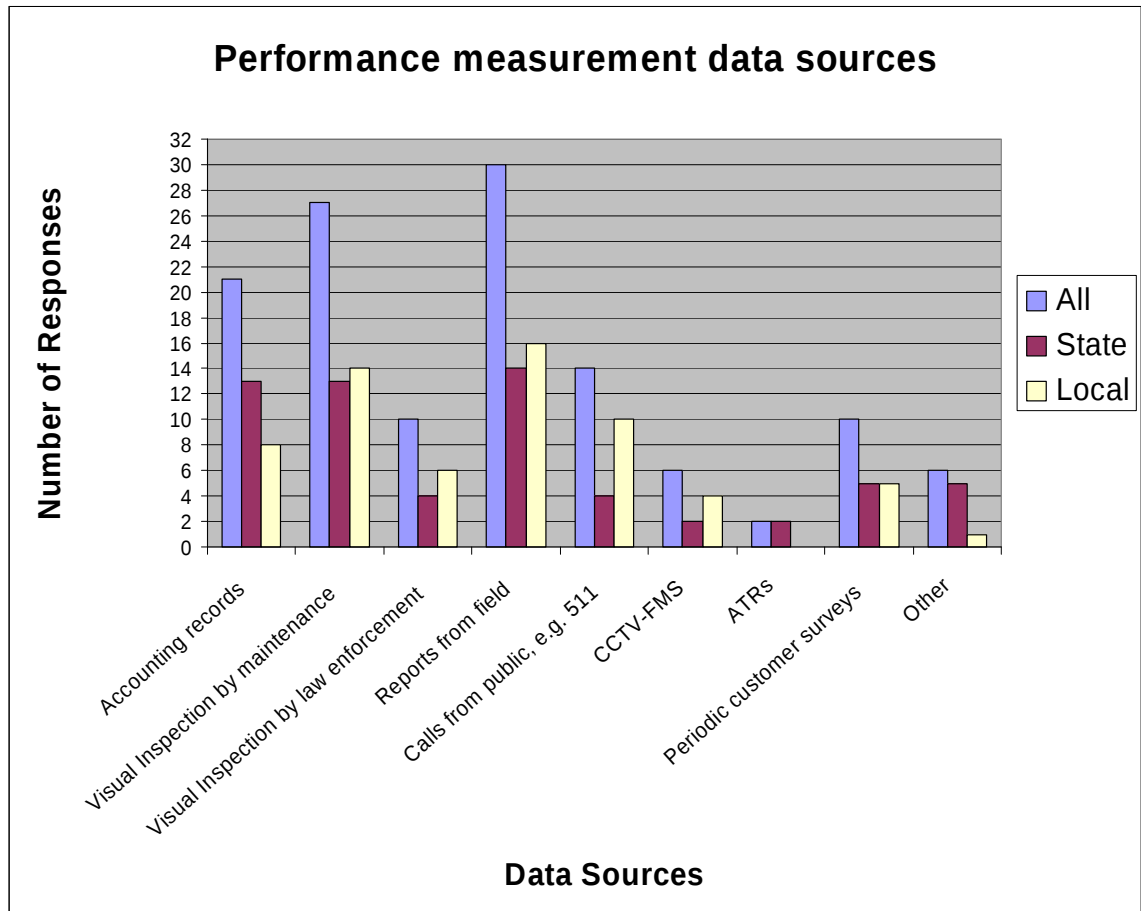


Figure 7. Data sources for performance measurement

As for other measurements, Ohio DOT and the Swedish National Road Administration (SNRA) use friction measurements. The SNRA contracts the snow and ice control, and then obtains the contractors' records including automated vehicle location (AVL). The contractors must meet ISO 9000 quality standards. Ontario's contractors also have AVL in some locations. Through tracking these vehicles, the contracting agency can better ensure the vehicles are treating possible problem areas.

The respondents were then asked whether they conducted surveys of the general public about the agency's performance of snow and ice control. This is important because several agencies

indicated that customer satisfaction was viewed as a critical measure to their performance. The respondents were evenly divided as to whether they conducted surveys of the general public (see Figure 8).

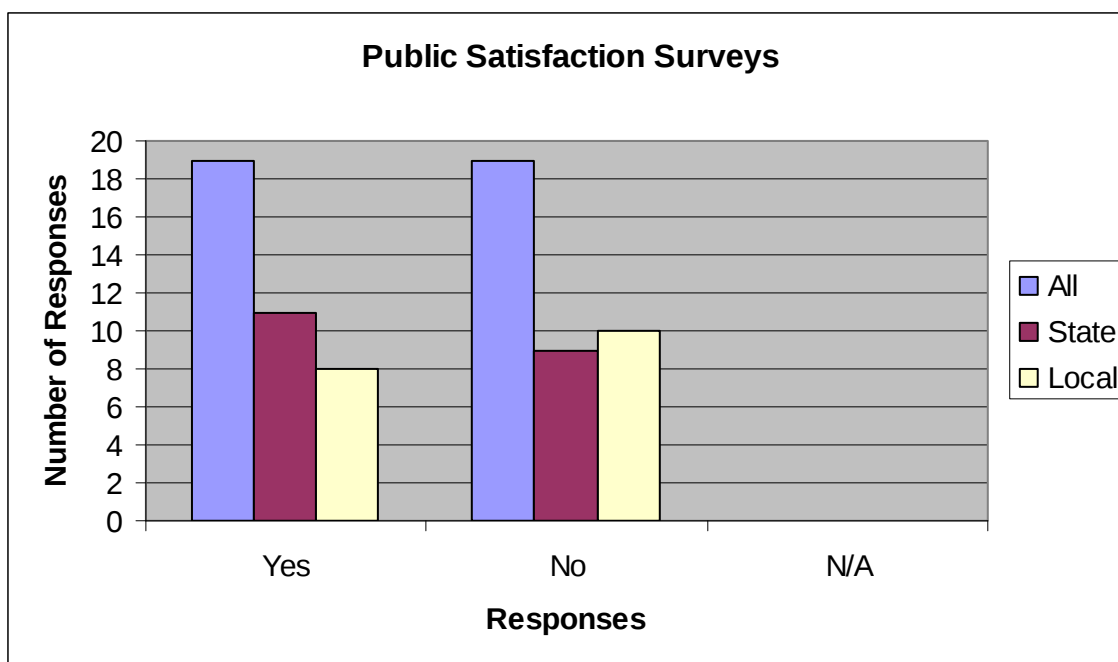


Figure 8. Agencies using public satisfaction surveys

Agencies that have conducted surveys reported that the public viewed their performance favorably, although several respondents indicated that the public's expectations of service are higher than anticipated. For example, the Colorado DOT indicated that the public rated its performance between B and B-. Sweden stated that its survey indicated that the public rated its performance on higher traffic volume roads as good, but poor on lower traffic volume roads. (This ranking is consistent with the priority placed on higher traffic volume roads.)

About four of the respondents use the same performance measures for roads with different volumes and surfaces (see Figure 9). About one-third reported that higher traffic volume roadways receive priority and are treated first, before those roads with lower traffic volumes such that the higher volume roads are reaching near-normal conditions faster than the lower traffic volume roads. (A listing of agencies that conducted public satisfaction surveys is included in Appendix C.)

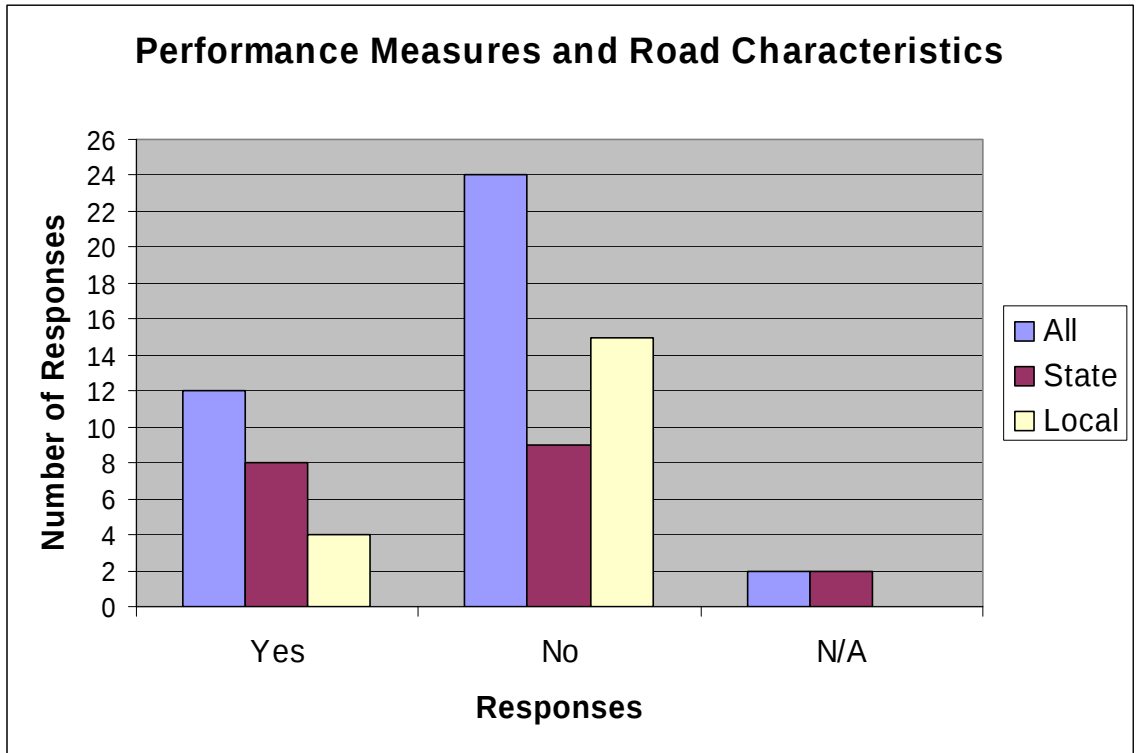


Figure 9. Performance measures and road characteristics

As Figure 10 shows, a majority (55%) of the respondents indicated that performance objectives do not vary with road or storm characteristics, although state agencies were nearly equally divided. For the most part, local agencies indicated that their objectives did not vary with storm or road characteristics. The variations of performance objectives were very similar to the question earlier in that the respondents indicated that the higher traffic volume roads had higher priority for treatment than lower volume roads. The roads with the higher traffic volumes are to achieve bare pavement status more quickly than lower traffic volume roads.

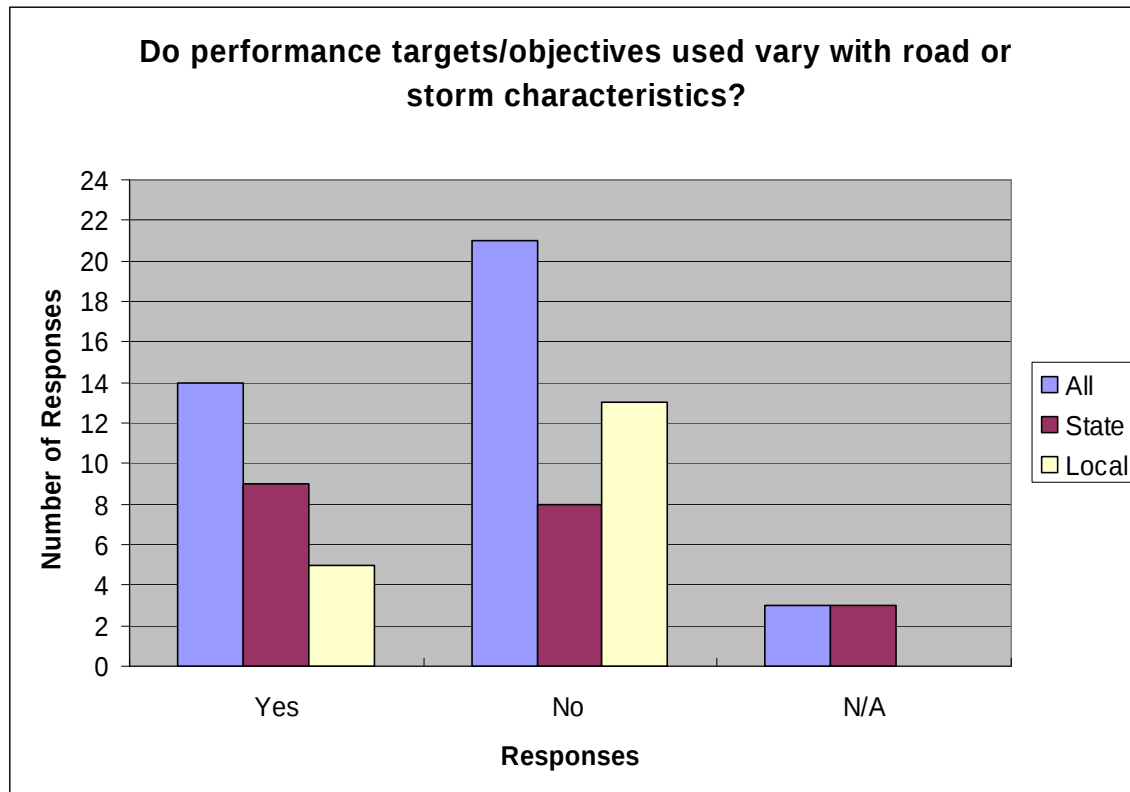


Figure 10. Performance objectives and storm characteristics

Non-storm events, such as the treatment of black ice and bridge frost can be problematic for the agency. As Figure 11 shows, the majority of the respondents (66%) indicated that performance measurement was not used specifically for these non-storm events, although several agencies incorporated such events into the overall snow and ice control plan, and that treating bridges, black ice, blowing snow, etc. are part of the agency's snow and ice control procedures. However, many of these non-storm events are treated after the treatments on the priority routes are completed. In Sweden, for example, after the precipitation has ended, all Class 1 roads are to be snow- and ice-free and achieve a 0.25 friction coefficient. Alternatively, the Iowa DOT indicated that bridge frost events are handled separately and are made part of the forecasting service. Garages are asked to report on bridge frost, regardless of whether a frost event was forecast.

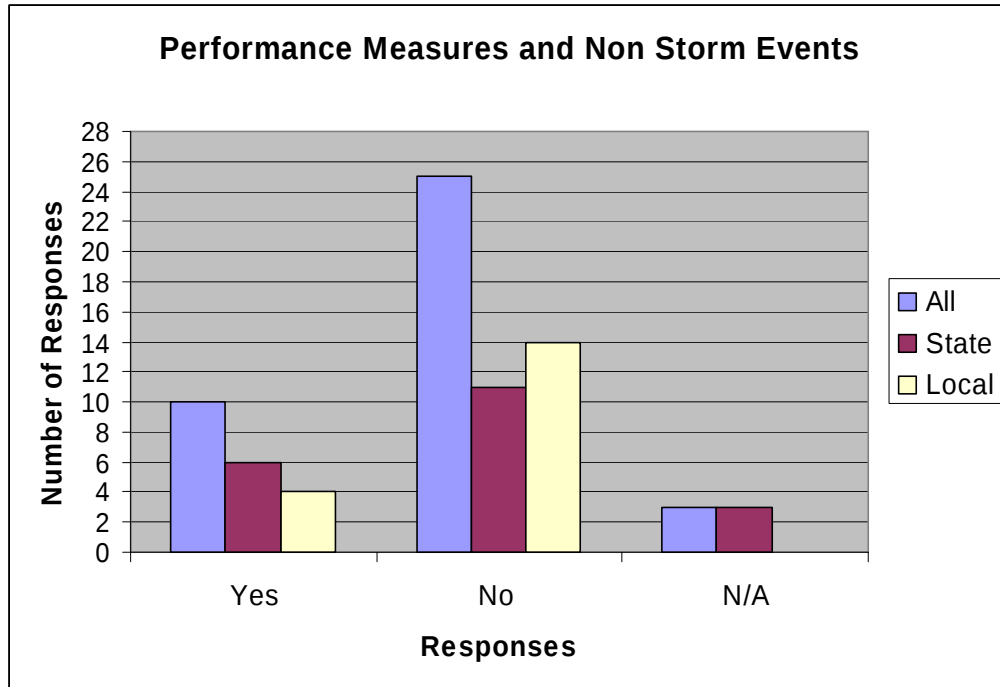


Figure 11. Agencies using performance measurement used for non-storm events

As Figure 12 shows, the majority of respondents (74%) indicated that they did not use a storm severity index as a means to classify or rank winter storms so that improved methods can be developed to combat the storms.

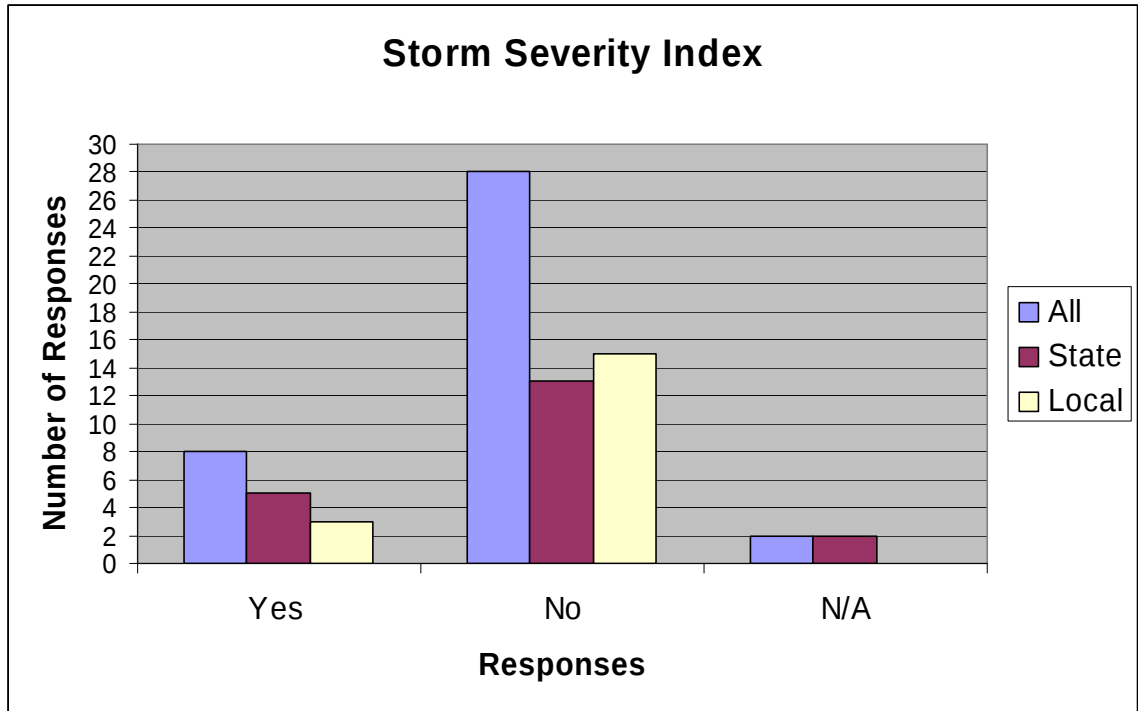


Figure 12. Agencies using storm severity index used

The agencies using an index stated that the indices are still fairly new and under development. Two respondents indicated using the weather index developed by under SHRP H-350. However, other agencies have been developing indices to meet their particular needs. The Indiana DOT, for example, is using a weather index developed by Purdue University that incorporates data from the National Weather Service and four regions in Indiana. The Iowa DOT reported that it is working on an index that includes data from its daily reports to provide more detailed weather information than is available from other sources.

The majority of the respondents (63%) indicated that they do not report road and pavement conditions to the general public based on any performance measurement system (see Figure 13). The most common methods used to report road and pavement conditions to the general public are on the agency web sites and broadcast media, such as radio and television. The use of these methods allows agencies to reach as many people as possible. However, Sweden reported using cell phones to report road and pavement conditions to specific individuals

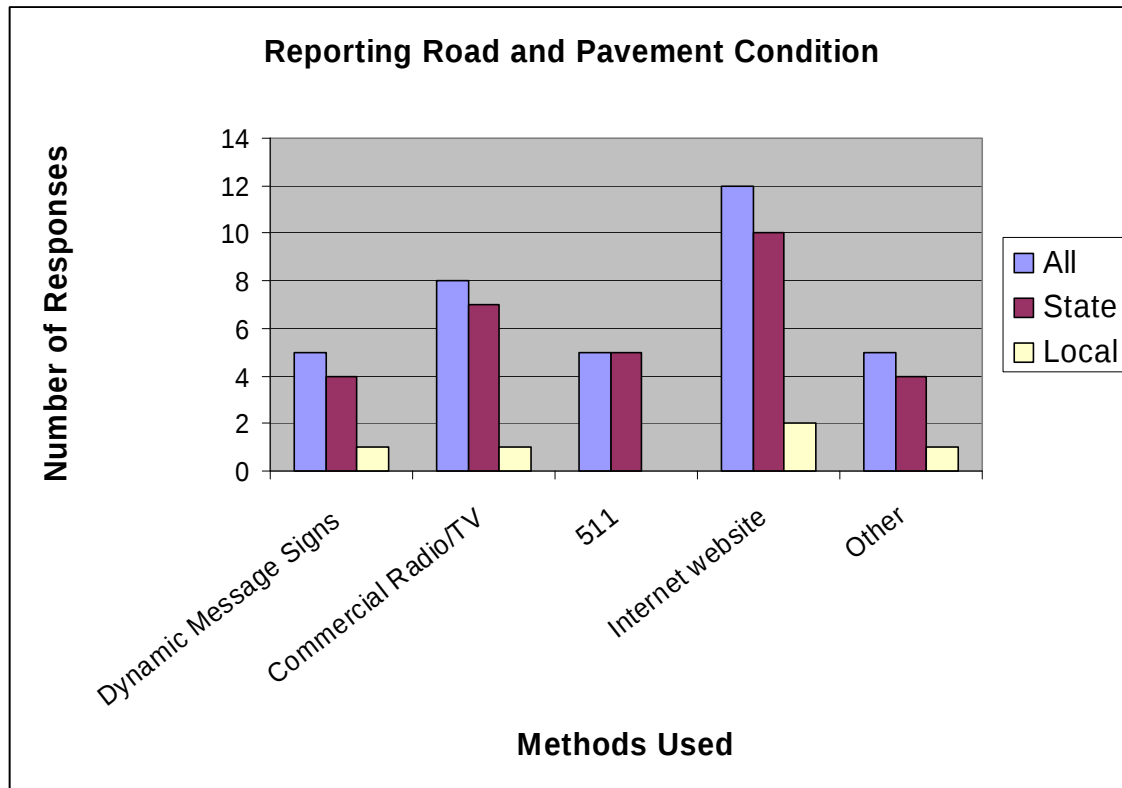


Figure 13. Methods to report road condition

Budget and Operations

Virtually every agency reported budget concerns such that budget constraints could impact performance measurement. Most of the respondents indicated using a type of financial management system to track expenditures. Several respondents indicated that they budget for a “normal” winter season, and then track expenditures. Most of the respondents indicated that they review their activities at the end of the winter season in an effort to gauge performance. Several agencies indicated that they tracked costs by activity, lane-miles plowed, material usage, personnel hours, equipment used, and general costs of operations. Budgets are set based on historical data and respondents indicated availability of budget information dating back years that they can use to track expenditures. For example, Maryland has a Quality Assurance Team that prepares a detailed report following the season to review its performance and that of the weather service provider and the Colorado DOT uses the survey and expenditure information to form its LOS-based budget. In spite of the detailed cost information little information is available on determining effectiveness.

As Figure 14 indicates, 58% of the respondents that measure performance segment the highways for measurement. Most of the roadways were segmented by location, either by maintenance district, county, or highway route. Other areas were segmented based on traffic volume. A unique method of segmenting the measurement area is used in Colorado, which uses a random number generator to select mileposts within a number of routes and then classifies the selection

by ADT and roadway type. This segmentation is done to prioritize resources to where they are most needed.

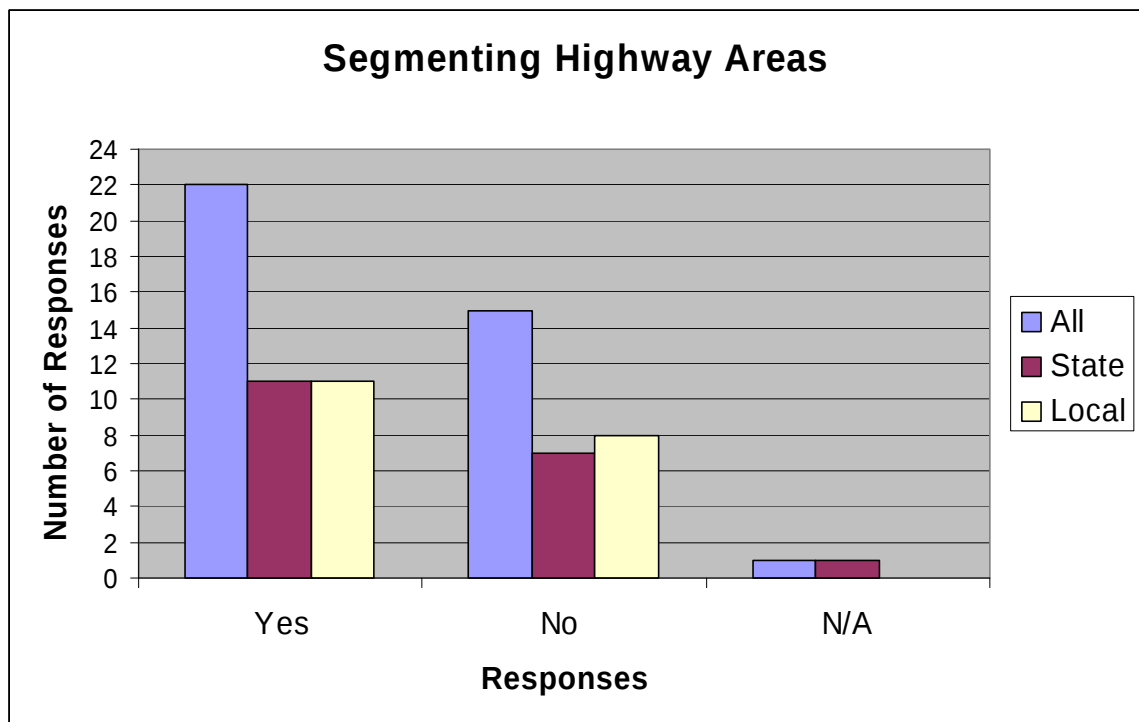


Figure 14. Agencies segmenting highway areas

Benefits of Performance Measurement

Figure 15 shows that slightly more than one-third (34%) of the respondents indicated that performance measurement led to improved decision making in snow and ice control. Improved communication, both internally and externally, were listed as important benefits as well. There were only slight differences in the responses from state or local agencies. Both groups identified similar benefits. Other described benefits included uniformity of services delivered, more effectiveness in products being applied, and the ability to present a budget model that supports funding levels necessary to achieve the target LOS. These benefits can lead to a more uniform LOS throughout the state while reducing expenditures.

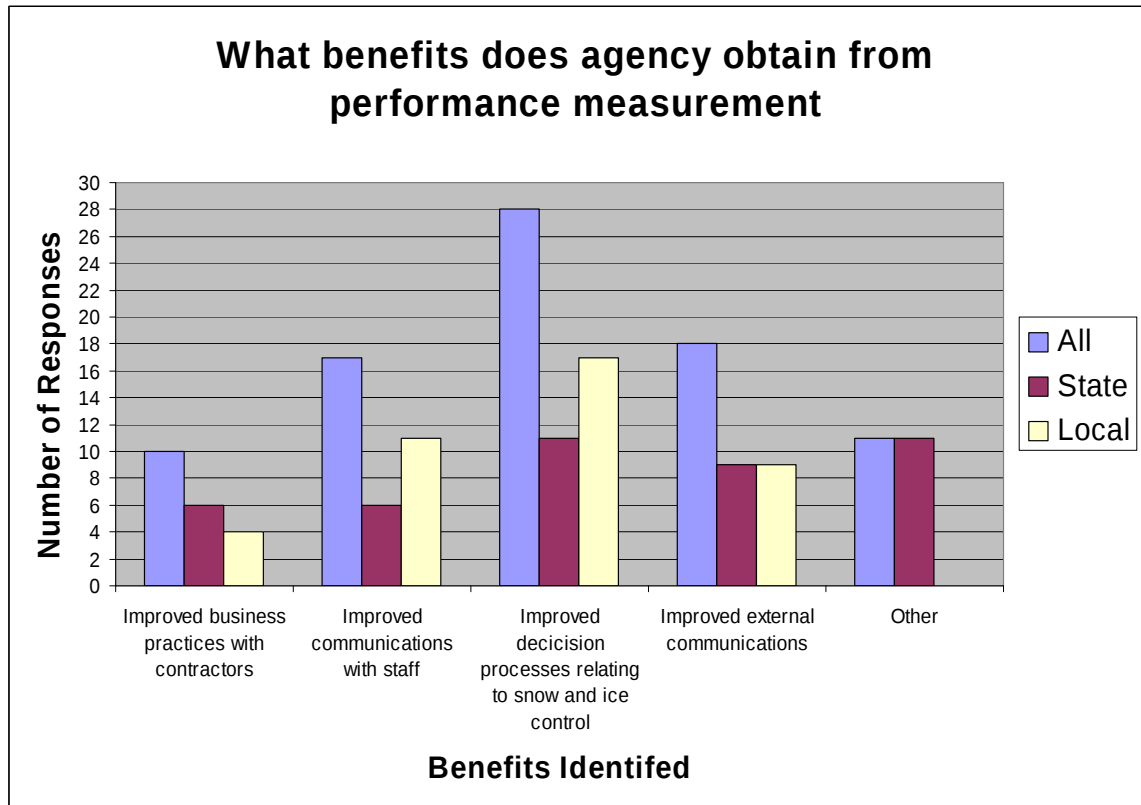


Figure 15. Agencies identifying benefits

Technology Applications

The use of automated vehicle location (AVL) and global positioning systems (GPS) on equipment was a popular choice among the responding agencies to help better measure performance. Contractors in Ontario, for example, use AVL and GPS, Saskatchewan also uses GPS to track its trucks and materials and the New York State DOT has vehicles equipped with AVL. The AVL systems allow agencies to track equipment and better determine where resources are to be deployed.

The deployment of friction wheels is another technology application used by some of the respondents. This is a technology that has had mixed results. While these devices have been used extensively in the aviation industry to measure runway friction, they have not been widely used on highways. The Ohio DOT is currently evaluating the use of friction meters. Sweden has incorporated friction measurement into its performance standards. Friction coefficients have been established for each class of roadway that are to be met by the contractors. Conversely, the Iowa DOT experimented with friction wheels, found the concept to be sound, but the devices to be unreliable and too costly to deploy statewide. Ontario is considering a pilot project using friction measurement. Previous testing has shown it to be promising.

Other technologies being used include expanding the uses of RWIS data in making operational decisions. Road Weather Information Systems (RWIS sites) are typically owned by

transportation agencies and automatically report ground (or roadway) level weather variables such as ground, pavement, and bridge deck temperatures, wind speed at the surface, the presents of surface level participation, pavement contaminates, and other ground level weather parameters. For example, the Maryland State Highway Administration uses data from RWIS stations to supplement and occasionally validate that the pavement is actually bare as reported. RWIS data are also used in some areas to verify the salinity of the road treatment. The Iowa DOT uses automated traffic recorder (ATR) data in some areas to obtain traffic speed, and plans to experiment with combining speed and RWIS data in its performance measures program.

The New York State DOT, New Mexico DOT, and Nevada DOT reported that RWIS data are unreliable or that the coverage was lacking. Conversely, the Iowa DOT and Maryland State Highway Administration, report expanding the use of RWIS and combining those data with other applications. At present, the use of RWIS is widespread throughout the country and is critical to winter maintenance operations. The Federal Highway Administration project on environmental sensor stations will produce consistent guidance for state and local agency personnel responsible for procuring, situating, operating, and maintaining environmental sensor stations along the roadways.

Another challenge that maintenance officials face is the reliability of weather forecasts. Three of the respondents indicated the need for better weather forecasting, specifically improved timing of the forecasts as to when the events start and stop, and the types and measurements of precipitation forecasted.

Several respondents indicated the need for instrumented means of receiving real-time road condition data, e.g. friction levels, plow status, and pavement condition. At present, much of the road condition information received is through visual means, usually from field personnel. Instrumented maintenance vehicles have been tested in several states over the past few years. For State Transportation Agencies in Iowa, Minnesota, and California have evaluated a range of technologies on snow plows that have had varying degrees of success. Many of the concepts tested during these evaluations have been widely accepted. For example, pavement sensors, AVL, and computerized material applicators have found acceptance, while technologies such as heads-up displays, friction meters, and salinity testers are not as widely accepted, and some of these devices are currently being tested.

The overall majority of the responses stated that improved technology, workforce training and education, and better proactive maintenance practices helped improve performance. The improved technologies cited by the respondents included improved trucks, sprayers, and communications. Improved training with the workforce related to changing practices to be more proactive with the approaching storm, for example, pre-wetting and anti-icing efforts and treating roadways prior to a storm. The responses indicate a willingness of the agencies to try new and innovative technologies. Many of the respondents share ideas and resources through associations such as the Aurora program, APWA, Clear Roads, and the Pacific Northwest Snowfighters. All of these improvements listed by the respondents are improvements in productivity to gain more ground and getting the most out of the resources available to them.

The majority of the responding agencies reported budget personnel constraints and resistance to change from either staff or management as barriers to improving performance with almost one-third (31%) of the responding agencies indicating budget concerns as a major barrier. Clearly, without proper resources, the agencies will have difficulty experimenting with or funding new technologies. These are issues felt by most managers, in that there are increasing customer expectations for snow and ice control and more roads to plow at all levels, but the budgets are not keeping up.

3.2. Summary and Conclusions

The survey was sent to 162 agencies in the United States, Canadian provinces, Sweden, and Japan. A total of 43 agencies responded to the survey. The survey indicates all levels of measuring performance from no performance measurement all to those that incorporate performance measures into their management plans. There are also indications for improved methods to measure performance for snow and ice control through technology. Clearly there is room for improvement in this area.

Most of performance measures cited by the respondents are tied to accounting and management systems, including lane-miles plowed, personnel hours, overtime hours, tons of material used, amount of equipment deployed, and cost of operations. Other measures used include time to bare pavement, time to return to a reasonably near-normal condition, LOS, and customer satisfaction. Customer satisfaction was cited by 21 respondents as a performance measure. Additionally, 19 respondents indicated that public was surveyed periodically, either by the department or in a city-wide survey and that the public was generally satisfied with the performance. Two respondents indicated that they measured customer satisfaction based on telephone calls or complaints.

The majority of the measures critical to the respondents' snow and ice control operations focused on public safety and mobility. Obviously, these subjects are central to the role of all transportation agencies, so it makes sense that the performance measures would focus on these subjects. By maintaining mobility and traffic flow, accidents are reduced and public safety is enhanced.

While state and local agencies are generally interested in providing the best service to the public, budget and staffing constraints make it difficult for agencies to experiment with new methods or technologies. Because agencies want to be able to provide these services at the lowest possible costs, performance measures that are established cannot be too time consuming or costly to measure.

Eventually, more winter maintenance agencies will adopt more performance measurement practices. The public will continue to expect clear roads and less harm to the environment from snow ice control operations. Technologies such as AVL, GPS, friction meters, and RWIS will help obtain additional data to enhance measuring performance. Expanded use of these technologies will lead to reduced prices as production and competition increases. Both field

personnel and management would have to focus more on outcomes when using these more costly technologies.

The objectives selected by each agency can drive performance measurement by creating targets toward which activities can be directed. Performance measures need to also include a short-term result, an improvement strategy, hold entities accountable and responsive data systems so that accurate and timely data are generated.

In general, performance measurement for snow and ice maintenance is very mixed bag of measures used by specific agencies throughout the world. They vary by time interval; continuous data, storm-by-storm data, and seasonal measurements; they vary by focus; input, output, or outcome; they vary by data collection technology and archiving methodology; to collect data some use visual subjective collection methods, and others use repeatable objective collection or automated collection; and they vary by the degree each agency holds managers accountable to meet performance goals. Before choosing from the rich variety of performance measures, an agency must understand its goal and objectives and it must understand the cost implication of collecting performance measures. For example, one state agency collects bare pavement regain time from each operator, each operator is trained so that subjectivity is removed from the measurement, and the data are archived in a statewide GIS for later management review. Another state transportation agency has district level staff annually select 14 knowledgeable highway systems users (trucking company managers, ordinary commuters, transit managers, etc.) to serve on an annual winter maintenance evaluation panel. Every week, about ten individuals from each district's panel are called and asked their impression of the snow and ice removal services on state owned roads. These opinions are compiled and reported as performance measures. These systems are very different, have very different cost implications, and probably offer very different outcomes. However, both are measure performance, both are a valuable tools, and each method achieves an agency goal and objectives.

CHAPTER 4. SELECTED PRACTICES FOR PERFORMANCE MEASUREMENT

During the process of reviewing literature and surveying transportation agencies, considerable insight was gained into the operations and use of performance measures by several agencies. An overview of how these approaches and measures used by agencies are described. The agencies and practices that are included here are those that reported methods to help them save time, reduce labor, cut costs, increase their level of service, or otherwise improve their ability to get the job done.

4.1. State Transportation Agencies in the United States

Alaska Department of Transportation and Public Facilities

The survey revealed that the Alaska Department of Transportation and Public Facilities (Alaska DOT and PF) utilizes and evaluates the performance of both internal department personnel and contractors. It also links winter maintenance performance to contractor payment. The Alaska DOT and PF uses customer satisfaction as the principal measure of overall performance of snow

and ice control operations. Although no specific metric to gauge satisfaction was noted, satisfaction was measured through a customer survey at the end of each winter season, and annual surveys have shown that the public has been highly satisfied with the agency's efforts.

The Alaska DOT and PF noted that the time to complete clean up after a storm event in urban areas is one of the most critical performance measures. and that travel speed was of some importance but was not definitively quantified by the department. The time to clean up after a storm event in urban areas is measured after each event, based on a visual inspection by maintenance personnel, and subsequently averaged for an entire season. An annual average over the entire winter season of 18 hours was established for satisfactory performance. Performance measures or levels are not set for non-urban areas. The Alaska DOT and PF dedicates more effort to higher classified roadways.

The department identifies and tracks all snow and ice activities that are performed with objectives of reducing highway fatalities, achieving customer satisfaction, and keeping traffic moving safely. External communications was identified as a principal means of measuring performance, although automated cycle time and amount of materials being expended are some of the desired information the agency that are not readily available. Additional resources, new technology, and a dedicated staff comprise the most important factors that contributed to the agency's improved performance in recent years.

California Department of Transportation

Information provided by the California Department of Transportation (Caltrans) in responses indicated that Caltrans utilizes internal staff to perform snow and ice control and measures several performance indicators covering inputs, outputs, and outcomes such as:

- Time to bare pavement
- Time to return to reasonably near-normal winter conditions
- Traffic flow/LOS
- Customer satisfaction
- Crash rates
- Traffic volumes during storm event
- Time for traffic volume to return to normal after storm
- Lane-miles plowed
- Personnel hours and overtime hours
- Tons of materials used
- Amount of equipment deployed
- Cost of winter operations per lane-mile

In addition, total time of road closures, hours of chain restrictions, accuracy of weather forecasts, timing and amount of snow received, accuracy of travel services (such as changeable message signs, radio advisories, chain control signs, etc.), and number of people assigned to snow duty during storm (in addition to personnel hours) are also considered. The above items were chosen to help improve safety and mobility across the state. The percentage of time a route is closed

during a storm event, percentage of time under chain restrictions during a storm, and weather forecast accuracy are the three most critical winter maintenance measures used. Caltrans. However, explicit performance levels and standard approaches have not been established for the first two measures, although predicted weather forecasts are compared to actual outcomes. Based on annual assessments the targets for performance objectives are met

Although specific performance targets/levels are not set, performance is evaluated through a variety of ways, including accounting records, visual inspection by maintenance personnel, reports from the field, closed circuit television cameras, customer surveys, and the department's accounting program for tracking road maintenance activities and associated costs, (the Integrated Maintenance Management System.)

The department segments its routes into "snow-affected lane-miles," which are determined by the elevation of snowfall and may vary by storm. Overall, Caltrans feels that utilizing performance measurements, results in improved communications with staff, improved decision making and performance, and improved external communications. The need for more accurate measurement of precipitation type and amount as well as storm start and end times was noted and that reduced funding and personnel was regarded as the most significant barriers to improving performance. Caltrans currently surveys the public concerning snow and ice control performance every two years, using the Internet; results indicated that the department is performing to the public's satisfaction.

Colorado Department of Transportation

The Colorado Department of Transportation (CDOT) utilizes internal department staff and local government agencies in some instances, to perform snow and ice control operations. CDOT evaluates performance of the internal and contracted governmental staff and measures performance of snow and ice control, using the following measures:

- Time to bare pavement
- Traffic flow or LOS
- Customer satisfaction
- Lane-miles plowed
- Personnel hours
- Overtime hours
- Tons of material used
- Amount of equipment deployed
- Miles traveled with plow down
- Cost of operations per lane-mile

In addition, the number of road closures and duration of each, number of chain events and duration of each, percent of maintenance employees completing required courses, percent of pre-trip and post-trip reviews done on a fleet, percent of equipment operable at beginning of storm,

and percent of materials available for snow event are considered. The time to bare pavement is considered the most critical measure the department uses.

CDOT has a written procedure establishing service levels for different road classes, based on ADT, but no standard is available to judge whether this goal is met in a timely manner. Several approaches to collecting data, including accounting records and random visual inspection, are used as input into CDOT's mature maintenance management system that tracks snow and ice control costs. The department also conducts periodic customer surveys to collect data on performance.

Performance targets or objectives vary by storm characteristics, which includes non-storm events, as well as by road classification. Maintenance personnel are required to achieve bare pavement faster on roads with higher traffic volumes than those with lower volumes, using a method that tracks both factors. CDOT also provides information on road conditions to the public through the Internet, commercial radio and television, and dynamic message signs. CDOT reported that efforts into measuring performance have resulted in improved business practices, improved internal and external communications, improved decision process, and support of a budget model that subsequently supports necessary funding levels for achieving target service levels.

CDOT reported that improvements in performance are attributed to chemical de-icers and anti-icers and improved communications with the public, and noted that consistency in reporting of weather and road conditions is the most significant barrier.

Indiana Department of Transportation

The Indiana Department of Transportation (INDOT) utilizes only internal staff to perform snow and ice control operations. The department is in the process of developing measures that will ultimately be based on several factors, such as, customer/public concerns, desired LOS, and the ability to evaluate or "measure" a specific measure.

The department uses an annual winter storm severity index developed by Purdue University that utilizes data from the National Weather Service and four regions within Indiana and currently tracks material usage monthly and maintains ten-year averages. The department sees a need for information on actual road conditions during and after a storm event.

INDOT's ability to improve performance in recent years is attributable to management support for developing and supporting a winter operations team that has shared and tried new concepts, communication of ideas and experience with other states, and participation in research groups and initiatives. Funding and resistance to change were noted as the most significant barriers to improvement of winter maintenance performance.

Iowa Department of Transportation

The Iowa DOT utilizes and subsequently evaluates the performance of both internal department personnel and other governmental agencies in winter maintenance. The Iowa DOT measures several performance indicators including the following:

- Time to return to reasonably near-normal winter conditions
- Time to provide one wheel track
- Traffic flow
- Lane-miles plowed
- Personnel hours
- Overtime hours
- Tons of material used
- Costs per lane-mile

The Iowa DOT tracks material, labor, and equipment hours and costs. The department has utilized several items from winter supervisor daily reports and weather information (from RWIS, automated weather observing systems, etc.) and continues using other items, such as friction and crash data, as potential indicators of performance. In recent years, the Iowa DOT has also been evaluating speed data from existing ATRs as a performance measure. The response noted that the department has also used surveys of customers, as well as the state patrol, in the past. Accounting records and field reports are the primary sources of performance data used in Iowa.

The Iowa DOT considers any measure with a direct impact to travelers, such as speed, volume, or crashes to be critical to its operations. Current objectives are safety, returning roads to near-normal driving conditions as soon as possible, and using the right type and amount of deicing materials at the right place and time. The department also acknowledges the need to achieve a balance between budget, customer service, and the environment. Iowa is one of the states using different performance levels or targets for different roadway classifications. The Iowa DOT also measures its performance during non-storm events and has begun to utilize a weather severity index.

The department segments the road network by class and garage area. Measuring performance and setting quarterly and annual targets were reported to have improved the decision process for snow and ice control operations. In recent years, Iowa has tried various approaches and new technologies to measure performance, found friction wheels to be too expensive and is now focusing on correlating speed data with weather data to measure snow and ice control performance and is also working on the use of crash data. The weather index is being used to determine performance by linking it with budget records.

In order to improve its overall measurement of performance, the agency noted the need for improving speed data and subsequent impact on traffic operations and potential delay. The Iowa DOT surveys the public about snow and ice control performance and found that expectations are higher than originally thought. Furthermore, rating snow and ice removal is a top priority, and the public has indicated that the Iowa DOT is doing a good job. The department attributes this

success to proactive operations, materials used, and improved equipment. Driver behavior, budget, and staffing were considered the most significant barriers to success.

Kansas Department of Transportation

The Kansas Department of Transportation (KDOT) utilizes only internal staff to perform snow and ice control operations. KDOT measures winter maintenance performance, using a “level of service” based on road condition across road categories. KDOT’s objectives were noted as providing a safe travel way and using resources efficiently. The specific measures used by KDOT to indicate a safe travel way vary across three roadway categories, but not across storm type or characteristics. Data indicating these measures are derived from reports by field personnel and a computer system where field personnel record road conditions. The three categories, measures, and performance levels are as follows:

- Category I. Two bare/wet wheel paths
- Category II. Both lanes on two-lane roads with intermittent bare/wet wheel paths
- Category III. One wheel path on two-lane roads with intermittent bare/wet wheel paths

KDOT utilizes a storm severity index, adopting the winter index from SHRP H-350 and utilizing data from the National Weather Service. Road condition information is reported to the public in Kansas via the 511 system and an Internet web site.

Massachusetts Highway Department

The Massachusetts Highway Department relies heavily on hired equipment for snow and ice operations. Currently, the department is entering the second year of a two-year contract with the hired equipment vendors, and, is considering options to provide a fuel adjustment to the vendors because of the increasing cost of fuel. The department is currently considering the following:

- The adjustment will be in the form of an additional payment (in addition to the contract hourly rate).
- The adjustment based on fuel price data available on the Internet from the U.S. Department of Energy (via the Energy Information Administration).
- The adjustment based on the assumed fuel consumption for the equipment, using a factor that takes into account the miles traveled in an hour’s worth of work, engine efficiency (miles per gallons), fuel consumption during idling, and the an assumed split between idle time and running time (each hour).
- The fuel adjustment considering amount of the fuel price increase (starting from the beginning of the contact) multiplied by the assumed consumption rate (gallons/hour).

In preliminary work, the department has been using a typical engine efficiency of six miles per gallon (equipment under load), and an idling fuel consumption rate of three-quarters of a gallon per hour. The overall fuel consumption rate is estimated at approximately five gallons per hour.

Minnesota Department of Transportation

The Minnesota Department of Transportation (Mn/DOT) uses bare pavement regain time as a primary performance measurement. Based on predefined road classes, the following statewide range in hours is determined for bare pavement. (Keranen 2002):

Table 4. Minnesota DOT Pavement Regain Time by Roadway Class

Road class	Statewide range (hrs.)
SC: Super commuter (>30,000 AADT)	SC1 to SC10
U: Urban commuter (10,000–30,000)	U1 to U10
R: Rural commuter (2,000–10,000)	R1 to R10
P: Primary (800–2,000)	P1 to P10
S: Secondary (<800)	S1 to S10

Mn/DOT has developed a graphical representation to indicate the performance on a particular road segment, called the Bare Lane Indicator. Graphs are produced that look like automobile dashboard gauges with green, yellow, and red areas. An arrow is used to show the range of the response time to bare pavement within the target range. The graphs can show areas of improvement or enhancement for training, method, funding, equipment, or personnel (Bourdon 2001). Mn/DOT assigned a bare pavement indicator to three road classes, with specific target values: Super commuter at 1.5 to 2 hours, Urban Commuter at 2 to 3 hours, and Rural Commuter at 4 hours (Keranen 2002). Other information is collected along with bare pavement regain time to develop an overall maintenance management plan. Other information gathered includes RWIS information, salt and sand use, costs per lane-mile, and best practices 48 hours after a storm event. RWIS information can be correlated with salt and sand use, labor and equipment costs to analyze current maintenance performance (Keranen 2002). Because precipitation in storm events varies, specific routes and areas can be analyzed by performance independently from other areas.

New Hampshire Department of Transportation

The New Hampshire Department of Transportation (NHDOT) exclusively utilizes internal staff to perform snow and ice control operations. The department's three most important objectives are uniform compliance with the department's "Winter Maintenance Snow Removal and Ice Control Policy", implementation of salt management plans, and implementation of anti-icing procedures

NHDOT uses a computerized maintenance activity system that tracks budgets and summarizes the cost of snow and ice control activities. Improved weather forecasting, improved equipment, and increased training of employees have been the three most significant factors contributing to the department's improved overall efficiency in the past few years. Funding for new technologies was noted as the most significant barrier to further improving performance.

South Dakota Department of Transportation

The South Dakota Department of Transportation (SDDOT) utilizes internal staff, private contractors, and other governmental agencies to perform snow and ice control operations. The SDDOT does not formally measure performance, although the department does “informally” consider measures such as time to reasonably near-normal winter condition, traffic flow, and customer satisfaction. The SDDOT attempts to budget labor- hours, equipment hours, and materials for a “normal” winter and tracks these items through payroll and inventory systems.

To better manage snow and ice control operations, the department would like to have better information on the amount and effectiveness of chemicals. SDDOT surveys the public and has received generally positive responses. Better equipment and experimentation with new methods and materials are reported to have helped the department improve performance in the past few years.

Virginia Department of Transportation

The Virginia Department of Transportation (VDOT) uses outcome-based pay when contracting out winter maintenance operations. Under this system, the contractor receives a pre-agreed upon lump sum payment for maintaining a given section of road or facility (Bourdon 2001). VDOT developed an Asset Management Best Practices Manual for snow and ice control operations that includes a table describing the LOS for snow and ice control. Roads were divided into priorities 1, 2, 3, and 4. The routes are then given specific treatments with specified outcomes based on total accumulation. Priority 1 routes are to be treated, plowed and cleared to obtain 100% bare pavement within a specified number of hours. Priority 2 routes are to receive chemical treatment and plowing during the storm, with an end result of completion within a specific number of hours after the end of a storm. Priority 3, residential streets, are to be sanded as needed and plowed when feasible to provide a passable roadway. Priority 4 roads are to be sanded as needed and plowed when feasible with no specific end results (VDOT 2005). Variable message signs are deployed throughout the state for winter maintenance. The contractor must achieve bare pavement within 24 hours after the end of a storm event.

VDOT has developed a best practices manual that contains performance targets for all activities. It is just beginning the process of monitoring operations, with the focus on activities that can be easily measured. VDOT is the first agency to post performance measures and actual performance on the web (<http://dashboard.virginiadot.org/>). On this site, an operations section shows a real-time map of system incidents, other sections show success (or failure) to meet budget projections.

Washington State Department of Transportation

In 1996 the Washington State Department of Transportation (WSDOT) implemented the Maintenance Accountability Process (MAP) that combines performance measures into an end result of a performance based service levels. Performance measures are based on customer

oriented outcomes or the results that highway users are able to identify once the results are collected by field evaluations of highway conditions (Baroga 2004).

A pilot project to assess the service levels for snow and ice control activities by field measurements and performance measures was implemented. The results were assessed in the spring of 2000 using roadway traction provided at the time of a field measurement and the time taken to regain bare pavement at the end of a snowfall event as performance measures. The roadway traction provided was measured once a week and given a rating from 1 to 5. With a rating of 1 designates bare or completely sanded pavement, and variations from this condition are given higher point values. To relate the performance to individual storm events, the time to regain bare pavement after a winter precipitation event was measured in hours and used a second performance measure. Point values were assigned to different hour thresholds. A value of 1 was assigned to a road with a fast regain time, increasing to a 5 for a slow regain time. Highway categories were also taken into account. For example, a highway with a high ADT would need to be kept bare throughout a storm event to receive a high rating, while a highway with a low ADT would require a high rating if bare pavement was regained within six hours. In the end, the point measures were translated into letter grades similar to the LOS ratings: A, B, C, D, or F (Baroga 2002).

WSDOT has also developed a frost index that relates directly to performance measurements in winter maintenance operations. The frost index can be used to justify the snow and ice budget overruns and support requests for supplemental funding (McCullough et al. 2004).

WSDOT uses internal staff for all winter maintenance operations. Performance is measured for storm and non-storm events as the time to bare pavement, wet pavement, and the return to reasonably near-normal winter conditions. The data for the performance management system are obtained through visual inspection by maintenance personnel and reports from field personnel. The staff decides if sand or a chemical deicer will be used and a follow up is done to evaluate the result of the application, considering the following:

For Chemical Applications:

1. Bare Pavement
2. Patches of frost, black ice, slush, or compact snow
3. Wheel tracks bare, frost, snow, or ice encountered regularly
4. 50% of roadway with compact snow and ice buildup
5. Entire roadway covered with compact snow and ice
6. Unable to evaluate current road conditions

For Sand Applications:

1. 100% of roadway has sand present
2. 50% or more of roadway has sand present
3. All emphasis areas have sand present
4. 50% or more of emphasis areas has sand present
5. 50% or less of emphasis areas has sand present

6. Unable to evaluate road conditions

The three most important current objectives for snow and ice control operations are to move towards a statewide chemical priority program, evaluation of all chemical applications to refine the necessary application in different weather events, and the calibration of all equipment used in sand and chemical application. These objectives are regularly tracked by application records. Highways are ranked by priority, from one through five, into treatment categories. Road conditions are reported to the public based on the performance management system by dynamic message signs, commercial radio, television, 511, and an internet radio station.

Due to the varying climates within the state of Washington, treatments and performance goals are divided into east and west regions. As funding levels and other resources require prioritization of different roads for snow and ice control services, different treatments are employed for individual roads and sections of roads. Area supervisors choose sand or chemical deicers applications to meet the goals. If chemicals are used, the time to wet or bare pavement is measured. If sand is used, a follow-up evaluation is conducted to determine conditions, e.g., how much of roadway has sand present (100%, 50%, all emphasis areas, etc.)

WSDOT has developed LOS measures based on visual description of conditions supplemented with pictures. The agency also describes four treatment levels that are linked to LOS. “Levels of Service” (LOS) are reported on a scale of “A” through “F” are defined as follows:

- **LOS A:** A very high LOS in which the roadway and associated features are in excellent condition. All systems are operational and users experience no delays.
- **LOS B:** A high-maintenance service level in which the roadway and associated features are in good condition. All systems are operational. Users may experience occasional delays.
- **LOS C:** A medium-maintenance service level in which the roadway and associated features are in fair condition. Systems may occasionally be inoperable and not available to users. Short-term delays may be experienced when repairs are being made, but would not be excessive.
- **LOS D:** A low-maintenance service level in which the roadway and associated features are kept in generally poor condition. System failures occur because it is impossible to react in a timely manner to all problems. Occasionally, delays may be significant.
- **LOS F:** A very low service level in which the roadway and associated features are kept in poor and failing condition. A backlog of system failures would occur because it is impossible to react in a timely manner to all problems. Significant delays occur on a regular basis.

The department’s efforts are prioritized by service levels. High-priority service levels are directed to major highways (such as Interstate 90), and other highways are assigned appropriate service levels. These service levels range from Level 1 to Level 4. The service levels represent the expected condition after the treatments are completed and the storm event is ended. On a Level 1 roadway, the department attempts to make the roadway bare and dry or bare and wet as soon as possible. Level 2 roadways may have snow and ice buildup at times. Level 3 roadways

can have snow and ice buildup on a regular basis, and Level 4 sections are often covered with compact snow. Each service level has a corresponding roadway treatment action using liquid anti-ice chemicals, solid chemical treatment, plows, and sand.

Wisconsin Department of Transportation

The Wisconsin DOT uses a single measure to measure the LOS for snow and ice operations. Periodic field condition surveys are conducted to measure the traction conditions on the travel lane of the road surface. These conditions are determined by observing a mile of road after a winter operation has taken place. Bare pavement is considered if 95% of the roadway is free from ice and snow. A roadway is considered sanded if at least 60% of the travel lane has sand on the surface. This is equal to a travel lane with bare tire tracks with sand on the remainder of the lane (Conger 2005). The state reimburses 72 counties to perform winter maintenance on state and federal roads (Adams et al. 2003).

The Wisconsin DOT's performance measurement program has been adapted from that of the WSDOT. Winter maintenance operations is contracted out to county highway departments, and performance is measured as the time to wet pavement, by customer satisfaction, crashes per VMT, cost of winter operations per lane-mile, and percent of salt spreaders/controllers calibrated. The most critical measures are public satisfaction and time to bare/wet pavement; however, target measures have not yet been established. The three most important current objectives are providing bare/wet pavement in a reasonable amount of time and effort, improving the coefficient of friction between vehicle tires and the pavement, and providing good winter driving conditions using the most efficient methods possible. The methods used for obtaining data for the performance measurement system include accounting records, visual inspection by law enforcement, and periodic customer surveys.

Ontario Ministry of Transportation

In order to develop performance measurements and benchmark methodology for Ontario's municipal roads, the Ontario Good Roads Association formed a committee of road professionals in 1997. This committee created an activity map divided into six categories, including winter control. This map has been adopted by the Ministry of Municipal Affairs for their Municipal Performance Measurement Program and by the Ontario Municipal CAO's Benchmarking Initiative. The committee enlisted a select group of municipalities to use various performance measures on high traffic volume roads. One winter maintenance group focused on rural arterial systems, while the other focused on urban local residential systems. The following performance measures were documented (Anderson 2004):

- Cost per lane-kilometer
- Annual cm of snowfall
- Total annual tons of abrasive, including salt per system kilometer
- Total annual tons of salt per system kilometer
- Usage of the road system (vehicle-kilometer /lane-kilometer)
- Median operating costs per lane-kilometer

- Average number of winter event responses
- Average usage in vehicle kilometer/lane- kilometer
- Average percent of plows/salters/combination units, municipally owned
- Percent of municipalities pre-wetting salt prior to application to the road surface
- Average length of plow route
- Percent of municipalities using a wingman in the truck

Non-event response activities such as snow fence operations, winter standby staff and contractors, winter patrol, winter drainage, spring clean up, and overhead were also documented.

The Ontario Ministry of Transportation measures the performance of private contractors, who perform all winter maintenance activities, by time to bare pavement. The time to bare pavement, in hours, varies by road classification and storm characteristics. Road conditions are monitored by a patrol vehicle and reported by either highway number or patrol number. The data for the performance measurement system is obtained through accounting records, visual inspection by maintenance personnel, reports from field personnel and AVL at certain locations. The overall, most important, objectives are to maintain safe conditions during a storm, recover bare pavement after a storm event, and minimize salt loading to the environment. In addition to measuring the time to bare pavement, the number of plows and spreaders operating and response time are monitored to ensure conformance with established operating guidelines and public safety. Information, such as daily hours of operation for each piece of contracted equipment and tons of salt and sand applied, are collected for audit and payment of private contractors.

The Ontario Ministry of Transportation has a system of “Best Practices” and “Levels of Service.” The “Best Practices” (formerly referred to as “quality standards”) specify how and when an operation (plowing, salting, sanding) is performed. “Levels of Service” define the expected end result (level packed snow, centre-bare or fully bare pavement) and the maximum elapsed time after the storm until that result is achieved. The Ministry also has targets for how often those service levels are achieved (e.g., 98% of the storms in a winter).

Finland

Road officials in Finland use a patrol vehicle to measure the friction on a roadway and the operator determines whether the roadway meets the frictional requirements and recall the maintenance fleet to treat the unsatisfactory location (Al-Qadi et al. 2002).

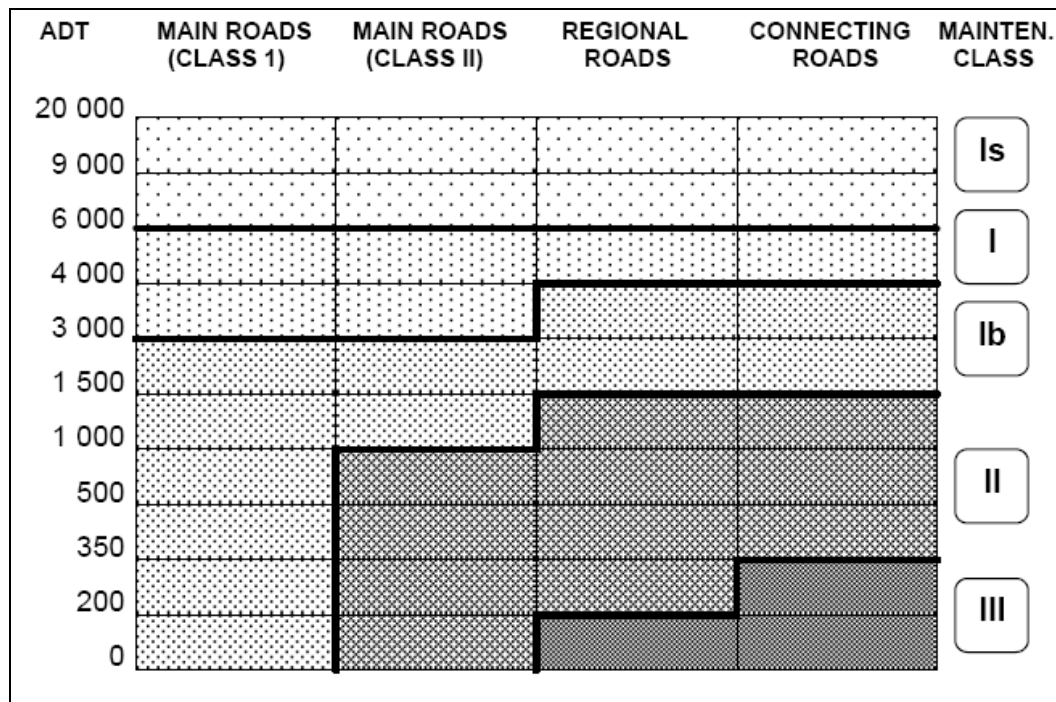
The Finnish National Road Administration (FnRA) sets the policies and LOS that the contractors have to meet. The FnRA also specifies the environmental parameters that are to be met. For example, contractors are required to have the proper knowledge and skill in the use of road salt so as little salt as possible is used while keeping the road in safe condition.

The road network is divided into five main maintenance classes (Is, I, Ib, II, III) and class Ib has a corresponding maintenance class, T-Ib, for built-up areas. Each class has a different LOS and quality standards. In deciding the maintenance class of a road, not only are the classification

criteria taken into consideration, but also local conditions, the nature and composition of traffic, the speed limit, and qualitative integration with the LOS of the municipality's road network.

Road classes are defined in a logical pattern from the viewpoint of road maintenance personnel. Thus, snow and ice control operations can be implemented as economically as possible. The road network is defined in Table 5.

Table 5. Finnish Road Network (Finnish Road Maintenance 2001)



Finland is also a leader in using friction measurements as an indicator of effective snow and ice control. The FnRA has established standards in using friction, as shown in Tables 6 and 7.

Table 6. Quality standards and friction indicators (Finnish Road Maintenance 2001)

	Winter maintenance class					
	Is	I	Ib an TIb	II	III	K1 K2
Friction requirement	Road surface below -6°C 0.25	Road surface below -4°C 0.25	Spot sanding 0.25 Line treatment 0.20–0.22			
Normal	0.30	0.28	0.25	According to traffic demands		
At night	2200–0500* 0.28	2200–0500* 0.25	2200–0500* As needed	2200–0600* As needed	2200–0600* As needed	After 2200* K1 by 0500* K2 by 0600*
Cycle time	2 hr	2 hr	Salt 3 hr Sand 4 hr	6 hr line sanding	10 hr line sanding	2 hr

*Time listed in 24 hour format

Table 7. Friction indicators and driving conditions (Finnish Road Maintenance 2001)

	Friction value					
	0.00–0.14	0.15–0.19	0.20–0.24	0.25–0.29	0.30–0.44	0.45–1.00
Description of driving conditions	Bad driving conditions, wet ice	Icy	Tightly packed snow	Rough, packed ice and snow	Bare and wet	Bare and dry
	Very slippery	Slippery	Satisfactory winter conditions (based on friction value)	Good winter conditions (based on friction value)	Not slippery	Not slippery

According to the administration's policy, the following friction indicators must be met criteria:

- The friction requirement must be met on at least half of the surface area of the lane.
- The friction requirement for Classes Is and I roads is 0.25 when the temperature of the road surface is lower than the limit value.
- In freezing situations Classes Is and I are treated using preventative salting to prevent slipperiness or to at least minimize its duration.
- At night the friction requirement is 0.28 for Class Is and 0.25 for class I.
- In Class Ib the friction requirement is 0.25 in early and late winter.
- During stable winter conditions class Ib requires sufficient treatment procedures when the friction value drops below 0.25. The entire length of the road must be treated no later than when the friction value is expected to drop below 0.20. On specified busy Ib roads the entire length of the road must be treated no later than when the friction value is expected to drop below 0.22.
- In maintenance Class TIb (built-up areas), salt is used as necessary only in early and late winter.
- In Classes II and III, sufficient friction needed by traffic is required.

- In Class II, regular anti-slipping procedures are implemented at problem sites, so traffic ability is guaranteed in all conditions. The entire length of the road is sanded during particularly difficult driving conditions.
- Anti-icing procedures in Classes II and III are supplemented by coarsening the surface of packed snow.
- In Class III, particular problem sites are spot sanded to keep the road in travel condition. The entire length of the road is sanded during especially difficult driving conditions.

Snow removal must adhere to the following criteria (also illustrated in Table 8):

- The maximum snow depth must not be exceeded while it is snowing or during maintenance procedures thereafter.
- Only half as much slush is allowed as snow.
- Plowing must be started no later than when half of the maximum amount of snow has accumulated. This starting threshold is not used at night in classes II, III, and K. In Class Ib and TIb, the starting threshold at night is 4 cm.
- The maximum amounts of snow refer to normal snowfalls. In exceptional snowstorms (a few times a year), these values may be exceeded.
- Snow depth refers to the prevailing situation in the lanes, including snow piled by traffic.

Table 8. Quality standards for snow removal (Finnish Road Maintenance 2001)

Winter maintenance class	Is	I	Ib and TIb	II	III	K1	K2
Maximum snow depth when snowing	4 cm	4 cm	4 cm (8 cm at night)	8 cm (10 cm at night)	10 cm (10 cm at night)	3 cm (8 cm at night)	
Cycle time, clean after snow stops	2.5 hr (slush 2 hr)	3 hr (slush 2.5 hr)	3 hr	4 hr	6 hr	3 hr	4 hr
If snowing after 22 at night	Plowed clean within cycle time		05, or cycle time	06, or cycle time	06, or cycle time	05	06

To obtain the proper LOS, well-timed management, seamless cooperation between different contracts, safety, and environmental friendliness, the FnRA establishes quality assurance plans, the entire personnel of the contractor operate according to this plan. The quality plan also functions as a winter maintenance plan, which identifies the issues that have the most impact on the work, such as operating routes and resource allocation. Post-winter maintenance control requires reporting of the following items:

- Costs by maintenance class
- Implementation of contracts

- Quality and the LOS on the road
- Road user feedback
- Description of wintertime road safety
- Environmental impact information
- Description of the prevailing weather

A winter maintenance report based on the above items is compiled within FnRA at the contract, district, and administrative levels. Costs are reported by maintenance class to help compare and control the price level of different areas. Implementation of contracts (quality) is reported as the contract supervisor's personal evaluation and the number of deviation reports, complaints, penalties and bonuses.

The LOS and quality on the road is reported by means of quality monitoring based on random sampling. An annual study of the LOS also provides a general overview of the quality of winter maintenance and especially its development.

Sweden

The SNRA mandates contracting out for all winter service, and its own forces compete in the bidding. Different highway classes, based on function and traffic volume, require different standards. The standards are tied to roadway surface temperature, precipitation, and roadway appearance in different conditions. Friction is measured by a supervisor using a Corabla friction tester in a light truck, separate from the production truck, (Harrigan 1999).

Sweden stipulates that its "highest volume road shall be free from snow and ice no later than two hours after the snow has stopped falling if the road surface temperature is above -8 degrees C (18 degrees F) and that during the period when the snow is actually falling, the depth of snow shall not exceed 2 cm (0.8 in.) and slush depth shall never be more than 1 cm (0.4 in.)" (Olander 2000).

Sweden also surveys 14,000 people annually from all seven regions to link performance measures to customer expectations. Questions deal with how the SNRA manages snow, slipperiness, and slush, along with attitudes towards salt use (Harrigan 1999).

The contractor's payment is linked to performance measurements, such as time to bare pavement, time to return to a reasonably near-normal condition, friction, customer satisfaction, and tons of materials used. The most critical items to snow and ice operations are friction and snow depth.

The three most important objectives for the agency are friction, snow depth, and time to "normal" conditions. For the measure of friction, a friction value is used as the performance level, while snow depth is measured in centimeters, and time is measured in hours. The data for the performance management system are obtained by accounting records, visual inspection by maintenance personnel, reports from field personnel, calls from the public, and the contractor's

records. The performance measures on roadway conditions are reported to the public by dynamic message signs, commercial radio and television, 511, an Internet website, and by cell phone.

Norway

The Norwegian Public Roads Administration measures performance by testing friction using a friction meter. A required LOS of 0.4 (coefficient of friction) is used throughout the country for public and private operations (Harrigan 1999). Along with measuring friction, photographs, activity logs and observations are used to evaluate specific friction improvement methods (Al-Qadi et al. 2002). The administration also uses thermal mapping to improve service and reduce costs.

Japan

The Hokkaido Regional Development Bureau developed guidelines for goals, based on ADT volume and road surface conditions, of recommended LOS in winter conditions. Patrolling inspectors visually measure the effectiveness of the procedures (Pisano, 2004). The Japan Highway Public Corporation has published a national maintenance manual. Japan also uses a neural network to predict friction from various data, including weather, traffic, and pavement condition (Al-Qadi et al. 2002).

The Japanese Ministry of Land Transport and Infrastructure has developed a national performance measurement program, of which road maintenance is a part. This is an outcome-based program designed to make the Ministry more efficient and accountable to the public. The Ministry established 17 performance indicators (Table 9) as targets; although snow and ice control is not specifically mentioned, it falls under the safety policy theme (Japanese Ministry of Land Transport and Infrastructure 2004).

Table 9. Japanese road management performance plan

Policy Theme	Performance Indicator	Current Indicator Val. (FY2002)	Target for FY2003	Target for FY2007 (under constr.)
1. Vitality (restoration of economic vitality through urban renewal and regional coordination)	1. Time loss due to traffic congestion (congestion monitoring zone)	610 million man hr/yr	590 million man hr/yr (2.5% reduction)	about 10% reduction
	2. Ratio of electronic toll usage			
	National	5%	15%	70%
	Metropolitan expressway	6%	20%	85%
	Hanshin expressway	3%	15%	85%
	3. Hours of road work	235 hr/km/yr	225hr/km/yr (4% reduction)	About 20% reduction
	4. Ratio of high standard road usage (targeted traffic that will be newly switched over to expressways during the current fiscal year)	13%	13% (switchover of 2.1 million vehicle-km/day)	15%
2. Living (better quality of life)	5. Ratio of roads with access to hub airports and ports	59% (access to 39 locations)	61% (access to 40 locations)	68%
	6. Ratio of main cities in neighboring regions that are connected to each other by an upgraded national road	72%	73%	77%
	7. Percentage of people who are able to have a safe and pleasant drive into the city, the center of daily life, in under 30 minutes	63%	64%	68%
	8. Percentage of barrier-free main roads in the vicinity of passenger facilities with an average daily user volume of more than 5,000	17%	21%	About 50%
3. Safety (ensuring secure and safe life)	9. Percentage of trunk roads in urban areas without telephone poles	7%	8%	15%
	10. Ratio of death and injury due to road accidents	118.4 incidents/ 100 million vehicle-km	116 incidents/ 100 million vehicle-km	108 incidents/ 100 million vehicle-km
	11. Road structure maintenance ratio	Bridge 86% Pavement 91%	87% Maintain current level	93%
	12. Percentage of cities that have rescue routes covering a wide area in the event of disasters	66%	68%	76%
4. Environment (preservation and creation of environment)	13. Reduction of CO ₂ emission	-	Reduce CO ₂ emission by transportation sector to about 250 million tons CO ₂ by 2010	
	14. Ratio of NO ₂ environmental goal achievement	64%	67%	About 80%
	Ratio of environmental goal achievement for suspended particulate matter	-	About 10%	About 60%
	15. Achievement rate of required limits on nighttime noise	61%	63%	72%
5. Road administration reform	16. Level of road user satisfaction	2.6 points	2.7 points	3.0 points
	17. Number of hits on homepage	15.46 million access/year	26 million access/year	100 million access/year

The Japan Highway Public Corporation, part of the Japanese Ministry of Land Transport and Infrastructure, has developed a national maintenance manual and is developing regional manuals. The Hokkaido Regional Development Bureau also has developed a winter road surface maintenance guideline. The documents describe recommended LOS during wintertime conditions. The guideline includes road management goals for various highway facilities defined by combinations of ADT volume and area type. The management goals are defined in terms of five classes of road surface conditions. Charts relate the classifications of road surface conditions to ranges of friction coefficients determined by research. The performance evaluation of winter maintenance operations in Hokkaido is based on a visual inspection of road surface conditions by patrolling inspectors.

In Japan, private contractors are used in snow and ice operations. The performance measures indicated are tons of materials used and equipment operation hours. The contractors submit records of the equipment hours and materials used to the Ministry for payment.

Criteria for the mobilization of snow and ice control staff and vehicles and winter road LOS are set for each road category according to the amount of snowfall, air temperature, and traffic volume in each cold, snowy region. Snow and ice control operations, including the plowing of snow, the application of material and the operation of snow hauling, is based on such criteria and on LOS. The Hokuriku Regional Bureau of the Ministry of Land, Infrastructure, and Transportation, for example, sets mobilization criteria for each type of winter maintenance operation.

City of Sapporo, Japan

The City of Sapporo, Japan, sets LOS using photographs and descriptions of snow and ice conditions (see Tables 10 and 11). The results of the business owner survey led to measuring performance in terms of the outcome indicators of maintained road width and friction. Winter maintenance activities included plowing, road width widening, hauling snow, and anti-freezing agent applications. For securing effective road width, the input activities included the staff, time, facilities and equipment specifications. The input indicators were targets of results, the results and correlated achievement rate. The output was securing effective road width, indicated by the actual measured passable road width.

The outcome measurement was traffic delay and achievement rate based on the number of days when the effective road width was secured. For the goal of securing skid resistance, the input was budget allocation based on the totals of annual snowfall. The output was securing friction and the measure was measuring the skid resistance. The outcome was the number of days when friction was secured, measured by the number of traffic accidents. The project was evaluated by a service effectiveness report, financial report, and efficiency indicators (Yamamoto et al. 2004).

Table 10. Snow and ice operations for Sapporo, Japan

Road category	LOS and the target road condition
Major trunk road, trunk road	Level 4 (daytime): Powder snow, wet snow, slush
Collector road A	Level 3 (daytime): Compacted snow, or wet snow or ice
Collector road B	Level 3: If possible, compacted snow, or wet snow or ice
Residential road	Level 2 (daytime): Ice sheet, or powder snow over ice

Table 11. Winter road standards and LOS for Sapporo, Japan (PIARC 2006)

Standards for highways and trunk roads	Standards for sub-arterial roads 4 and 5	Standards for residential streets	
			
Level 4	Level 3	Level 2	Level 1
			

4.2. Summary

The case studies summarized in this chapter describe agencies that are using various methods to ensure acceptable levels of snow and ice control performance. Because statistically sufficiently extensive quality monitoring of the entire road network is difficult and expensive, agencies are proceeding deliberately to fully implement performance measures programs while experimenting with systems incrementally. Existing snow and ice control operations still use traditional practices such as plowing and material spreading while striving to improve the processes. Road condition and weather information have become a crucial parts of snow and ice control operations. Agencies are keenly aware of the costs of gaining efficiencies and are taking advantage of the increasingly available weather data as much as possible to improve snow and ice control operations.

Snow and ice control agencies have more weather and road condition information better equipment, more materials, and are providing higher levels of service to the traveling public than ever before. Likewise, the expectations of the traveling public have risen along with budget constraints and environmental concerns, to force snow and ice control agencies to incorporate improved tactics and operations.

CHAPTER 5. SYNTHESIS AND ASSESSMENT OF PERFORMANCE MEASURES

5.1. Introduction

Based on the review of relevant literature and survey of agencies, more than 20 distinct performance measures were identified. Agencies used a variety of approaches to collect the data to calculate the measures. Within this data set, more than 40 combinations of approaches and measures were identified. This chapter categorizes the various measures as input-, output-, or outcome-based and summarizes their frequency of use.

Generally, the data for input and output measures come from the agencies' accounting systems or maintenance logs. There is not much variation in the approach to acquiring these data.

However, it is more difficult to obtain data for outcome measures, since the majority of outcome measures are based on some form of manual observation. Developing technologies in the experimental stages can provide solutions to acquiring outcome measure data.

Additionally, any measure used for time-series analysis would benefit from applying a storm severity index. The various indices are provided here based on the availability of data to calculate the index and its usefulness in improving understanding of performance or communicating performance to administrators.

To provide direction for this synthesis and assessment, the study team developed criteria (listed in section 5.3) for evaluating measures and the associated approaches to acquiring data. These criteria were applied to eliminate measures or approaches that do not exhibit these desired characteristics:

1. Related to controllable facets of performance
2. Reliable
3. Understandable
4. Timely
5. Consistent
6. Sensitive to data collection costs

5.2. Performance Measures in Use

Snow and ice control performance measures and efficiency measures are also grouped with outputs in this classification system. Efficiency is a measure of input divided by output. Outcome measures are based on an assessment of how well operational goals were met; these measures include time needed to regain bare pavement and the friction coefficient after treatment. Input and output measures are usually based on accounting records or operational reports, while outcome measures require some form of monitoring.

The survey of agencies responsible for snow and ice removal revealed more than 20 distinct measures in use in the United States and other countries. The responses for each measure, grouped into input, output, or outcome categories, are listed in Table 12.

Table 12. Summary of snow and ice control performance measures by category

Input measures
Fuel usage (4)
Overtime hours (18)
Personnel hours (18)
Percent of salt spreaders calibrated (8)
Output measures
Lane miles plowed (15)
Tons of material used (20)
Amount of equipment deployed (14)
Plow-down miles traveled (4)
Cost per lane mile (efficiency) (15)
Outcome measures
Time to bare pavement (9)
Time to wet pavement (3)
Time to return to a reasonably near-normal winter condition (10)
Time for traffic volume to return to “normal” after the storm (5)
Time to provide 1 wheel track (1)
Friction (5)
Level of service (11)
Travel Speed during storm (2)
Customer satisfaction (18)
Crashes per vehicle mile (2)
Traffic volume during storm (2)

Table 13 reports the agencies responding to the survey that use various performance measures. This table is the inverse of a case study, which focuses on a single agency; Table 12 instead focuses on the measure.

Table 13. Agencies using various performance measures

Input Measures	
Fuel usage (4) New Mexico DOT Saskatchewan Department of Highways and Transportation Washington Co., Minnesota Cuyahoga Co., Ohio	Personnel hours (18) Ohio DOT New York State DOT Caltrans Detroit Indianapolis DPW El Paso Co. Colorado McHenry Co., Illinois New Mexico DOT City of Seattle Douglas Co., Nebraska Edmonton, Alberta, Canada City of West Des Moines, Iowa Saskatchewan Department of Highways and Transportation Washington Co., Minnesota Cuyahoga Co., Ohio Iowa DOT Minnesota DOT Ada County Idaho
Overtime hours (18) Ohio DOT New York State DOT Caltrans Detroit Indianapolis DPW El Paso Co. Colorado McHenry Co., Illinois New Mexico DOT City of Seattle Douglas Co., Nebraska Edmonton, Alberta, Canada City of West Des Moines, Iowa Saskatchewan Department of Highways and Transportation Washington Co., Minnesota Cuyahoga Co., Ohio Iowa DOT Minnesota DOT Ada County, Idaho	Percent of salt spreaders calibrated (8) New York State DOT El Paso Co. Colorado McHenry Co., Illinois Edmonton, Alberta, Canada City of West Des Moines, Iowa Saskatchewan Department of Highways and Transportation Ada County Idaho Minnesota DOT
Output Measures	
Lane miles plowed (14) Caltrans Ohio DOT Detroit King County, Washington El Paso Co., Colorado McHenry Co., Illinois New Mexico DOT Douglas Co., Nebraska Edmonton, Alberta, Canada City of West Des Moines, Iowa Saskatchewan Department of Highways and Transportation	Amount of equipment deployed (14) Ohio DOT New York State DOT Caltrans Detroit Indianapolis Cedar Rapids, Iowa McHenry Co., Illinois City of Seattle Douglas Co., Nebraska Edmonton, Alberta, Canada Saskatchewan Department of Highways and Transportation Cuyahoga Co., Ohio

Washington Co., Minnesota Iowa DOT Ada County Idaho Plow-down miles traveled (4) New Mexico DOT New York State DOT Edmonton, Alberta, Canada City of West Des Moines, Iowa Cost of winter operation per lane mile (efficiency) (15) Ohio DOT New Mexico DOT Iowa DOT Maryland State Highway Administration New York State DOT CalTrans Detroit Indianapolis King County, Washington El Paso Co. Colorado Edmonton, Alberta, Canada City of West Des Moines, Iowa Saskatchewan Department of Highways and Transportation Washington Co., Minnesota Minnesota DOT	Ada County, Idaho Minnesota DOT Tons of material used (19) Sweden Ohio New York State DOT Caltrans Detroit Indianapolis King County, Washington Cedar Rapids, Iowa McHenry Co., Illinois City of Seattle Douglas Co., Nebraska Edmonton, Alberta, Canada Maryland State Highway Administration City of West Des Moines, Iowa Saskatchewan Department of Highways and Transportation Washington Co., Minnesota Cuyahoga Co., Ohio Iowa DOT Ada County, Idaho
Outcome Measures	
Time to bare pavement (10) Sweden New York State DOT Caltrans Ontario, Canada Maryland State Highway Administration Edmonton, Alberta, Canada McHenry Co., Illinois Cook County Illinois Highway Department Ada County Idaho Minnesota DOT Time to wet pavement (3) Missouri Washington Co., Minnesota Ada County, Idaho	Travel speed during storm (2) Ohio DOT Ada County Idaho (Iowa is evaluating but has not incorporated into operations) Customer satisfaction (18) Sweden Ohio DOT New York State DOT Caltrans Alaska Dept. of Transportation and Public Facilities Detroit Street Maintenance Division King County, Washington El Paso Co., Colorado Cedar Rapids, Iowa

Time to return to a reasonably near-normal winter condition (10) Sweden Ohio DOT New York State DOT Caltrans Iowa DOT Saskatchewan Department of Highways and Transportation Edmonton, Alberta, Canada El Paso Co., Colorado Douglas Co., Nebraska City of West Des Moines, Iowa Time for traffic volume to return to “normal” after the storm (5) Caltrans Detroit Street Maintenance Division Cedar Rapids, Iowa Cuyahoga Co., Ohio Ada County Idaho Time to provide 1 wheel track (1) Iowa DOT Level of service (11) Ohio DOT New York State DOT Caltrans Iowa DOT New Mexico DOT Detroit Street maintenance Division Kansas DOT (Pavement condition for the category of route) Cedar Rapids, Iowa (traffic flow) City of Seattle Saskatchewan Department of Highways and Transportation Ada County Idaho	McHenry Co., Illinois New Mexico DOT Douglas Co., Nebraska Edmonton, Alberta, Canada City of West Des Moines, Iowa Washington Co., Minnesota Minnesota DOT Cuyahoga Co., Ohio Ada County Idaho Friction (5) Sweden Ohio DOT Douglas Co., Nebraska Cuyahoga Co., Ohio Ada County Idaho Crashes per vehicle mile (2) CalTrans Ohio DOT Traffic volume during storm (2) CalTrans Ada County Idaho Time until low-volume roads open to traffic Missouri Annual quality assurance reports Ohio Time since last treated Indianapolis Contract trucks deployed in a reasonable manner Maryland State Highway Administration Total Hours Road Closed CalTrans
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Table 14 lists the approaches used by agencies to acquire data for outcome measures. Clearly human observation is the most common approach.

Table 14. Outcome measures and approaches used by responding agencies

Measure	Approach
1. Time to reasonably near-normal winter conditions	1.1 Visual inspection by maintenance personnel (AK) 1.2 Visual inspection by maintenance personnel (CA) 1.3 Reports from field personnel (IA) 1.4 Reports from field personnel (CA) 1.5 Reports from field personnel (NV) 1.6 Visual inspection by maintenance personnel (NV) 1.7 Reports from field personnel (NM) 1.8 Visual inspection by maintenance personnel (NM) 1.9 Visual Inspection by law enforcement (NM) 1.10 Reports from field personnel (NY) 1.11 Visual inspection by maintenance personnel (NY)
2. Customer satisfaction	2.1 Annual survey at end of season (AK) 2.2 Internet survey (CA)
3. Travel speed	3.1 Automatic traffic recorders (NY) 3.2 Testing automatic traffic recorders (IA)
4. Time to bare pavement	4.1 Visual inspection by maintenance personnel (CO) 4.2 Report from field personnel (CO) 4.3 Visual inspection by maintenance personnel (MD) 4.4 Reports from field personnel (MD) 4.5 Reports from field personnel (MO) 4.6 Reports from field personnel (NV) 4.7 Visual inspection by maintenance personnel (NV) 4.8 Visual inspection by maintenance personnel (OH) 4.9 Reports from field personnel (OH) 4.10 Visual inspection by maintenance personnel (WA) 4.11 Reports from field personnel (WA) 4.12 Visual inspection by law enforcement (WI) 4.13 Visual inspection by maintenance personnel (ON)
5. Total time of road closure	5.1 Accounting records of hours closed (CA)
6. Total time of chain restrictions	6.1 Records of chain restriction hours (CA) 6.2 Records of chain restriction hours (CO)
7. Time to single bare wheel track	7.1 Reports from field personnel (IA) 7.2 Reports from field personnel (KS)
8. Time to two bare wheel paths	8.1 Reports from field personnel (KS)
9. Time to treat critical areas	9.1 Reports from field personnel (MO)
10. Friction	10.1 Testing (OH) 10.2 Established friction coefficient (Sweden) 10.3 Preliminary testing (ON)

Other practices that emerged in the survey comments include the following:

- A PSIC chart to help identify uniform pavement conditions by combining traffic flow characteristics and visual observation.
- Various outcome measures are sometimes combined to form an overall LOS rating for a roadway.
- Contracts with private sector operators are written such that reimbursement is based on a combination of input (pay items) and output or outcome measures (expectations).
- Innovative technologies such as AVL, GPS, friction meters, and various sensors of materials, equipment, and temperature are installed on winter maintenance vehicles to help collect performance measure data.
- Winter weather severity indices have been developed to help quantify the relationship between the severity of winter weather events and roadway condition or safety factors.

5.3. Screening of Approaches

Analysis of the survey findings identified 4 input measures, 5 output measures, and 11 outcome measures used by public agencies to measure snow and ice control performance. To identify measures and approaches that warrant further study, the following criteria were applied to available measures and approaches:

Measure criteria

- Does the measure directly measure safety, mobility, or public satisfaction?
- Does the measure improve snow and ice control?
- Is the measure mapped to roadway segments?
- Is the measure reported for garages or districts?
- Is the measure sensitive to storm characteristics?
- Does the measure examine storm events individually or annually?

Approach criteria

- Is the approach quantitative?
- Is the approach stable across observers?
- Is the technology likely to improve?
- Is a major capital or operational investment required?
- Can the approach be “piggy backed” on another system to reduce installation cost?

Applying these criteria revealed that input and output measures are valuable management tools because they measure the amount of material, labor, and money consumed, as well as the amount of material applied to roads, lane-miles plowed, etc. However, these measures do not directly address the goals of the agencies, regarding public safety and maintenance of mobility. As they

are, input and output measures help with budgeting and can be used roughly to compare efficiency between garages or districts that experience similar snow and traffic conditions. The measures do not improve snow and ice control, but help track the investment required to do so. The measures are generally not mapped to roadway segments, although they are often reported by garage or by district. Input and output measures are not observed to be sensitive to storm characteristics, although they could be if an index were applied.

Input and output measures rate high on the “approach” criteria because the investment in accounting and maintenance management personnel is used to produce the reliable and quantitative numbers. Input and output measures are reasonably easy to obtain and measurement is stable from year to year. However input and output measures do not measure safety or mobility of the roadway system. Input and output measures can be difficult to obtain if the measure requires data from smart on-board controllers. Plow-down time is the only performance measure reported that requires (or would benefit from) an on-board system, and only four agencies reported using this measure, probably because they invested in the on-board control systems and can now easily report plow-down time. Extensive work has been done to develop smart snow plows, and equipment that has been tested includes the following:

- GPS receivers with real-time mapping of truck location
- Plow-position reporter
- Material dispensed, linked to vehicle location
- Pavement temperature sensor
- Sensor to detect melting point of road slush
- Friction wheel
- Heads up display of road center line

These technologies make it possible to report outputs by road segments and link output variables to vehicle location. The development of smart snow plows is continuing to provide operational benefits. Successfully measuring friction has obvious implications for performance measurement, but, recent work by the NCHRP has determined that friction measurement is experimental. For these reasons, pursuing smart snow plow technology as part of a performance measure project is not recommended.

Snow and ice control operations also need individual storm information, e.g. precipitation, intensity, duration, temperature, etc. to be effective. Accordingly, there is a need to quantify the severity a given storm in order to normalize the efforts expended fighting that storm. Weather indices are useful for normalizing storm data. Most existing weather indices work on a season-by-season basis, rather than a storm-by-storm basis. There exists a trade-off between monthly and seasonal averages: while seasonal data are more normal, fewer observations are available for analysis. Alternately monthly data offer more observations, but are not as normally distributed. Maintenance personnel require this information to improve snow fighting capabilities. Seasonal averages do not provide sufficient data for meaningful analysis for fighting individual storms.

In contrast to input and output measures, outcome measures could measure safety and mobility, and they affect snow and ice control. Targets for clear pavement or wet pavement by road class are used by several agencies. Some measures are roughly sensitive to storm characteristics

because they identify the maximum allowed accumulation during a storm and maximum time for removal after snow stops falling. Outcome measures require some form of human observation that while error can be reduced through training or field guides, human observation always results in some subjectivity. Additionally, replacing human observation with some form of technology requires large capital and operational expenses. In the early stages, calibration problems may actually introduce more variation into the measurements than human observation. While several technologies are promising, no U.S. agency has been willing to invest in fully deploying the technology to measure snow and ice control outcomes.

Measures of outcome will help improve safety and mobility. Some form of observation technology must be deployed to rate outcome measures high in the “measure” and “approach” criteria. However, widespread deployment is unlikely unless the surface condition data can be obtained from enhancements to the technology being deployed for other purposes.

To help determine the measures and approaches having potential for use the 11 outcome measures observed in this study were reduced to three basic categories and two approaches were identified for each:

1. Measure: Degree of clear pavement
Approach: Manual observation
Approach: Camera-assisted observation
2. Measure: Traffic flow
Approach: Detector-based traffic flow
Approach: Road closure
3. Measure: Crash risk
Approach: Friction (or slipperiness)
Approach: Reported crash data

The Outcome Measure of the Degree of Clear Pavement

Approach: Manual Observation

Measures of the degree of clear pavement by roadway type are common can be used to relate conditions to safety and mobility. The issue of measuring clear pavement in the winter is similar to that of measuring pavement distress in the summer as the basis for programming road improvements. However, snow and ice conditions used to be measured at much shorter intervals (hourly versus annually).

While it would be desirable to replace human observation with automated technology the fact is that maintenance supervisors are on duty during storms and can provide condition data at no additional cost makes it attractive with the use of pictorial guides, a reasonably objective determination is possible. While potential for improvement in this approach is not envisioned best practices for manual observation could be compiled as part of a future research effort

Approach: Camera-Assisted Observation

No agency reported using freeway-monitoring cameras as an aid to human observation. However, because most large urban areas are deploying cameras as part of regional traffic management systems, it is possible that these cameras can be used to observe road conditions on urban freeways. Maintenance supervisors may not have access to the cameras or they may be on the road making manual observations anyway, and thus the cameras would not help significantly. However, the use of cameras appears to be an appropriate measure for snow and ice control. While the use of cameras is limited, primarily to metropolitan areas, the technology is proven and can aid agencies in observing road conditions with limited personnel. Furthermore, cameras are known to being studied to enhance human observation, rather than actually detecting surface conditions. Detectors are discussed in the following section.

The Outcome Measure of Traffic Flow

Approach: Detector-Based Traffic Flow

This approach considers measures of traffic flow, including speed, volume, and occupancy. The Ohio DOT and Ada County, Idaho, are the only agencies that reported speed during a storm as a performance measure. Caltrans and Ada County reported using traffic volume during a storm as a measure. The Iowa DOT is currently experimenting with the use of ATRs to measure traffic speed and volume. The following five agencies use time to return to “normal” traffic volume after a storm as a measure:

- Caltrans
- Detroit Street Maintenance Division
- City of Cedar Rapids, Iowa
- Cuyahoga County, Ohio
- Ada County, Idaho

Despite the lack of widespread use, there appears to be great potential in traffic flow measures. Traffic speed, volume, and road occupancy are direct measures of mobility. While speeds do not always drop as much as expected in bad road conditions due to aggressive driving, drivers do increase the spacing between vehicles, resulting in reduced volume or reduced occupancy. Traffic flow theory will provide the relationships between occupancy, throughput, and speed.

Currently, cameras and traffic flow detectors are being deployed as components of ITS across the U.S. Several detectors show promise as tools for measuring road conditions, including cameras that utilize the visible spectrum and the non-visible spectrum. Other research has produced cameras that utilize lasers or the infrared spectrum to analyze surface conditions. Such cameras, some of which are being field tested in the United States, have shown promise in accurately sensing the presence of differing amounts of water, frost, snow, and ice on a roadway surface. Side-fire radar has also become quite reliable for measuring speed and occupancy.

We recommend pursuing detection-based approaches deployed as upgrades to ITS monitoring. The ITS investment is being made in most urban areas already, and winter maintenance measurement capability could be added at an incremental cost rather than at full cost. Additionally, state agencies already collect speed and volume data by deploying ATRs periodically along the interstate and national highway systems for the routine monitoring of VMT. Identifying snow and ice event times and capturing the ATR data as the basis for performance measurement is attractive because it uses an existing investment for a new purpose.

The disadvantages involved in pursuing traffic flow approaches include the following:

- Low density of detectors in rural areas
- Institutional barriers within DOTs: neither traffic data nor traffic control centers have a winter maintenance mission; their mission would have to be restructured to deliver this information to maintenance personnel and, perhaps, to the public
- Upgrades to the operations platform that drives the ITS

In general, the lack of technological approaches to measuring snow and ice control performance indicates that the benefits are not now perceived as worth the investment. By adding winter condition measurement capability to ITS upgrades and capturing ATR data for this purpose, the cost of acquiring road condition data can be reduced. The technologies involved are mature enough to deliver the desired result.

Approach: Road Closure

Road closure is a simple measure of traffic flow, since none is allowed. This is a very useful measure to record because it is an input for calculating the economic cost of lost mobility. Little can be done to improve upon it, however. We recommend that road closures be recorded, possibly as lane-hours of closure. However, the measure is only appropriate when the struggle against snow and ice has been lost.

The Outcome Measure of Crash Risk

Approach: Friction (Slipperiness)

NCHRP Project 6-14, which resulted in *Feasibility of Using Friction Indicators to Improve Winter Maintenance Operations and Mobility*, determined that friction is a feasible quantity to measure. Thus, we recommend additional work on friction measuring technology, and pursuing the type of performance measurement that could be based on friction. Ohio is the most pioneering state on this topic. We recommend documenting more fully Ohio's activities in friction-based performance measures.

Approach: Reported Crash Data

Crash data collected during winter storm events can provide a basis for measuring performance. Trends in crashes during snow and ice conditions could be used to measure change in maintenance performance. Analysis tools are already used in many states that allow users to search the crash records by weather condition as reported by the officer at the scene of the crash, and, if correlated with storm severity, provide a fairly robust measure.

One of the early findings of preliminary work by Iowa State University is that crash risk during the first storm of the season is always far worse than succeeding storms. Apparently, drivers must relearn winter driving skills each year. (Maze et al. 2005)

As part of the overall safety programs, states continuously improve their collection and analysis of crash data. The analysis of crash data will likely yield best practices including specific recommendations for the type of weather data to include in crash reports and the best tools for analyzing crash data. For example, we know that all crashes that occur during a winter storm are not reported, but crash databases will include personal injury crashes. We know from prior analysis of the Iowa crash database that the number of reported crashes skyrockets for winter storm periods. (Maze et al. 2005).

Storm Severity Index

In addition to the 11 different types of outcome measures reported in the survey, 15 measures of storm severity were identified in the literature search. We recommend agencies develop an operational storm severity index that can be applied to normalize any other measure over time. This would be a great benefit to comparing costs by time period. Our analysis shows that storm severity models using monthly and seasonal data that the models using monthly data are more useful for managers fighting storms.

Customer Satisfaction

Customer satisfaction sets the level of performance that the public expects, as a measure of performance. Because the performance measures measure how close winter road maintenance comes to meeting public expectations, those outcomes can also be measured by surveying the public directly. Most agencies use a periodic survey to determine public expectations, and agencies also track complaints and 511 calls. We recommend defining best practices for determining customer satisfaction and linking operational performance to those expectations.

5.4. Summary of Approaches

In summary, we recommend the following:

- Document best practices for manual observation of pavement conditions.

- Document the use of traffic control center cameras or remote cameras to aid manual observation inputs to performance measures.
- Pursue detector-based approaches that use traffic speed, volume, or occupancy as means of acquiring data measuring performance.
- Document measures that are or can be based on friction.
- Document best practices and opportunities for recording and analyzing crash data during winter storms for use as a performance measure.
- Develop a reasonable procedure for incorporating a winter storm severity index to normalize input, output, and outcome measures.
- Determine best practices in the measurement of customer satisfaction and link those measures to measures of operational performance.

CHAPTER 6. CREATING PERFORMANCE MEASURES TOOLBOX FOR SNOW AND ICE CONTROL OPERATIONS

6.1. Introduction

Interviews with snow and ice control operations personnel revealed that performance measurement programs are established for numerous and various reasons. Many reasons focused on budgetary management, while others were more political, such as legislature mandating performance. The first step in evaluating effectiveness of performance measures are to determine why they are in place and to ask what is to be accomplished by instituting a performance measurement program. This chapter focuses on developing a toolbox to evaluate relevant performance measures for snow and ice control operations.

6.2. Benefits of Using Performance Measurement

The basic purpose of any measurement system is to provide feedback, relative to the agency's goals, that increases the chances of achieving these goals efficiently and effectively. Measurement thus gains true value when used as the basis for timely decisions.

The accounting firm of Price Waterhouse (Artley and Stroh 2001) has suggested three main reasons for establishing metrics in an organization that are applicable to snow and ice control operations.

1. **Measurement clarifies and focuses long-term goals and strategic objectives.** Performance measurement involves comparing actual performance against expectations and setting up targets by which progress toward objectives can be measured.
2. **Measurement provides performance information to stakeholders.** Performance measures are the most effective method for communicating about the success of programs and services. For example, in public education, states and school districts routinely issue "report cards" highlighting test score outcomes and other key indicators of

educational performance. These have become centerpieces of attention among not only educators, but many other stakeholders. Snow and ice control agencies can also benefit from “report cards” regarding their performance.

3. **Measures encourage delegation rather than “micro-management.”** Hierarchical structures and extensive oversight requirements can hinder organizational effectiveness. Performance measures free senior executives for more strategic decision making and collective intervention, while clarifying the responsibilities and authority of managers down the line.

Organizational metrics are important for these organizations. Working with employees, management, and affected stakeholders, organizations involved in strategic planning can develop measures of performance in the production of goods and services and in meeting the organization’s most important objectives.

There is no single model or process for developing performance objectives and measures, nor is there a process that will guarantee good results. We have attempted to synthesize lessons learned from the literature as well as the insights gained from our surveys and work with agencies in applying performance measurement to the management of snow and ice control operations issues.

Developing a Performance Measurement Toolbox

One method used to develop performance measurements for snow and ice control is to apply a toolbox to the problem. A performance measure toolbox brings structure to performance planning and clarifies the connection between activities, outputs, and results. The toolbox uses the following steps relative to the objectives specified in an agency’s strategic plan:

Step 1. Confirm Snow and Ice Control Operations Role.

The agency should define the role that snow and ice control operations are intended to play with respect to strategic objectives and should provide a basis for establishing overall targets and performance measures. This step will guide the type of goals and objectives to be measured. For example, if the reason for establishing a performance measurement program is budgetary, then the measures used will involve ranking investments and allocating resources based mostly on internal decisions. Externally based reasons may have to do with evaluating the department against peer comparisons and establishing comparable benchmarks to other peer organizations. Defining the role that the program is intended to play with respect to strategic objectives provides a basis for establishing program targets and performance measures. That is, have the links between the main activities and outputs of the program and the department’s snow and ice control objectives been established (e.g., activity/output “Y” contributes to, or detracts from, strategic objective/outcome “X”)? The department’s snow and ice control strategy should identify the department’s significant snow and ice control aspects as well as its strategic objectives for addressing these aspects and the measure that will be used to indicate progress. Table 15 shows the link between the department’s activities and the strategic outputs. Plowing and anti-icing, for example, directly contribute to mobility.

Table 15. Linking program activities and outputs to strategic objectives

Main program activities or outputs	Contribution to / detracting from strategic snow and ice control objective(s)	Strategic objectives or outcomes that the program activity or output contributes to
Plowing, Anti-Icing	Y	Mobility
Plowing, Anti-Icing	Y	Safety
Plowing, Anti-Icing	Y	Productivity
Plowing, Anti-Icing	Y	Environmental Quality

For instance, consider the budget-driven model of the Wisconsin DOT, in which the state reimburses 72 counties perform winter maintenance on state and federal roads (Adams et al. 2003). The three most important current objectives for Wisconsin are as follows:

1. Provide bare/wet pavement in a reasonable amount of time and effort.
2. Improve the coefficient of friction between vehicle tires and the pavement.
3. Provide good winter driving conditions using the most efficient methods possible.

The agency uses a single measure to measure the LOS for snow and ice operations. Periodic field condition surveys are conducted to measure the traction conditions due to anti-icing chemicals, sand application, or plowing on the travel lane road surface. These conditions are determined by observing a mile of road after a winter operation has taken place. Bare pavement is considered 95% of the roadway being free from ice and snow. A roadway is considered sanded if at least 60% of the travel lane has sand on its surface. This is equal to a travel lane with bare tire tracks with sand on the remainder of the lane (Conger 2005). The data sources for the performance measurement system include accounting records, visual inspection by law enforcement, periodic customer surveys, and AVL data from plows.

The measures of these objectives include the time to bare/wet pavement and costs per lane-mile, while the performance levels have not yet been established. The impetus of the Wisconsin performance measurement program is thus budget driven. The program developed by the Wisconsin DOT combines the vehicle data obtained by the on-board systems with weather event data, labor inputs, and equipment costs, and spatial data. According to Adams et al. (2003), this system provides information that managers can use to show relationships by vehicle, patrol section, and storm (e.g., salt application rate, pavement temperature versus weather conditions).

Step 2. Identify the Key Snow and Ice Control Activities and Outputs

This step is to direct winter maintenance managers and staff to identify and focus on the key program activities. Only those activities that directly relate to the department's strategic objective should be measured. Subsequently, only those measures that provide useful information should be used. Collecting data and information can be time consuming and expensive so it may be impractical to collect data on every departmental activity.

This step is essential to ensure that program managers and staff focus on key issues that contribute to the achievement of the department’s strategy for snow and ice control. When establishing the toolbox, it is important to ask whether the key activities and outputs of the snow and ice control program, in terms of their importance (e.g., high, medium, low) in contributing to the department’s strategic objectives, have been identified. Table 16 illustrates an example of this process.

Table 16. Identifying the key program activities and outputs

Program activities and outputs	Rank, in terms of significance		
	Strategic objective from Table 16: safety	Strategic objective from Table 16: mobility	Strategic objective from Table 16: Productivity
Plowing	High	High	High
Output: Road Condition	High	High	High

KDOT, for example, identifies key activities of snow and ice control based on road condition across road categories. Specifically, KDOT’s objectives were noted as providing a safe travel way and using resource efficiently. The specific measures that KDOT uses to indicate a safe travel way vary across three roadway categories, but not across storm type or characteristics. Data indicating these measures come from reports by field personnel and a computer system where field personnel record road conditions. The three categories, measures, and performance levels are as follows:

- Category I: two bare/wet wheel paths
- Category II: both lanes on two-lane roads with intermittent bare/wet wheel paths
- Category III: one wheel path on two-lane roads with intermittent bare/wet wheel paths

However, while these performance levels measure the road condition, they do not necessarily indicate a safe travel way. The road condition measure indicates the plowing effectiveness; however, “safety” is generally measured by the absence of crashes. That measurement is not indicated among the performance measures.

KDOT currently obtains these observational, road condition data from each district and then segments the data by district, area, and sub-area for analysis. The data, however, are not collected on a routinely, timely basis, and much of the analysis is performed well after the storm event is completed. Thus, there is no immediate feedback provided.

Step 3. Identify Program Stakeholders and Issues.

To identify the customers whom the winter maintenance activities and outputs should serve, influence, or target; the other principal groups affected are; and the ways these groups are affected. For example, to focus on reasonable access to farms and ranches in rural state might involve different performance measures than a focus on keeping long-distance roadways clear to allow reliable and safe movement of freight.

To formulate a set of snow and ice control objectives, it is essential to identify the customers to be served. Generally, snow and ice control managers have two groups of customers, internal and external. The internal group is the performance measurement user, generally upper management. Management uses the performance measurement information as a decision support tool for budgetary and planning functions. The data gathered from the process help determine program needs, allocation of funds, and selection of projects.

The external customer is the road user. This is also an important stakeholder. The road user provides input in the development of the agency's goals and objectives. In particular, the road user's opinions about the strengths and weaknesses of the snow and ice control agency can influence the agency's goals and objectives. Many of the snow and ice control agencies we surveyed indicated that they periodically solicit public opinion to assess their job performance. By identifying and addressing customer needs performance measurement can help agencies respond to those needs.

Regarding the main program activities and outputs identified in Table 17, managers must also determine how the relevant snow and ice control issues affects the stakeholders. Managers must be aware that the activities and outputs associated with the activities can have both desired and undesirable effects on the stakeholders. When possible, actions must be taken to mitigate undesirable effects.

Table 17. Identifying key snow and ice control issues and affected stakeholder groups

Main program activities and outputs, in order of significance	Snow and ice control issues		Stakeholder groups (affected parties)	
	Desired program effects	Undesirable program effects	Positively affected	Negatively affected
Example: plowing	Clear roads	Inefficient energy use	Road users	Possible environmental damage
Example: chemical usage	Snow and ice removal	Inconsistent application of chemicals	Road users	Possible environmental damage

Caltrans, for example, uses a variety of performance indicators for both its internal and external customers. As input measures, Caltrans uses personnel hours and overtime hours. For input

measures, Caltrans uses tons of materials used, lane-miles plowed, amount of equipment deployed, and cost of winter operations per lane-mile.

Explicit performance levels and standard approaches have not been established for the “time to bare pavement” measures, although the department does compare predicted weather forecasts with actual outcomes. Overall, they noted that targets are set annually for meeting performance objectives in California.

Utilizing performance measurement results in improved communications with staff, improved decision-making and performance, and improved external communications. If the agency can identify specific targets and timelines for the measures that have been identified, then a more comprehensive and effective performance measurement program can be achieved.

Step 4. Identify What the Snow and Ice Control Operations to Accomplish

This step is to illustrate that the results are defined in terms of outcomes that then become the focus for determining appropriate objectives, milestone targets, and measures (e.g., that managers receive appropriate feedback).

The organization must establish the results it expects to achieve in terms of outcomes that then become the focus for determining appropriate objectives, milestone targets, and measures. In this step, consider whether the desired long-term snow and ice control outcomes for each program activity or output have been established, document the positive effect(s) that need to be produced, and consider whether near-term outcomes that can be expected to lead to the long-term outcomes have been established. While this work step often focuses on establishing objectives to redress identified undesirable outcomes, it is possible that positive effects can also be further reinforced or improved. Table 18 illustrates an example of this step.

Table 18. Defining results

Program activities and outputs, in order of significance	Desired snow and ice control results (objectives)	
	Long-term strategic	Near-term intermediate
Example: plowing	Maintain mobility	Roadways plowed within 8 hours after storm
Example: chemical distribution	Reduce highway accidents	Treat roadway surfaces prior to approaching storm

For example, when asked what performance measures are the most critical to its operations, the Iowa DOT stated its overall goal is to minimize travel disruptions during winter storms. Current objectives were listed as safety, returning roads to near-normal driving conditions as soon as possible, and using the right type and amount of deicing materials at the right place and time; the department also acknowledged the need to strike a balance between budget, customer service, and the environment. In terms of specific performance measures, Iowa’s survey response identified Iowa as one of the states using different performance levels or targets for different roadway classifications.

Step 5. Identify Responses and Performance Requirements.

This step determines how objectives are to be achieved. Performance objectives must be defined in operational terms to be managed effectively. It is important to consider whether the necessary performance requirements have been defined to achieve the desired snow and ice control results. Table 19 illustrates an example of this step.

Table 19. Performance requirements relative to responses and results

Objective(s)	New or modified activities, outputs, or other necessary program response(s)	Performance reqs. relative to each activity, output, or other necessary response
Example: Time to bare pavement	Plowing, clearing roadway	Bare lane indicator, Friction measurement

For example, using friction as a performance measure. The friction coefficient is determined there are “trigger” values of the friction measurement that would require prompt treatment in those areas where the friction is less than adequate. Friction measurement devices can detect icy conditions earlier, provide input for operational decisions in a timely manner, and pinpoint problem areas with geo-referencing devices.

Establishing Performance Measures

The next four work steps are intended to help snow and ice control operations personnel establish sound performance measures as well as accountability and resource requirements for implementation.

Step 6. Identify Potential Performance Measures.

In this step, the agency should develop a list of performance measures that correspond to performance targets. Performance measurement is required to understand the gap between actual and expected levels of achievement and the times when corrective action may be warranted. The results indicated by a performance measure will generally be compared with expectations specified by a performance target (which might be based on a benchmark best practice, a technical standard, or some specified progression from the baseline value). Therefore, performance measures should correspond to performance targets and indicate the extent to which the organization is achieving these performance expectations. Performance measures are an important source of feedback for effective management.

The set of measures should address each aspect of the performance framework or toolbox. Recalling the performance framework outlined above, some performance measures will reflect how well the program was managed. Such measurements may, for example, focus on time to reach bare pavement, number of accidents, or costs per lane-mile. Measurement in this area can involve observation (checking the roadway using traffic cameras) or feedback (e.g., public comments or survey responses). Finally, some measures will allow a judgment to be made for

long-term objectives. These measures involve monitoring long-term efforts such as environmental impacts (chemical usage, roadway impacts, vegetation impacts, etc.) that can plausibly be linked back to the program initiatives, outputs, and intermediate effects. These measures serve as the ultimate barometers of program success. Table 20 provides an example of establishing performance measures.

Table 20. Establishing potential performance measures

Objectives	Activities, outputs, or other program responses	Performance requirements	Potential performance measure(s)
Example: Provide winter storm event response to minimize disruption to normal operations	Plowing, sanding, chemical application	Time to bare pavement, time to bare lane	“X” hours after storm completed
Example: Provide efficient snow and ice control services	Plowing, sanding, chemical application	Costs per lane mile(fuel, equipment, personnel, chemicals, etc)	Costs per lane mile met or exceeded target

The specific measures used may vary from garage to garage or county to county, based on geography, weather conditions, road patterns, traffic, etc. The overall organizational goal will be the same, but specific measures may have to be adjusted to accommodate geographic and operational conditions.

Step 7. Establish Information Capabilities and a Baseline for Each Measure

In this step, agencies should establish the initial value or baseline of each measure. Understanding the information currently available to the organization as well as the organization’s capabilities for gathering and analyzing information is an important first step in the selection of performance measures. Moreover, establishing baseline measures for each measure will shed light on the organization’s information capabilities and gaps. Baseline measures help clarify the implications of objectives in terms of “level of effort” and resource requirements, and they facilitate assessment of the extent to which progress has been made from an initial condition. Baseline information provides a further context that helps clarify the magnitude of performance challenges and achievements. Table 21 provides examples for establishing baseline measures.

Table 21. Establishing baselines for measures

Potential performance measure	Units	Initial or baseline value
Time to bare pavement	Hours	Hours after storm ends
Return road to near normal conditions	Hours	ADT

Step 8. Assess the Adequacy of Performance Measures

Once a list of candidate performance measures has been developed, the next step is to select a set of performance measures that are suitable for tracking performance toward the specified snow and ice control objectives. Managers should select requirements that are important to the organization's overall goals and performance measures. Screening the set of measures also helps to ensure that there are no costly measurement redundancies or gaps.

Table 22 is intended to help users assess the candidate performance measures developed in previous steps. Note that there is a high degree of consensus about the attributes of a good performance measure. The table summarizes the attributes of a good performance measure and concludes that good performance measures are meaningful, reliable, and practical.

Table 22. Quality criteria for performance measures

Attributes		Explanation
Meaningful		
<i>Understandable</i>		• clear (clearly and consistently defined) • context (explained) • concrete (measurable)
<i>Relevant</i>		• lack of ambiguity in direction • relates to objectives • significant and useful to the users
<i>Comparable</i>		• attributable to activities • allows comparison over time or with other organizations, activities or standards
Reliable		
		• accurately represents what is being measured (valid, free from bias) • data required can be replicated (verifiable) • data and analysis are free from error • not susceptible to manipulation • balances (complements) other measures
Practical		
		• feasible financially • feasible to get timely data

For example, Mn/DOT uses bare pavement regain time as a meaningful, reliable, and practical performance measurement. Based on predefined road classes, a statewide timeframe, in hours, stipulates when bare pavement should be achieved. These ranges are shown in Table 23 (Keranen 2002).

Table 23. Mn/DOT ranges for bare pavement regain time

Road class	Statewide range (hrs.)
Super commuter (>30,000 AADT)	SC1 to SC10
Urban commuter (10,000-30,000)	U1 to U10
Rural commuter (2,000-10,000)	R1 to R10
Primary (800-2,000)	P1 to P10
Secondary (<800)	S1 to S10

The performance measures must also be screened against criteria for quality considerations. Table 24 can help agencies assess the quality of a performance measure and determine its overall value for decision making.

Table 24. A screening tool for quality considerations

Performance measures that satisfy snow/ice control criteria	Meaningful (y/n)			Reliable (y/n)	Practical (y/n)	Satisfies content and quality criteria (y/n)
	Und.	Rel.	Comp.			
Time to bare pavement	Y	N	Y	Y	Y	N
Costs per lane mile	Y	Y	Y	Y	Y	Y
Safety	Y	Y	Y	Y	Y	Y
Mitigate environ. impacts	Y	Y	Y	Y	Y	Y

Generally, snow and ice control performance measures should correspond to management objectives. Therefore many of the performance measure developed in support of overall snow and ice control strategies will be agency-specific. In the case of “cross-cutting” policy issues addressed by programs or common operations management issues that departments must confront, departments may have similar objectives and performance measures. Coordination of objectives and measures may improve management, reporting, and oversight of the overall agency’s performance.

Step 9. Establish Accountability and Resources for Implementation

Agencies should establish an accountability system that formalizes the relationship between results, outputs, activities, and resources. It allows people to see how their work contributes to the success of the organization and clarifies expectations for performance. Table 25 illustrates an example of implementing accountability, and Table 26 provides an example of identifying resource requirements.

Table 25. Establishing accountability for implementation

Stage in the accountability process	Example measure 1	Example measure 2
Program objectives for snow and ice control	Objective 1	Objective 2
Responsible party(s) for achieving objective		
Activities, outputs, or other responses necessary to meet objectives	Response 1	Response 2
Responsible party(s) for managing activities or outputs and meeting the requirements		
Performance measure(s)	Measure 1	Measure 2
Responsible party(s) for evaluating measures		

Table 26. Identifying resource requirements for implementation

Snow and ice control objectives	Activities, outputs, or other responses necessary	Resource requirements		
		Human	Equipment	Other
Safety	Plowing, anti-icing	Drivers	Trucks, plows	
Level of service	Plowing, anti-icing	Drivers	Trucks, plows	
Mobility	Traffic speed	Drivers	ATRs, WIM, cameras	

In addition to internal accountability measures, several states have an externally oriented, highly visible performance reporting process. Typical audiences include oversight and policy commissions, the governor's office, the legislature, and the public. Agencies typically make their performance data available and accessible through public reports and the Internet. For example, WSDOT's *Gray Notebook* (<http://www.wsdot.wa.gov/accountability/graybookindex.htm>) is presented to the state transportation commission, posted on the Internet, and distributed around the state to legislators, tribal governments, major media outlets, and transportation interest groups. The agency's accountability web site includes a subject index that allows users to see the results of all published performance measures.

6.3. Conclusions

Achieving reliable and relevant performance data for a snow and ice control performance measurement program is a large task for any organization. The challenges and problems associated with performance measurement are multiplied by the unpredictable nature of working with winter weather.

Complex factors influence the usefulness of performance measures. First, the performance measures must be perceived as reliable. Straightforward processes are best suited for obtaining reliable data because complexities can cause variations in reporting. Furthermore, each district or

garage should have a clear understanding of what to include and exclude from the performance measurement program. The program should also involve key people in the creation of performance target definitions and in the reexamination of existing definitions and measures.

In addition to reliability, relevance is a key ingredient in data use. As discussed, relevance takes many shapes, and managers and jurisdictions each have their own unique needs. Factors influencing relevance include managerial control, timeliness, fruitfulness, organizational capacity, and the organizational philosophy of performance measures. This is not an exhaustive list, yet it is enough to demonstrate that achieving data use is not effortless.

Agencies may be able to improve their snow and ice control services by measuring the effectiveness of services they provide. Measuring performance, or the results of services, provides several benefits. The results can demonstrate value to taxpayers. Knowing the results of the service allows an agency to tell whether it has accomplished its intended objectives, and, if necessary, adjust its procedures or practices. Concentrating on results also helps agencies be more responsive to the needs of their customers and may help agencies communicate more effectively with taxpayers.

CHAPTER 7. DEVELOPING A FIELD TEST PLAN

The purpose of this chapter is to outline a field test plan for developing a performance measurement program and examining the tools, best practices, and limitations for snow and ice control. The field test plan is also designed to help the practitioner understand when to use and when not to use these tools and practices. In addition, a performance measurement program encourages progressive changes in snow and ice control practices that will help reduce chemical usage and mitigate environmental impacts while meeting the safety and mobility needs of roadway users.

The research revealed the organizational objectives associated with snow and ice control performance measures that relate to the inputs, outputs, and outcomes of snow and ice control operations as follows:

- Accounting for inputs used for snow and ice control
- Accounting for outputs accomplished
- Operational efficiency
- Meeting outcome goals
 - a. Highway safety
 - b. Highway mobility
 - c. Public satisfaction
 - d. Controlling negative environmental impacts

7.1. Measures of Input, Output, and Operational Efficiency

The measures associated with inputs, outputs, and efficiency are based on the accounting system and shop records: fuel used, person hours, material used, equipment deployed, and plow-down miles. All of this information originates at the operating unit level and is aggregated up to higher levels for management review. Since the information originates at the operating unit level, it makes sense to maintain performance measures at this level.

Measures derived from these data can be used for tactical decision making if the reporting interval is short. For instance, if data reports are received within about two weeks, shops can examine the resources used and efficiency in light of recent weather. A road classification dimension can also be added to measure resources used on different classes of roads. Doing so requires a truck-based GPS recording system to record the truck's location and the miles, hours, fuel, material, etc., by road classification.

Adding a seasonal weather index can also lead to some financial planning parameters, linking material and labor hours to inches of snow or some other weather severity measure. Because the number of severe storms cannot be reliably forecasted for upcoming winters, the value of this index is not clear. However, adding a storm severity index to these measures can be beneficial if this index were linked to standards for time to bare pavement or similar outcome measures. Thus, the cost of achieving the standard could be measured and factored into refining the standards.

An example of measuring inputs, outputs, and efficiency at some level Minnesota's bare lane regain time indicator. In Mn/DOT's case, bare lane regain time is determined to be a relatively direct measure of snow and ice control effectiveness because management decided that bare lane regain time was a reasonable direct measure of performance. (Other measures, such as crash frequency and traffic flow, would be useful as secondary methods of assessing performance.) Mn/DOT measures bare-lane regain time in hours. These target clearance times for snow and ice removal provide a relative LOS goal for each road class. The results of the bare lane indicator are shown on the Minnesota state map for each highway link during a winter storm in Figure 16. The color on the links indicates whether the objective for that specific segment was achieved (remember that in Minnesota, goals are dependent on roadway classification).

Mn/DOT Snow and Ice Operations Cost Analysis

December 14, 2005 Storm
Snow and Ice Operations Performance

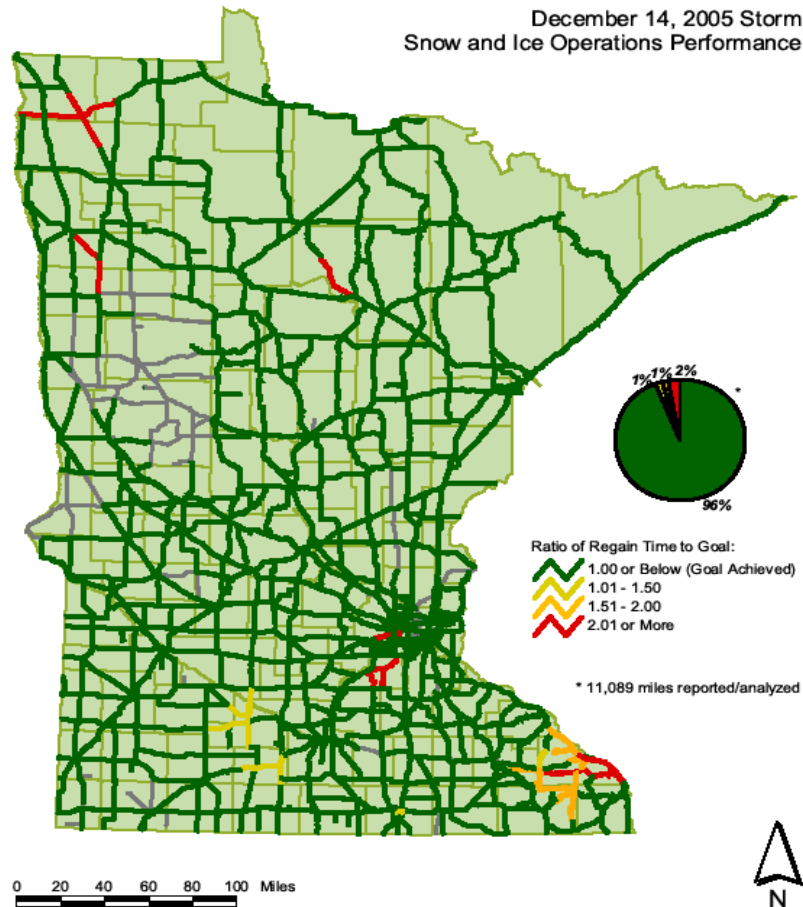


Figure 16. Map of Minnesota districts and regain time

In general, implementing performance measures for snow and ice control requires commitment from management, labor, and financing. Our discussions with several states revealed that, while there was a commitment to the idea of implementing performance measures but there was no real financial data available identifying the benefits and costs of performance measurement. Snow and ice control departments, however, understand the need for performance measures that can improve the effectiveness of their operations and better serve the public. A cohesive performance measurement program, understood by departmental personnel, that supports strategic snow and ice control objectives enables the agency to organize measures, keep track of results, and take action to improve results.

7.2. Measures of Highway Safety

The measures of highway safety most often cited are friction measurement and some form of snow- and ice-related crash reporting. Developing friction measurement as practical as possible and incorporating those data into its performance measurement program.

Another measure that is to be considered is the use of friction measurements to determine LOS. The objective of using coefficient of friction ratings is to objectively quantify the boundaries for good-fair-poor ratings and to determine the length of time it would take to recover those ratings to acceptable values. While equipment does exist to measure the coefficient of friction of a segment of road, the challenge would be to come up with ratings on a continual basis and to come up with the rating boundaries. Data issues with coefficient of friction ratings are as follows:

- Cost
- Frequency of data collection
- Benchmarks
- Liability implications

To use snow and ice crashes, per VMT as a performance measure the agency must have a crash reporting system that captures the crash time and location accurately and the reports the crash information quickly. Second, underreporting in a storm is a problem, because law enforcement officers are overwhelmed by the number of run-off-road crashes. Present reporting is at best partial. Finally, crash rate is the most representative measure, but it must be linked to traffic volume during the storm, not to normal traffic volume. Capturing volume information requires a dense network of recording stations. States are experimenting with the use of ATRs, weigh-in-motion equipment, and traffic cameras to obtain traffic volume information.

7.3. Measures of Highway Mobility

The measures of mobility include travel time, travel speed, travel time reliability, traffic volume, and lane occupancy. Travel speed and volume are basic inputs to ITS-based traffic management systems, and using the information for winter maintenance-related performance measures is a valuable byproduct. ITS systems are capable of reporting estimated travel times to known points. If this information is estimated during storms and archived, it can be used to measure travel time reliability. Speed can be measured in a similar way.

Another method of collecting this information is from ATRs already deployed in most states. Agencies can collect and archive traffic volume, vehicle type, and vehicle speed from various locations. Using this type of information, the agency can determine a relationship between travel time and travel time reliability to weather factors in a snow event such as temperature, snow amount, and average amount of snow.

Still, there are many unanswered questions about speed reduction in a snow event such as the impact of traffic volume, type of snow, time of day, driver behavior characteristics. A recent study by Maze et al. found that during snow days (days when more than one inch of snow fell), crashes increased and were highly correlated with visibility and wind speed. During low visibility conditions (visibility of one quarter mile or less) and high wind speeds (winds as high as 40 miles per hour), crash rate increased to 25 times the normal crash rate. While there are fewer vehicles on the road during the winter storms, those that remained are much more likely to be in crash and, as a result, the crash rate skyrockets (Maze et al. 2005). To advance this

procedure for implementation in the field, additional extensive research will be required with a larger sample size. Also, calibration of the regression model will allow this performance measure to demonstrate more meaningful results to both government agencies and the public.

7.4. Measures of Public Satisfaction

Another method to gauge an agency's performance is to measure public satisfaction. Measuring public satisfaction with agency performance will help identify a program's strengths and weaknesses. Such research lays the groundwork for improvement.

The collected data must be used to improve the agency's performance. To be effective, the data gathered must be used for improvement, not to criticize poor results. Public surveys in several states and countries are pushing agencies to pursue new and different ways to measure the quality of winter maintenance services being provided and to identify measurements that correlate with the customer's experiences, their perceptions and their expectations in terms of time to clear roads. Meeting public expectations directly relates to road condition and to tie maintenance LOS to investment choices in dealing with the department's funding sources.

The scale of implementation can be wide or narrow, depending on the agency. If a state agency conducts the public satisfaction research, the scale will be statewide and will focus on the interstate and state highway system. If a city performs the research, the scale will be more localized and focused on snow routes and residential streets. The data can be assembled by garage area or district- or area-wide. By defining response areas geographically, the data may show where the public ranks one area ranks above another area. The data can then be analyzed as to the cause of the satisfaction and well performing practices can be passed along to other garages or districts.

The cost of conducting surveys is a moderate cost, but it can provide great benefits. One of the benefits of conducting public satisfaction surveys is an increased knowledge of the public's expectations, the agency's performance expectations, ways to measure these performance expectations, and ways to pay for achieving them. By addressing these issues, it is expected that agencies can better meet public expectations.

7.5. Measures of Environmental Impacts

Highway maintenance agencies strive to provide safe travel during hazardous winter driving conditions while keeping traffic delays to a minimum. However, these agencies must also consider the environmental impacts of snow and ice control operations and the traveling public's expectation that high levels of service are to be maintained.

Although there are differing opinions among experts as to the magnitude of damage caused by the application of salt and other chemicals to roads, it is generally believed that these chemicals do cause some damage to vegetation, accelerate the corrosion of bridge decks and vehicle underbodies, and pose a danger to waterways (Transportation Association of Canada 2003). Another environmental concern is the use of sand and other abrasives, specifically their effects

on air quality following storm conditions; dust from airborne particulate matter is generated by vehicles driving over the applied abrasives.

Regarding environmental issues, snow and ice control agencies are continually challenged to provide a high LOS and improve safety and mobility in a cost-effective manner while minimizing corrosion and other adverse effects to the environment. To this end, it is desirable to use the most recent advancements in the application of anti-icing and de-icing materials, winter maintenance equipment and vehicle-based sensor technologies, and road weather information, as well as other decision support systems. Such best practices are expected to improve the effectiveness and efficiency of winter highway operations, to optimize material usage, and to reduce associated annual spending and corrosion and environmental impacts (Caltrans Snow and Ice Control Operations 2005). For instance, the Pacific Northwest Snowfighters Association, consisting of the transportation agencies in the states of Washington, Oregon, Montana, Idaho, Colorado, and British Columbia, has strived to “serve the traveling public by evaluating and establishing specifications for products used in winter maintenance that emphasize safety, environmental preservation, infrastructure protection, cost-effectiveness and performance” (<http://www.wsdot.wa.gov/partners/pns/>).

Caltrans implemented a reduced salt-use policy starting in October 1989, which required transportation districts to develop specific route-by-route plans (Caltrans 2005). That policy mandated that “Snow removal and ice control should be performed as necessary in order to facilitate the movement and safety of public traffic and should be done in accordance with the best management practices outlined herein with particular emphasis given to environmentally sensitive areas.” During the first winter, Caltrans reduced salt usage by 62% statewide compared to the previous winter, helped by improved control of the application frequency of de-icing salt.

Storm tracking with the aid of pavement sensors and miniature weather stations, placed strategically around the state, give vital information to the counties to maximize their resources of time and materials. Advances in equipment monitors enable the snowplow truck drivers to be more effective in treating the roads. Optimizing truck routing can save time and money for districts through reduction in the “dead-head time” where a truck must return empty to a yard to refill.

Other Environmental Issues in Snow and Ice Removal Operations

In addition to these strategies thorough training for managers and operators regarding environmental issues, is also recommended especially in material application. For this reason, effective training programs must demonstrate the value of new procedures and ensure that personnel are competent in delivering the new program. This can be a significant shift for long-time winter snow and ice control operators. For instance, the MnDOT developed a performance-based program for reducing application rates, called “Salt Solutions,” that provided operators with tools and systems for making better application rate decisions. Application rates dropped when the entire organization actively supported the operators in making better decisions and the agency took the time to measure and reward improved performance (Broadbent 1999).

In general, snow and ice operations are growing in complexity and importance, and the need to adopt best management practices for environmental issues will only increase. Moreover, more stringent enforcement of current regulations will probably affect future maintenance programs significantly. Much of the public attention has centered on mobility and LOS, since commerce doesn't stop during snow storms. However, environmental impacts can be incorporated into the performance measures. Data can be obtained using available RWIS to collect environmental data and salt impact near environmentally sensitive areas. Lessening environmental impacts will also require additional training in the application of chemical and other operational practices.

7.6. Conclusions

Although the concepts of performance measurement and performance management have existed for many years, there is increasing demand that agencies begin to transform their organizations to institutionalize these practices. This pressure is the result of the convergence of two forces (ICF 2006):

1. Increased demand for accountability on the part of governing bodies, the media, and the public in general
2. Mounting commitment of managers and government agencies to focus on results and work more deliberately to strengthen performance

To meet these pressures, an effective performance measurement and management system links individual and teamwork behaviors to the organization's business strategies, goals, and values. For an organization to achieve its goals, it is essential for each employee to understand individual roles and responsibility for goal achievement, and there must be continuous dialogue between leaders and employees to set performance expectations, monitor progress, and evaluate results. Together, leadership and staff must work to plan, measure and analyze, and manage performance. These three essential action steps are interlinked and ongoing in an organizational culture that successfully measures and account for performance.

During the performance-planning phase, the first phase of performance measurement, the organizational business strategy is defined, including its mission, vision, and objectives, and specific outcomes required to achieve the overall strategy. Goals and plans for how to measure achievement must be identified in this step, outputs and measures must be defined and requisite data collection and analysis processes and procedures must be developed and implemented. Additionally, and most importantly, employees must come to understand their individual roles and responsibilities with respect to performance measurements and should be given the fundamental information, resources, competencies, and motivation to ensure their successful execution.

In the second phase of the performance measurement process, the measurement and analysis phase, data that inform areas of success and challenge for the organization are collected and analyzed. Specific elements and factors that contribute to successes or challenges, along with new and/or modified information needs and lessons learned, are identified. Once performance data have been collected and analyzed, they must be effectively managed.

The third phase of the process, performance management, is the phase in which solutions to address identified challenges are developed and implemented, along with mechanisms to ensure the continuation of program or organizational successes. Additionally, performance measurement systems and processes may be modified as needed to ensure that information collected through the performance measurement process is timely, relevant, and sufficient. These steps then cycle back to performance planning (ICF 2006).

Unfortunately, many snow and ice control agencies have not moved beyond collecting performance data to utilizing these data to proactively manage the agency. A successful snow and ice performance program relies on the ability to obtain meaningful data, use these data to manage the program, and institutionalize these practices so that they become routine. It is important to promote understanding and support the organizational mission, and demonstrate commitment to managing for results. Staff must buy into the program and feel empowerment and continuity. Finally, the results of performance management must be communicated among relevant stakeholders is crucial to the success of any performance measurement or management system.

While performance measurement is beginning to become more common, very few snow and ice control agencies are actively involved in using that data to proactively manage. In other words, performance measurement has not yet become performance management. Careful planning, consistent implementation, and thorough communication will help shift the snow and ice control agency beyond performance data collection to effective performance management.

Suggested Research

In this research, we have attempted to produce a method for snow and ice control agencies that can easily be used to evaluate appropriate performance measures for snow and ice control operations. While this research laid out the foundations for such an evaluation, more work needs to be done in this area, particularly in a real-world application.

At a minimum, more data are needed; specifically, the weather and cost impacts estimated for a wide range of treatment options should be compared against those experienced in a real-world execution of the same treatment plans. In this way, the evaluation can be brought into closer alignment with the reality it seeks to represent.

More work is needed to develop protocols to tie safety with performance metrics. For example, research needs to be conducted that will explore the relationship between snow and ice control operations and accident rates, and to find a statistically valid relation between the two. Such a metric could conceivably be used in future work to construct snow and ice control operations and schedules which directly seek to minimize predicted accident rates in the road network without the intermediary step of predicting snow depth or road coverage percentage.

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ABBREVIATIONS

ADT	Average daily traffic
ATR	Automated traffic recorder
AVL	Automated vehicle locator
Caltrans	California Department of Transportation
CDOT	Colorado Department of Transportation
DOT	Department of Transportation
FnRA	Finnish National Road Administration
GPS	Global positioning system
INDOT	Indiana Department of Transportation
ITS	Intelligent transportation systems
KDOT	Kansas Department of Transportation
LOS	Level(s) of service
MAP	Maintenance accountability process
Mn/DOT	Minnesota Department of Transportation
PSIC	Pavement snow and ice condition
RGT	Road grip tester
RWIS	Road weather information services
SNRA	Swedish National Road Administration
VDOT	Virginia Department of Transportation
VMT	Vehicle miles traveled
WSDOT	Washington State Department of Transportation

APPENDIX A. WINTER MAINTENANCE OPERATIONS PERSONNEL SURVEY INSTRUMENT

Survey for Winter Maintenance Operations Personnel

Introduction:

Measuring agency performance is recognized as an important part of a public agency's mission. Why measure an agency's performance? There are four primary reasons to do so.

1. To continuously improve services
2. To strengthen accountability
3. To communicate results of programs and services
4. To provide better information for effective decision making including resource allocation

Iowa State University's Center for Transportation Research and Education (CTRE) is conducting a survey for the National Cooperative Highway Research Program (NCHRP) to determine what types of performance measures are being implemented and how they are working in the area of winter maintenance operations and snow and ice control.

Please complete this brief survey about your agency's experiences with implementing performance measures in snow and ice control operations. It will take approximately 15 minutes to complete.

Name of Respondent:

Agency:

Telephone:

Email:

1. For snow and ice control operations, does your agency use: (Please check all that apply)

- ☐ Internal staff
- ☐ Private contractors
- ☐ Contractors with other governmental agencies

2. If contractors, or other governmental agencies, are utilized, do you evaluate contractor, or agency, performance?

- ☐ Yes
- ☐ No
- ☐ Not applicable

3. Is contractor, or governmental agency, performance linked to payment?

- ☐ Yes
- ☐ No
- ☐ Not applicable

4. Does your agency measure the performance of snow and ice control operations?

- ☐ Yes
- ☐ No
- ☐ Not applicable

4a) If yes, what performance measures do you use? (Please check all that apply):

- ☐ Time to bare pavement
- ☐ Time to wet pavement
- ☐ Time to return to a reasonably, near-normal winter condition
- ☐ Time to provide one wheel track
- ☐ Friction or "slipperiness"
- ☐ Level of service, e.g. traffic flow
- ☐ Travel speed during storm
- ☐ Customer satisfaction
- ☐ Crashes per vehicle miles (or km) traveled
- ☐ Traffic volume during storm
- ☐ Time for traffic volume to return to "normal" after storm
- ☐ Fuel usage
- ☐ Lane miles (km) plowed
- ☐ Personnel hours
- ☐ Overtime hours
- ☐ Tons of materials used
- ☐ Amount of equipment deployed
- ☐ Miles (km) traveled with plow down
- ☐ Cost of winter operations per lane-mile (km)
- ☐ Percent of salt spreaders/controllers calibrated

☐ Other (please describe):

5. How does your agency decide what items to measure in snow and ice control operations?
6. What performance measures are most critical to your snow and ice control operations?
7. How frequently do you set targets or objectives for measuring snow and ice control?

- ☐ Quarterly
☐ Annually
☐ Every 2 years
☐ Other (please describe):

8. Specifically, what are your agency's three most important current objectives for snow and ice control operations?
 - a.
 - b.
 - c.
9. What measures do you track regularly on each of these objectives, and what is your performance level on each? (For example, the measure is time to bare pavement, and the performance level is 8 hours.)

Measure
A.
B.
C.

Performance Level

10. How do you obtain the data for the performance measurement system? (Please check all that apply)

- ☐ Accounting records
☐ Visual inspection by maintenance personnel
☐ Visual inspection by law enforcement
☐ Reports from field personnel
☐ Calls from the public, e.g., via 511
☐ Closed circuit television (CCTV) from freeway management systems
☐ Automated Traffic Recorders (ATR) for travel speed and lane occupancy
☐ Periodic Customer Surveys
☐ Other (please describe):

11. Do the performance measures used by your agency vary with road classification and storm characteristics?

- ☐ Yes
☐ No

11a) If yes, how do they vary? (If yes, please attach examples with returned survey.)

12. Do the performance objectives/targets used by the agency vary with road classification and storm characteristics?

☐ Yes
☐ No

12a) If yes, how do they vary? (If yes, please attach examples with returned survey.)

13. Do you measure agency performance for managing non-storm events (e.g., blowing snow, black ice, frost)?

☐ Yes
☐ No

13a) If yes, please describe (If yes, please attach examples with returned survey.)

14. Do you use a storm severity index or similar method for categorizing storm characteristics?

☐ Yes
☐ No

14a) If yes, please describe:

15. Does the agency report the road condition to the public based on the performance measurement system?

☐ Yes
☐ No

15a) If yes, how do you report the road condition to the public? (Please check all that apply):

☐ Dynamic message signs
☐ Commercial radio and television
☐ 511
☐ Internet website
☐ Other, please describe:

16. Please describe the methods used by your agency to budget, track, and summarize the costs of snow and ice control and road maintenance?

17. In measuring performance for snow and ice control operations, do you segment the highway areas for measurement? For example, snowplow routes, mileposts by roadway type, garage or service areas, or other.

☒ Yes
☐ No

17a) If yes, please describe.

18. What benefit does your agency obtain from performance measurement? (Please check all that apply.)

- ☐ Improved business practices with contractors, e.g., scheduled payments, delivery of materials, etc.
- ☐ Improved communications with staff
- ☐ Improved decision processes relating to snow and ice control, e.g., decisions as to when to plow, how to plow, how much material to use, etc. are more straightforward.
- ☐ Improved external communications, such as, with the public, vendors, contractors, etc
- ☐ Other, please describe:

19. Describe technologies that you have tried for measuring performance and your level of satisfaction with those technologies. (For example, friction measuring device, global positioning systems, salinity measurement, video logging, automated traffic recorders (ATR), others.)

20. Regardless of technology what information do you need that you are not now receiving for measuring and managing snow and ice control operations?

21. Do you survey the public about the agency's performance in regards to snow and ice control?

- ☐ Yes
- ☐ No

21a) If yes, what do the surveys say about your agency's performance in regards to snow and ice control?

22. In your opinion, what three factors most account for your agency's ability to improve performance over the past few years?

- a.
- b.
- c.

23. What have been the most significant barriers your agency has encountered in improving performance?

24. Excluding your own, which agencies around the world stand out as leaders in performance measurement and/or management, in your opinion?

THANK YOU FOR YOUR TIME AND PARTICIPATION.

You may return the survey, by October 15, 2005 via email to:
andrle@iastate.edu or you may return the survey via U.S. mail to:

Center for Transportation Research and Education
Iowa State University
2901 S. Loop Dr., Suite 3100

Ames, IA 50010-8634 U.S.A
Tel: 515-294-8103

or FAX your completed survey to: 515-294-0467

If you have any questions regarding this survey, please contact Steve Andrlé at CTRE at 515-294-8103 or email to: andrlé@iastate.edu

APPENDIX B. RESPONSES TO SURVEY

This appendix summarizes the responses received for the survey presented in Appendix A. Responses are organized by question.

1. For snow and ice control operations, does your agency use: (Please check all that apply)

- ☐ Internal staff
1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26
- ☐ Private contractors 2,5,7,8,16,17,18,19,26
- ☐ Contractors with other governmental agencies 5,9,13,17,24,25

2. If contractors, or other governmental agencies, are utilized, do you evaluate contractor, or agency, performance?

- ☐ Yes 2,7,9,13,16,17,18,20,24,25,26
- ☐ No 5,8,19,
- ☐ Not applicable 1, 3,4,6,10,11,12,14,15,21,22,23

3. Is contractor, or governmental agency, performance linked to payment?

- ☐ Yes 2,7,9,13,16,17
- ☐ No 5,8,18,19,20,24,25,26
- ☐ Not applicable 1,3,4,6,10,11,12,14,15,21,22,23

4. Does your agency measure the performance of snow and ice control operations?

- ☐ Yes 1,2,3,4,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,26
- ☐ No 25
- ☐ Not applicable 5

4a) If yes, what performance measures do you use? (Please check all that apply):

- ☐ Time to bare pavement 1,9,13,17,18,21
- ☐ Time to wet pavement 1,3,20
- ☐ Time to return to a reasonably, near-normal winter condition 4,9,11,12,16,17,19,22,24,26
- ☐ Time to provide one wheel track 24
- ☐ Friction or “slipperiness“ 1,4,16,22
- ☐ Level of service, e.g. traffic flow 1,2,4,9,12,15,19,24
- ☐ Travel speed during storm 1,4
- ☐ Customer satisfaction 1,2,4,7,9,10,11,12,13,14,16,17,20,22,26
- ☐ Crashes per vehicle miles (or km) traveled 4,
- ☐ Traffic volume during storm 1
- ☐ Time for traffic volume to return to “normal“ after storm 1,2,22
- ☐ Fuel usage 11,14,19,20,22
- ☐ Lane miles (km) plowed 1,2,4,10,11,13,14,16,17,19,20,24,26

- ☐ Personnel hours 1,2,4,8,9,11,13,14,15,16,17,19,20,22,24,26
- ☐ Overtime hours 1,2,4,8,9,11,13,14,15,16,17,19,20,22,24,26
- ☐ Tons of materials used 1,2,4,8,9,10,11,12,13,15,16,17,18,19,20,22,24,26
- ☐ Amount of equipment deployed 1,2,4,8,9,11,12,13,15,16,17,19,22
- ☐ Miles (km) traveled with plow down 9,14,17,26
- ☐ Cost of winter operations per lane-mile (km) 2,4,8,9,10,11,14,17,18,19,20,24,26
- ☐ Percent of salt spreaders/controllers calibrated 1,9,11,13,17,19,26
- ☐ Other (please describe): 3,4,8,18,24

3-On lower volume roads (<1000 AADT) time from the end of the storm to plow roads open to two way traffic and treat all hills, curves, intersections and other critical areas

4-Formal process for annual Quality Assurance Reports (QAR) on a statewide basis

6-Level of service, pavement conditions for the category of route

5-The State of SD does not formally track performance measures for winter maintenance. Several of the above are informally looked at. Time to return to reasonably, near-normal winter condition; traffic flow; and customer satisfaction.

8-Time since route reported treated

18-Contract trucks reporting for winter storms in a timely manner as described in SHA' Hired Equipment for Snow Removal Services Contract.

24-Material, labor, and equipment hours and costs are tracked

5. How does your agency decide what items to measure in snow and ice control operations?

1. Resources, safety

2 Based on customer indicators and fiscal barriers

3- N/A

4- Existing guidelines and evolving technology (we are testing friction as a method of measurement)

5-n/a

6-it was determined to use data that was already being captured (road condition information)

7-Internal decision

8-We measure traditional inputs and outputs from typical maintenance management systems. We've considered others but budget restraints have kept up from moving to those areas.(AVL/GPS, return to baseline travel speeds, etc.)

9- Determined with input from statewide snow and ice committee and locally at the regional level through written operational plans.

10-Budget-planned vs. actual cost for Snow and Ice. The standard cost per mile v. actual cost per mile.

11-Customer satisfaction, snow policy, time of response, intensity, length, and geographic location of storm, level of service and classification of roads.

12-Snow policy manual

13-Most are recorded automatically and reviewed. Many of the above are being looked at for future applications.

14-Planning tools needed

15-Past practice

16-Normally, we use the above criteria for all storms.

17-Based on historical stats and customer expectation for a winter city. Maintenance

Management system outcomes and also derived from media questions as well. If you measure it you use it to develop K.P.I.s!

18-Performance measures on bare pavement, material usage and cost of operations are detailed in SHA's business plan which is developed by senior SHA managers. Performance measures for hired equipment is determined by Statewide Maintenance Quality Council which is composed of district and statewide maintenance managers.

19-Budget/political driven, environmental compliance, new technology

20-Selected as part of overall department performance measures. Also selected to help keep operators informed on their effectiveness and usage.

21-As stated in policy and procedure manual

22-Historical & Industry-wide standards

23-measure materials, personnel and amount of equipment used

24-Several item collected from our Winter Supervisor daily reports and weather information (RWIS/AWOS) are used to measure certain levels of winter operational performance. We continue to explore a number of other information sources (Speed, friction, crashes, weather indices, etc.) to determine if they are good indicators of performance. In the last two years speed data from the existing ATRs have been evaluated for measuring performance. The Department has also used customer survey information in the past as well as a survey of Highway Patrol Troopers.

25-Final decision by Dept. Commissioner

26-Capability to measure and if the information is useful or not.

6. What performance measures are most critical to your snow and ice control operations?
 1. safety
 2. Customer satisfaction and cost to provide service
 3. n/a
 4. Customer feedback, pavement conditions, traffic flow, resource deployment
 5. n/a
 6. road condition
 7. travel speed during event and time to complete clean up after event
 8. Time since route was reported treated (are all routes serviced and how long since last treatment.
 9. Level of service, customer satisfaction, time to normal conditions, and after storm clean up.
 10. Lane miles cleared and actual v. planned (standard) unit cost.
 11. Customer satisfaction and safety
 12. time to return to normal winter driving conditions
 13. Pavement conditions during and following each event and materials used.
 14. Dollar related items and customer satisfaction
 15. Condition of the streets and how traffic is moving
 16. Time to remove snow and amount of slick areas remaining.
 17. Bare pavement and/or customer satisfaction.
 18. Time to reach bare pavement
 19. Time to return to a reasonable near-normal winter condition
 20. Salt per lane-mile and miles plowed.
 21. Time to bare pavement
 22. Public Safety
 23. Public Safety and customer satisfaction

24. Any measure that shows a direct impact to travelers such as speed, traffic volume, crashes, etc. Our goal is to minimize travel disruptions during winter storms. If we can maintain 70 mph speeds, traffic volume is not reduced and cars are not in the ditch or having crashes, we would call that successful performance. We also need to strike a balance between our budget, level of customer service and the environment.
25. Time to return to reasonable winter pavement condition.
26. Amount of time to plow all streets
7. How frequently do you set targets or objectives for measuring snow and ice control?
- ☐ Quarterly 24
- ☐ Annually 1,2,4,7,8,9,10,12,13,14,16,17,18,19,20,21,22,23,24,25,26
- ☐ Every 2 years
- ☐ Other (please describe): 11,15
- 3-As deemed necessary
- 4-Ongoing-at various levels
- 5-n/a
- 6-
- 11-semi-annually
- 15-Objective is monitored regularly
8. Specifically, what are your agency's three most important current objectives for snow and ice control operations?
- a.
- 1- safety
- 2- to maintain passable roadways for emergency vehicles
- 3- Have all major highways restored to wet or dry condition
- 4- To provide bare pavement as soon as possible and practical
- 5-n/a
- 6- provide safe travelway
- 7-reduce highway fatalities
- 8-pre-treat city routes to prevent bonding
- 9-Providing reasonably safe and clear highways during and after the storm for the traveling public.
- 10-Provide for public and employee safety
- 11-Response time
- 12-Safe driving conditions
- 13-Anti-icing
- 14-Maintain all roads in passable condition
- 15-Keep traffic moving
- 16-Plow all County Highways
- 17-Bare Pavement Policy
- 18-Provide safety mobility for motorists which allows our customers to carry on their day to day activities and our business community to remain operational during and after winter storms.
- 19-Level of service: time to normal winter driving
- 20-Safety
- 21-Obtain bare pavement in minimum amount of time

22-Safe Roads
23-public safety
24-Safety
25-Keep Roads Clear
26-Time to plow all streets

- b. 1- traffic backup
2- To return traffic flow to normal as quickly as possible
3- Have all minor highways greater than 1000 AADT restored to a wet or dry condition
4-Continue to be effective and efficient
5-n/a
6-efficient use of resources
7-customer satisfaction
8-provide continuous service from pre-storm through post storm to minimize the negative on travel time, safety, etc
9- Maintaining an adequate level of service throughout and soon thereafter a storm.
10-Clear priority routes
11-Customer satisfaction
12-Cost effective snow and ice control
13-24 hour coverage
14-Prioritize efforts by road class
15-Use cost effective procedures
16-Plow all residential streets
17-Ready for Rush Hour (M–F)
18-Protect the environment
19-Cost and budget stability
20-Effective
21-n/a
22-Time utilization
23-driving conditions
24-Return roads to near-normal driving conditions as soon as possible
25-Traffic flow
26-Keep all streets safe for vehicular traffic
- c. 1- Time
2- To operate as efficiently as possible
3- Have all minor highways with less than or equal to 1000 AADT open to two way traffic and treated with salt and/or abrasives on all hills, curves, intersections, and other critical areas
4-Maintain excellence while considering environment and economic factors
5-n/a
6-n/a
7-keep traffic moving safely
8-provide clear pavement on city routes as quickly as possible
9-Clear roadways within 2 hours after the storm. Under “modified“ level of service, this can be up to 3 hours.
10-Cost effective snow removal
11-Safety of the traveling public

- 12-Customer satisfaction
- 13-Reduce salt usage
- 14-Shift resources for best effect
- 15-Do not harm environment
- 16-Spread all roads with ice control materials
- 17-Sidewalk clearing to meet Bylaws (48Hrs)
- 18-Provide services at the least cost to taxpayers
- 19-Salt tracking, better usage practices, new materials (pre-wetting)
- 20-Efficiency
- 21-n/a
- 22-Cost effectiveness of supplies and equipment
- 23- school zones
- 24-Use only right amount and type of de-icing materials at the right time in the right locations to get the job done
- 25-Accident free
- 26-Meet customers expectations

9. What measures do you track regularly on each of these objectives, and what is your performance level on each? (For example, the measure is time to bare pavement, and the performance level is 8 hours.)

Measure	Performance Level
A. 1. N/A	
2. Passability for emergency vehicles	2 continuous
3 Time to wet or dry condition	3 As soon as possible after end of storm
4-Performance levels not used	
5-n/a	
6-safe travelway for category I routes	6-bare/wet wheel paths
7-Time to clean up in urban areas after storm event	stops 7-18 hours
8. Pre-treatment	8-Starting 3 hours before beginning of storm
9-Monitor police and public observational/calls	9-minimal complaints/calls
10-Number of lane-miles cleared	10-n/a
11-Response time	11-1 hour
12-Safe driving conditions	12-Equipment dispatched to achieve goal
13-n/a	
14-Maintain all roads in passable conditions	14-n/a
15-Labor hours	15-n/a
16-plow county highways 2 passes	16-12 hours after snow stops
17-Areterials	17-48 Hours
18-Bare Pavement	18-Reaching wet or dry pavement within 8 hrs of the ending of frozen precipitation
19-Salt	19-Annual Usage
20-Safety	20-none set
21-Time to bare pavement	21-Minimum time
22-Related Safety forces	22-Feel roads are safe
23- Percentage reports on roadway conditions	23-2 – 3 hours to bare pavement

24-On high volume roadways, return roads to reasonable, near-normal conditions within 24 hours	24- 95%
25-Nothing specific	
26-Time to plow all streets	26-12 hours
B.	
2 Time to normal traffic flow	2- 24 hours
3 Time to wet or dry condition	3- As soon as possible after end of storm
4-n/a	
5-n/a	
6-safe travelway for category II routes	6-both lanes on two-lane roads with intermittent bare/wet wheel paths
8-Continuous service	8-person hours and material use
9-Mgt/staff perform patrols during storms to monitor conditions	9- prevent hardpack
10-Number of citizen action requests	10-n/a
11-complaint	11-number of calls
12-Cost effective snow and ice control	12-Entire city plowed 14-16 hours following conclusion of snow event
13-n/a	
14-Prioritize efforts by road class	14-n/a
15-Sand & Control products applied	15-n/a
16-Plow residential streets 1 pass	16-8 hours after snow stops
17-Collectors (Bus Routes)	17-48 Hours
18-Protect the environment by using least amount of materials for each storm	18-Unknown-storms never same
19-Costs	19-Budget Levels
20-Effective	20-8 hours to wet pavement
21-n/a	21-n/a
22-n/a	22-n/a
23- City plow and salted one cycle	23- Every 4 hours
24-On low volume roads, provide bare wheeltrack within 24 hours	24-85%
25-Nothing specific	
26-Visual observations surveys	26- A thru F
C.	
2- Operational efficiency	2- Regional standards
3- Time to open to two way traffic	3- As soon as possible after end of storm
4-n/a	
5n/a	
6- safe travelway for category III routes	6-one wheel path on two lane roads with intermittent bare/wet wheel paths
8-clear pavement	8-no specific criteria on time Depends on each storm
9-Clear Roadways	9-2 hrs
10-Unit costs	10-n/a

11-materials	11-amounts
12-Customer satisfaction	12-positive phone calls compare to negative
13-n/a	
14-Shift resources for best effect	14-n/a
15-How traffic is moving	15-n/a
16- Plow residential streets 2 nd pass and spread ice control materials	16-24 hours after snow stops
17-Sidewalk	17-48 Hours after last snowfall
18-Provide services at the least cost to taxpayers by using least amount of materials, equipment, and labor for each individual storm	18-Moving target, storm never same
19-Levels of Service	19-Hours
20-Efficiency	20-200 pounds per lane-mile per storm average for season
21-n/a	21-n/a
22-n/a	22-n/a
23-Visual inspection of plowing operations	23-n/a
24-On low volume roads, return roads to reasonable near-normal conditions within 3 days	24- 95%
25-Nothing specific	
26-Customer surveys	26- 80%+ Happy with service levels

10. How do you obtain the data for the performance measurement system? (Please check all that apply)

- ☐ Accounting records 2,4,9,10,11,12,13,14,15,18,19,20,24,26
- ☐ Visual inspection by maintenance personnel 1,4,7,9,10,11,13,14,15,16,17,18,19,20,21,22,25,26
- ☐ Visual inspection by law enforcement 1, 2,4,14,17,19,22,25,26
- ☐ Reports from field personnel 1,2,3,4,6,9,10,11,12,13,14,15,16,17,18,19,20,21,22,24,25,26
- ☐ Calls from the public, e.g., via 511– 4, 10,11,12,13,15,16,17,19,26
- ☐ Closed circuit television (CCTV) from freeway management systems 1, 2,9,15,26
- ☐ Automated Traffic Recorders (ATR) for travel speed and lane occupancy 9,17
- ☐ Periodic Customer Surveys 2, 11,14,20,26
- ☐ Other (please describe): 18,23,26
 - 4-testing friction measurements
 - 5-n/a
 - 6-the computer system where our field personnel record road conditions is used for the snow and ice performance measures
 - 8-Work Management System (may be same as accounting records.)
 - 18-SHA's Emergency Operations Reporting System (EORS) and Scan Web (RWIS) data
 - 23-GPS
 - 26-AVL information

11. Do the performance measures used by your agency vary with road classification and storm characteristics?

- ☐ Yes 1,3,4,6,7,14,16,17,18

☐ No 2,8,9,10,11,12,13,15,18,19,20,21,22,23,24,25,26
5-n/a

11a) If yes, how do they vary? (If yes, please attach examples with returned survey.)

4-Areas are tracked-not necessarily rated

6-see question #9

7-right now, performance measures are only in place in urban areas

14-Higher classifications get priority and first attention

16-Larger snowfall amounts and/or ice storms require longer times for removal operations. The time of day can also affect snow removal operations, i.e., during rush hour.

17-Time and level of service for sanding, plowing, and snow removal

18-Bare pavement performance measure is applicable only to interstate and primary highways, not secondary roads, however, the other two measures (environmental stewardship and cost-effective operations) are the same on all roads.

12. Do the performance objectives/targets used by the agency vary with road classification and storm characteristics?

☐ Yes 4,7,9,13,15,17,18,19,23,24

☐ No 1,2,3,6,8,10,11,12,14,15,18,20,21,22,25,26
5-n/a

12a) If yes, how do they vary? (If yes, please attach examples with returned survey.)

4-Same as #11

7-higher class roads receive more dedicated efforts

9-Interstates and major arterials are higher priority over secondary highways.

13-Higher AADT roads receive extra help in major storms.

15-We do not sand/plow non arterial street except for emergency routes to hospitals, etc.

17-Time and level of service for sanding, plowing, and snow removal.

18-Bare pavement performance level of 8 hours is applicable only to interstate and primary highways, not secondary roads, however, the other two levels (environmental stewardship and cost-effective operations) are the same on all roads.

19-Time requirements for treatment completed on different levels of roads.

23-Major storms that require snow removal and towing of parked cars

24-High volume roads have higher performance measures than lower volume roads.

Interstates and other higher volume roads are required to return to near-normal within 24 hours while lower volume roads must be returned to near-normal within 3 days.

13. Do you measure agency performance for managing non-storm events (e.g., blowing snow, black ice, frost)?

☐ Yes- 4,17,19,23,24,25

☐ No 1,2,3,6,7,8,9,10,11,12,13,14,15,16,18,20,21,22,26
5-n/a

13a) If yes, please describe (If yes, please attach examples with returned survey.)

4-Perform annual QAR's

17-Blowing snow and freezing rain are considered storm events

19-Miscellaneous winter maintenance: road inspections, snow fencing, sweeping winter sand, etc.

23-We measure all public work functions relating to snow operations.

24- Our definition of precipitation start and end times is the time when precipitation accumulates on the roadway surface. This would allow blowing snow events to be included in precipitation days- In Iowa snowfall may stop but it will be followed by several hours of blowing snow conditions that accumulate on the roadway. Therefore we defined start and end times to include any events that precipitation accumulates on the roadway surface. Bridge frost events are handled separately and are primarily a measure of the performance of our forecast service. We ask our garages to report whether or not frost was forecast. If forecast they are asked, was frost found, was frost found on adjacent bridges (county/city bridges), was frost not observed (used on weekedns when no one is around to look at bridges).

25-Same as storm events

14. Do you use a storm severity index or similar method for categorizing storm characteristics?

☐ Yes – 4,14,15,17,24

☐ No 1,2,3,6,7,8,9,10,11,12,13,16,18,19,20,21,22,23,26

5-n/a

14a) If yes, please describe:

2- We have not in the past, We plan to implement an index

4- Typically “record“ indicators-such as record snow fall amounts

6- We use the Winter Index from SHRP H-350 and data received daily from NWS

15-Our planned response is based on how much show is forecast, what time of day, and day of week.

17-Not storm specific but overall winter is reported to Environment Canada annually.

24- We are just starting to use a weather severity index to evaluate winter performance and are looking at a number of different weather data to measure severity. We have used the SHRP index, one developed by Mike Adams in Wisconsin and are currently looking at including data from our daily reports to provide more detailed weather information than is currently available from other weather resources.

15. Does the agency report the road condition to the public based on the performance measurement system?

☐ Yes 2,4,6,9,10,13,18,19

☐ No 1,6,7,8,11,12,14,15,16,17,20,21,22,24,25,26

3 N/A

5-n/a

15a) If yes, how do you report the road condition to the public? (Please check all that apply):

☐ Dynamic message signs 2,9

- ☐ Commercial radio and television 2,9,13,14,19
- ☐ 511- 6,14,19
- ☐ Internet website 2,4,6,9,10,13,14,18,19
- ☐ Other, please describe:

13-Internet site begins this season showing where equipment has been. Radio stations call us, we do not contact them.

14-Not really a system

16. Please describe the methods used by your agency to budget, track, and summarize the costs of snow and ice control and road maintenance?

1. Annual budget

2 Prior to 2003, costs nor performance were reviewed. We have implemented performance reviews to evaluate supply use, communication (internal/external), coordination between adjacent agencies (i.e. MDOT, Wayne County, and total costs.

3 Budget: Recent five year average cost. Track: Financial Management System. Summarize: End of fiscal year Expenditure Report.

4- Internal cost accounting system

5-SD tries to budget for what is considered a “normal“ winter. Through the budgeting process, estimates are made as to the number of man-hours, equipment hours and materials to be used in the upcoming season. These are tracked through the payroll and inventory systems.

6-We use a Highway Maintenance Management System

7-We identify and track all snow and ice control activities

8-Labor, equipment and materials are recorded in our work management systems (Hansen Infrastructure Management System). In addition, work orders are opened and closed as drivers begin and complete treatment on specific snow routes or if they are just patrolling or standing by. Reports are generated either direction from the IMS or via specialized report writing software. Because of variability of winter operations, budget are set on historical use rather than on influences of a specific year.

9-Data entry into computer program that tracks maintenance activities, personnel hours, materials, etc.

10-We use a Maintenance Management System based on inventory and history to develop plans and track actuals.

11-Accounting department and supervisory daily time and after action meetings

12-Previous year totals, current year totals.

13-Materials are tracked for each event and totaled for an annual cost. On board computers collect data and transfers then information wirelessly to a PC where the data are put into report form. Data and GPS are plotted to a map and can be reviewed by staff. Time for each event and total number of personnel needed are recorded but OT is kept in accounting.

14-Maintenance Management system

15-Our budget is developed with an adequate amount to deal with the small winter event. If the snowfall is frequent or heavy we will run over our budget and ask for emergency funds if needed. We compile costs for the response on a daily basis using info from the daily truck sheets from the crews.

16-Work order/cost accounting

17-SAP

18- SHA's snow and ice control annual winter budget is based on an average of previous winter expenditures. After the budget is determined, costs are tracked by SHA's Maintenance

Operations Support Team using SHA's EORS and the Financial Management Information System (FMIS). The team produces reports for senior SHA management throughout the winter season detailing expenditures for materials, personnel and equipment. Reports on the performance measures are prepared by SHA's Quality Assurance Team and distributed to senior managers as well as frontline maintenance managers. At season's end, the Maintenance Operations Support Team prepares a report on total season expenditures which is used as justification for a budget amendment if the agency overruns the original budget. The Quality Assurance Team prepares a report that details the agency's performance throughout the winter at the shop, district, and statewide levels. The report also details each storm and reviews the performance of the weather service provider.

19-Daily field reporting of equipment usage, employee time, material quantities used km treated into a computer database (CODES), Common Data Entry System.

20-All material and equipment usage is recorded daily on timesheets and entered into accounting system

21-Cost accounting

22-Payroll and supply records

23-Excel sheet for every storm complete costs

24- Each maintenance garage completes a winter daily report on their operations. The report provides a detailed account of the materials, equipment, crews and weather for the day. Cost and hours of operations data is also analyzed to measure operational efficiencies.

25-Set budget by category

26-Data review

17. In measuring performance for snow and ice control operations, do you segment the highway areas for measurement? For example, snowplow routes, mileposts by roadway type, garage or service areas, or other.

☒ Yes 3,6,8,9,11,12,13,15,16,17,18,19,23,24,25,26

☐ No 1,2,4,7,10,14,17,21,22,

5-n/a

17a) If yes, please describe.

3 - By major and minor highways and by maintenance building, superintendent area, district and statewide results.

6- By our District, Areas, Subareas, and highway routes

8- Indianapolis operates out of 3 main garages. Costs for operations are tracked individually and related back to the number of lanes miles of responsibility in each area. We do not segment to a finer detail than that.

9- Plow beats, and highway corridors

11- snow plow routes and segmented service areas

12- 95 snowplow routes

13-By route which averages 28 miles each. We maintain 550 lane-miles.

15-We have developed routes that can be handled by a truck using one load of sand for each route.

16-Major snow routes are numbered and residential areas separated.

17-We inventory and route everything.

18-Performance is measured at the maintenance shop, district, and statewide levels.

Performance at this time is not measured at the snow route level.

19-Level Classifications based on AADT and DHT Classification system.

23-We have 15 snow districts and also fleet mgt services.

24-Performance measured by service level of the roadway segment and the garage area responsibility.

25-District and road

26- Lane miles

18. What benefit does your agency obtain from performance measurement? (Please check all that apply.)

☐ Improved business practices with contractors, e.g., scheduled payments, delivery of materials, etc.

2,11,13,14,17,18,23

☐ Improved communications with staff

2,3,4,8,9,10,11,12,13,17,20,22,26

☐ Improved decision processes relating to snow and ice control, e.g., decisions as to when to plow, how to plow, how much material to use, etc. are more straightforward.

1,2,4,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,24,25,26

☐ Improved external communications, such as, with the public, vendors, contractors, etc

1,2,7,8,9,10,11,12,13,16,17,19,26

☐ Other, please describe: 20

3-The benefit of knowing how well we deliver services and products to our customers.

4-Uniformity of service across jurisdictional boundaries

5-n/a

6-Our current performance measures are very time consuming to generate on a timely basis and are currently not being used very widely.

14-Effectiveness of products applied per situation

20-operators do a better job knowing expectations are more than just "plow the road"

19. Describe technologies that you have tried for measuring performance and your level of satisfaction with those technologies. (For example, friction measuring device, global positioning systems, salinity measurement, video logging, automated traffic recorders (ATR), others.)

1 field personnel

2 N/A

4-Currently testing friction measurements-satisfaction undetermined

5-n/a

6-n/a

7-n/a

8-We're hoping to utilize some of these in the future, most specifically AVL/GPS and ability to track vehicle speed. We haven't used any of these to date.

9-Currently piloting AVL, RWIS (unfortunately RWIS has not been reliable), increased use of pre-treating with liquids.

10-n/a

11-Weather radar but will be setting up ATR

12-n/a

- 13-GPS, automated recorders in the trucks.
 - 14-n/a
 - 15-n/a
 - 16-n/a
 - 17-n/a
 - 18- Currently, SHA uses visual inspection by field personnel as a primary tool for measuring bare pavement performance. Office staff uses RWIS data to supplement and at times validate bare pavement performance. Our performance measure would be more valid if it came from a more objective source other than the folks who are actually performing the work.
 - 19-GPS, material tracking through hydraulic systems in new tandems, (km treated, material type, speed of truck, etc.)
 - 20-AVL in 3 trucks at another County
 - 21-None
 - 22
 - 23-We are in the process of implementing gps on snow contractors for the 2005-2006 season
 - 24- We have tried friction wheels but found them to be too costly. We are currently using speed information from ATR's but hope to also install additional speed sensors at RWIS sites in the future to combine weather and traffic information to use as a measurement. We also have worked with Iowa State University to use artificial intelligence to tie budget with weather severity for use as a measurement of performance. We also are working on crash data to determine if it can be used to measure performance.
 - 25-None
 - 26- AVL/Time and Labor Tracking Software
25. Regardless of technology what information do you need that you are not now receiving for measuring and managing snow and ice control operations?
- 1 N/A
 - 2. Radio reports from cities in the storm's path ahead of us (180 arc) on consistency, duration, temp., wind
 - 3-N/A
 - 4-Improved performance measure indicators/processes, improved communications
 - 5-A better handle on the amounts of chemicals used and the results of those applications. Efficiency needs to be realized in the use of the chemicals-more is not always better.
 - 6-Consistent data source of snow fall amounts. It is sporadic data available from NWS.
 - 7-automated cycle time and amount of materials being expended
 - 8-Specific equipment functions such as spreader rates, plow-up/down and plow speed.
 - 9-Reliable RWIS information
 - 10-GPS tracking
 - 11-ATR
 - 12-GPS
 - 13-We have many areas in which to improve. We need a benchmarking study.
 - 14-We want better RWIS coverage
 - 15-We have tools we need
 - 16-AVL
 - 17-RWIS road temperature measuring and incident detection with live cameras
 - 18- Currently, we do not have a means for capturing an average pavement temperature during winter storms at the shop, district and statewide levels. We can determine the pounds of salt used per lane-mile per inch of snow from RWIS data but pavement temperature

should be factored into the equation. It can be done manually but it would be an extremely time consuming operation. SHA RWIS programmers are currently working on this issue.

19-storm conditions and severity, real time road condition data (pavement temp/precipitation.)

20-Actual time plowing better time to wet pavement data

21-None

22-n/a

23-The throwouts of snow back into the street when residents are shoveling there cars out is a major problem we have a problem managing this due to the volume of parked cars and the congestion of the streets.

24- Speed of traffic and impact (inconvenience, delays, etc.) to roadway users. The airline industry understands the cost of shutting down an airport for a certain period and the impact it has on the system. Based on that information, airports started using sophisticated equipment and deicing materials to minimize down time for runways. Unfortunately there doesn't seem to be similar information available about the impact of snow and ice to the travelling public that could be used to lobby for more funding or resources for use on roadways.

25-Pavement temperature

26-Friction data

26. Do you survey the public about the agency's performance in regards to snow and ice control?

☐ Yes 2,5,6,7,11,12,14,17,18,20,23,24,26

☐ No 1,3,4,8,9,10,13,15,16,19,21,22,25

21a) If yes, what do the surveys say about your agency's performance in regards to snow and ice control?

5-It is good, but it can always be better. The highest priority amongst the public surveyed.

6-The survey was conducted several years ago and the public was very pleased.

7-public is highly satisfied with snow and ice control

11-Good performance

12-78% satisfaction rate

14-People's feedback varies, very little negative

17-50/50

18-Our surveys show that we provide good service.

20-93% approval of job being done

23-Mayors office surveys about all basic service functions

24- Expectations of the public are much higher than we expected. Overall they rated snow and ice removal as a top priority to them and said that we did a good job.

26-We are doing a great job.

27. In your opinion, what three factors most account for your agency's ability to improve performance over the past few years?

a.

1- training

2- Evaluating past performance

- 3- Knowing where our performance is at
- 4-Workforce education
- 5-Better equipment
- 6-increased training, experience and usage of anti-icing
- 7-additional resources
- 8-anti-icing technology
- 9-Input from our statewide snow and ice committee
- 10-Anti-ice material
- 11-Set policy
- 12-Training
- 13-Computerized dispensing systems
- 14-n/a
- 15-Increase in the number of snow plows in our fleet
- 16-Greater amount of ice control materials stored under roof
- 17-n/a
- 18-Increased number of contract trucks
- 19-Technology
- 20-Empowering operators to adjust salt rates
- 21-Wet kits on trucks
- 22-Planning –time for personnel
- 23-good communication between police, fire, transportation, and PWD
- 24-Proactive operations
- 25-One person plowing
- 26-Wing plows

b.

- 1- staffing
- 2- planning for seasonal preparation
- 3- Having well defined performance objectives
- 4- Extensive RWIS
- 5- Better understanding of chemicals, particularly liquids
- 6-increased availability and usage of wing plows
- 7-new technology
- 8-improved material performance
- 9-operator training
- 10-Better weather forecasts
- 11-Proactive supervisory response
- 12- Training
- 13-Liquid applications
- 14-n/a
- 15-n/a
- 16-More qualified operators
- 17-n/a
- 18-Increased use of liquid de-icing materials to supplement salt.
- 19-Materials
- 20-Calibrating spreaders, pavement temperature guns in each truck
- 21-ground speed controlled spreaders
- 22-Joint cooperative to bulk purchase equipment

23-increased our parking fines and towing services

24-Materials Used

25-Better route management

26-Employee involvement

c.

1- dedication

2 N/A

3- Having a way to track performance

4-Innovative technology (anti-icing techniques, improved equipment, better forecasting)

5- Willingness to experiment

6-pride of the employees to their best

7-dedicated staff

8-Union commitment to do whatever it takes

9-Improvements in equipment design

10-n/a

11-Excellent training and retraining

12-Training

13-Increased staff

14-n/a

15-n/a

16-Better management personnel

17-n/a

18-Increased spotlight on performance measures.

19-Staff Education

20-zero velocity spreaders.

21-n/a

22-Joint cooperative to bulk purchase salt

23-Mayor's support on clearing streets of vehicles blocking plows

24-Equipment improvements

25-Salt spreader calibration

26-new equipment technology

28. What have been the most significant barriers your agency has encountered in improving performance?

1- the unknown

2- Cultural transformation-increased customer expectations

3- Communicating the department's guidelines to all employees involved in snow removal

4-Education and overcoming existing paradigms

5- Getting over the hurdles utilizing new chemicals and more efficient rates

6-reduction of staff and resources

7-n/a

8-money

9-Lack of personnel and funding

10-Increase in traffic

11-County growth in numbers of miles of roads to obtained annually

12-Fleet turnover due to budgetary issues

13-Employee buy-in

14-\$\$\$

15-We do not have snowfall on a regular basis so we don't use the equipment enough to continue to improve all the driver skills.

16-Weather forecasting and traffic

17-Inventory growth, customer expectations, and environmental costs.

18- SHA's shops and districts have grown comfortable in their current snow and ice control operations. They have been very successful over the years and have shown limited interest in changing their operations. The highest levels of the organization need to challenge personnel to be more creative in order to get the job done with less materials and hired equipment.

19-Relating storm conditions/severity to costs

20-It's not seen as an area to put research or new tech money

21-Funds shortages for purchasing. New Equipment: wet kits, gsc spreaders

22. Union issues

23-the amount of cars parked all over the city which has no off street parking and the narrowness of the city streets

24-Careless drivers but budgets and staffing are always a factor

25-Union agreement

26-Budget/staffing/facility size

29. Excluding your own, which agencies around the world stand out as leaders in performance measurement and/or management, in your opinion?

1 no opinion

2 Illinois DOT

3-N/A

4- PNS group and other Midwestern states

5- Colorado, Minnesota

6-unknown

7-Minnesota, Iowa, and Finland

8-States of Minnesota, Iowa, and Washington seem to be leaders.

9-Iowa DOT

10-n/a

11-APWA

12- Iowa DOT

13-Iowa DOT, Mn/DOT, Ohio DOT

14-n/a

15-no opinion

16-n/a

17-n/a

18-Iowa DOT and Colorado DOT

19-n/a

20-n/a

21-Iowa DOT

22-Ohio DOT

23- the feds

24-Washington DOT

25-no opinion

26-McHenry County, IL, MnDOT, Iowa DOT

APPENDIX C. AGENCIES USING PUBLIC SATISFACTION SURVEYS

State Agencies	Local Agencies	Other Countries
Alaska DOT & PF	City of Cedar Rapids IA	Swedish Road Administration
Caltrans	City of Des Moines IA	
Colorado DOT	City of Detroit MI	
Illinois DOT	City of Edmonton AB	
Indiana DOT	City of West Des Moines IA	
Iowa DOT		
Kansas DOT		
Minnesota DOT	El Paso County, CO	
New Mexico DOT	Washington County, MN	
South Dakota DOT		
Wisconsin DOT		