Effective Practices for Activating Snow and Ice Personnel and Equipment for Winter Storms

Synthesis Report

CLEAR ROADS

research for winter highway maintenance

CTC & Associates LLC

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As a winter storm approaches, timing the activation and deactivation of winter maintenance operations has a significant impact on safety and budgeting. This synthesis report focuses on state practices in winter maintenance fleet activation for winter storms. A literature review and a survey of 25 Clear Roads states indicates that most agencies summon half or more of their workforce to come in before a storm arrives, if only just before. Meteorologists have become increasingly involved in winter maintenance programming, and a broad range of sophisticated systems, weather data and forecast sources are drawn upon in activation decisions, which are usually made at the district or regional level.

Activation and deactivation procedures are data-heavy activities. Fleet activation practices seem equally informed by current and forecast data. Many states have specific thresholds (fixed numbers) for air temperature, pavement temperature, precipitation levels and other factors that trigger activation.

Decisions about when to deactivate forces (send crews home) tend to be driven by a combination of fixed value thresholds and field observations. Current conditions are given more weight than forecasts, with the significant exception of precipitation forecasts. The increasing role of meteorology in winter maintenance activities suggests they may be becoming more data-driven.</td></tr>
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Executive Summary

Timing the activation and deactivation of snow and ice maintenance operations has a significant impact on safety and budgeting. Activating too early can strain budgeted resources, and activating too late risks diminishing roadway safety for the public and maintenance crews.

This report provides a synthesis of research and practice in winter maintenance fleet activation. Members of the Clear Roads pooled fund project were interested in learning state DOTs' practices regarding how much of a fleet is activated as a forecast winter storm approaches, what operational levels and roles are involved in fleet activation, and what information decision-makers draw upon when they plan maintenance fleet activation and deactivation activities for a coming storm.

A literature review and a survey of 25 state DOTs indicate that most agencies and districts summon half or more of their workforce before a storm arrives, if only just before. Meteorologists have become increasingly involved in winter maintenance programming, and activation and deactivation decisions are informed by a broad range of data culled from weather and forecast sources and transportation information systems. Fleet activation and deactivation decisions are usually made on a district or regional level, though in many agencies these decisions are monitored at the state level.

Decision-makers draw from a data-heavy toolbox in gathering information to consider in activation of winter maintenance fleets, but survey comments stressed the importance of supervisor and manager knowledge of the areas they oversee and the history of winter conditions at those locations.

Among the surveyed agencies, fleet activation practices are equally informed by current and forecast data. Indicator thresholds that may trigger activation decisions are often fixed numbers for air temperature, pavement temperature, precipitation levels and so forth. Relationships between values are weighed, with decision-makers factoring in quantitative data, historical information, and observations of current weather.

Fleet deactivation practices lean more heavily on current conditions and observation than on forecast conditions. Compared to activation thresholds, deactivation thresholds feature fewer fixed numbers and more contingencies between values and field observations. Deactivation decisions favor current over forecast measures, and qualitative data and assessments over quantitative data, with the significant exception of precipitation forecasts.

Maintenance managers and supervisors embrace a large and growing cache of quantitative data from meteorology and various transportation information systems. Whatever the art in balancing qualitative and quantitative data is, storm fleet activation and deactivation practices are data-heavy, if not necessarily data-driven, activities. The increasing role of meteorology in winter maintenance activities suggests they may be becoming more data-driven.

Survey of Practice

In consultation with the Clear Roads project subcommittee, we developed a 12-question survey designed to identify procedures and practices transportation agencies use in activating and deactivating maintenance fleets in anticipation of severe winter storms. The survey was sent to Clear Roads member agencies and to the Snow and Ice Listserv. We received responses from 25 Clear Roads states.

Overview

Surveyed agencies embrace a raft of quantitative data in marshalling a response to an impending winter storm event. A willingness to work with staff or consulting meteorologists, multiple weather forecasting sources, and a broad range of quantitative measures of present and predicted weather indicators represents each agency's approach to winter storm preparation. Most of the agencies bring 50 to 100 percent of their maintenance fleet workforce into service in the hours before a storm hits, and all observe some combination of multiple, often contingent, weather measures as they prepare for a coming storm. This level of data sophistication positions them well to utilize microclimate forecasting, a refined location-specific meteorological trend that some of the agencies have already embraced.

Tools for Fleet Activation

Agencies have a range of tools to draw upon in planning for storm events and appropriate winter maintenance responses, including storm monitors, maintenance decision support systems (MDSS), and various internal and external sources for forecasting and weather data.

Three quarters of agencies work with a storm monitor, weather manager or meteorologist, about half of whom are state employees. A little more than a third of agencies responding to the survey use an MDSS in their winter maintenance operations. All but one of the 25 agencies rely on road weather information systems (RWIS) for weather conditions data; 22 draw on both the National Weather Service and radar data for forecast information, with 20 agencies also looking to camera feeds. More than half the agencies rely on five or more sources for weather data and forecasting.

Activation Practices

The survey asked agencies about their use of nine weather-related indicators, both current and forecast, in gathering data about storm intensity and determining maintenance responses: pavement temperature, air temperature, dew point, wind speed, precipitation, forecast air temperature, forecast dew point, forecast wind speed and forecast precipitation. Seven of the nine indicators are used by most agencies, just under half of the agencies use the remaining two indicators (current dew point and wind speed). Agencies weigh current and forecast conditions almost equally in deciding when to call in their crews.

Current and forecast temperatures at or near freezing are a typical starting point for such assessments, with dew points, humidity, wind speed and other factors playing contingent roles in various approaches to fleet activations. Forty percent of agencies activate their entire fleet before a storm arrives, and another 16 percent activate half their fleet. Two-thirds of the agencies activate fleets in the two hours before a storm is expected to strike. Typical fleet activities are directed at a district or regional level, not a state level; 74 percent of agencies run anti-icing, deicing and snowplowing from district offices or shops, favoring a bottom-up approach to directing activities (though decisions are often monitored by a central, state office). Pulling personnel and equipment from less affected areas into more heavily impacted areas is a common practice informed by forecast data.

Deactivation Practices

Deactivation tends to fall to the same organizational level as the principal fleet maintenance activities do. In deactivation, current conditions may carry more weight than forecast conditions.

We surveyed agencies about use of 11 weather-related indicators, including the nine used as indicators for activation, plus traffic speed and the more qualitative value of "pavements clear." Seven of the selected indicators were used by 30 percent or more of the agencies considering deactivation data. The most popular were forecast precipitation (92 percent) and pavements clear (85 percent). Threshold values for these indicators, the values at which deactivation becomes attractive to supervisors and managers, tend to show a reliance on contingencies of wind speed, precipitation and other weather measurements focused more on current conditions than in activation considerations, with the significant exception of forecast precipitation. The ability to look out a window and see that a storm is fading may have a strong influence on deactivation decisions.

Literature Search

The literature search identified 27 research citations as representative of the research on severe storm planning and activation strategies and practices. It appears that Utah DOT was a leader in integrating meteorological data into winter maintenance operations and planning; in 2008, Utah's work with meteorologists, performance and cost-benefit data in its maintenance operations was the subject of related studies presented in Transportation Research Board publications. Research on decision and information systems was the largest group of studies, but the work had tapered off by 2015. Work on routing, planning and operational performance was as a group more current.

Conclusion

Meteorological data and information from transportation information systems like traffic camera feeds and RWIS are widely embraced by managers and supervisors that make decisions about activation levels of winter maintenance fleets facing a significant storm, and deactivation of fleets as or after a storm passes. As states employ more meteorologists within transportation agencies and as consultants, and as information systems develop and expand, the role of data in activation and deactivation practices can be expected to grow.

Fifty-six percent of responding agencies activate at least 50 percent of their maintenance fleet ahead of the arrival of a significant winter storm; 40 percent of the agencies activate their entire fleets. The bulk of this early activation falls within the two-hour window before a storm is expected to strike a maintenance area. These decisions are heavily informed by quantitative data on weather conditions, both current and forecast, as well as by historical knowledge of winter condition problem areas, and by observation and qualitative assessments of pavement conditions.

1 Introduction

Timing the activation and deactivation of winter snow and ice maintenance operations has a significant impact on safety and budgeting. Activating too early can strain budgeted resources, and activating too late risks diminishing roadway safety for the public and maintenance crews.

For this synthesis, we reviewed research on activation and deactivation planning, particularly with respect to timing the activation and deactivation of road crews in anticipation of a winter storm. Many studies have focused on the use of decision support systems and information systems to formalize such choices, but it is not clear how widely these technologies have been embraced by state transportation agencies in responding to or anticipating winter storm maintenance needs.

The Clear Roads project subcommittee requested a survey of practice to shed some light on how widely decision support systems are used, as well as what indicators agencies use in making activation and deactivation decisions and how early before a storm's arrival agencies marshal maintenance forces to begin road clearing operations.

2 Survey of Practice

2.1 Overview

In consultation with the Clear Roads project subcommittee, we developed a 12-question survey designed to identify procedures and practices transportation agencies use in activating and deactivating maintenance fleets in anticipation of severe winter storms. The survey was sent to Clear Roads member agencies and to the Snow and Ice Listserv. We received responses from 25 state DOTs:

- Arizona
- Colorado
- Connecticut
- Delaware
- Idaho (8 responses)
- Illinois
- Indiana
- Iowa
- Kansas
- Maryland
- Massachusetts
- Michigan
- Missouri
- Nevada
- New Hampshire
- New York
- North Dakota
- Pennsylvania
- Rhode Island
- Texas
- Utah
- Vermont
- Wisconsin
- West Virginia
- Wyoming

Idaho, a state that relies partially on its district offices to independently determine when to activate crews for winter storm events, supplied eight responses from district foremen or supervisors. To allow equitable comparison with the other responding agencies, we worked with the Idaho Transportation Department's maintenance services manager and Clear Roads liaison, Steve Spoor, to condense the eight district responses into one response representing the entire agency.

Survey responses indicated that meteorological and transportation information system-based data plays a significant role in activation and deactivation practices and decisions. More than half of responding state activate at least 50 percent of their maintenance forces shortly before a storm arrives. Activation and deactivation activities are directed by most agencies at a district or intrastate regional level, and area history and location-specific problem areas play a significant role in manager and supervisor decisions.

The following sections provide detailed discussion of the survey responses. The full text of the survey questions is provided in Appendix A.

2.2 Tools for Storm Response Activation

Five survey questions focused on tools available to agencies in planning for maintenance fleet activation. A storm monitor or meteorologist was used by 19 of the 25 survey respondents, and Maintenance Decision Support Systems were used by nine agencies.

2.2.1 Storm Monitors

Three-quarters of respondents indicated that their agency works with a storm monitor, meteorologist or weather manager. About half indicated that this role is filled by a consultant, while 37 percent said the role is filled by a state transportation agency employee and 11 percent indicated the position is held in another agency (see Figure 2.1). Several respondents indicated that the monitor, manager or consultant is a meteorologist (or holds a master's degree in meteorology) or works with a staff of meteorologists.

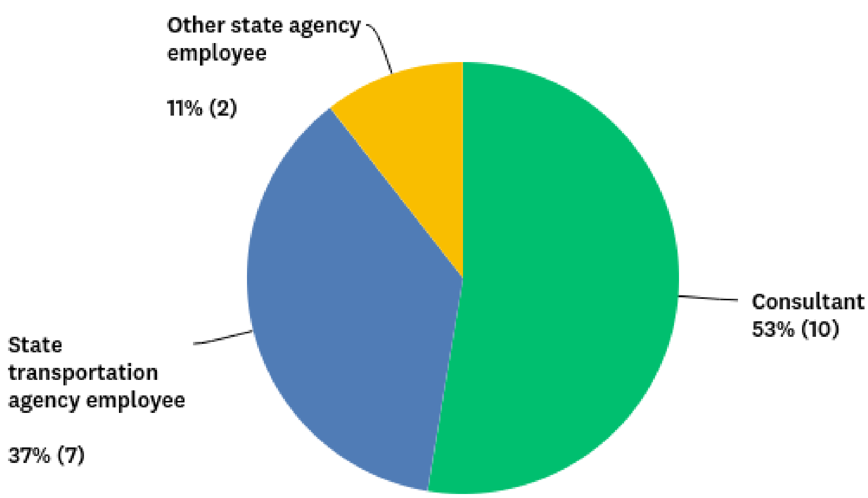

Figure 2.1 Professional Status of Storm Monitors and Meteorologists

2.2.2 Maintenance Decision Support Systems (MDSS)

Eleven state agencies indicated that they have access to an MDSS for winter storm maintenance activation and deactivation, but only nine responded that they use the MDSS for winter maintenance activities.

Among the uses of MDSS described were RWIS data and camera systems for monitoring storm progress, using MDSS forecast information in activation by determining shifts and deployment of maintenance activity, and using its data for predicting storm start times and anticipated precipitation levels.

2.2.3 Weather Forecast Sources

Most agencies rely on multiple sources for forecast information; 21 agencies draw on five or more sources. As shown in Figure 2.2, RWIS was the most common source of information about weather conditions for purposes of activation and deactivation, followed closely by radar weather readings and the National Weather Service. Camera feeds were also used by 80 percent of the respondents.

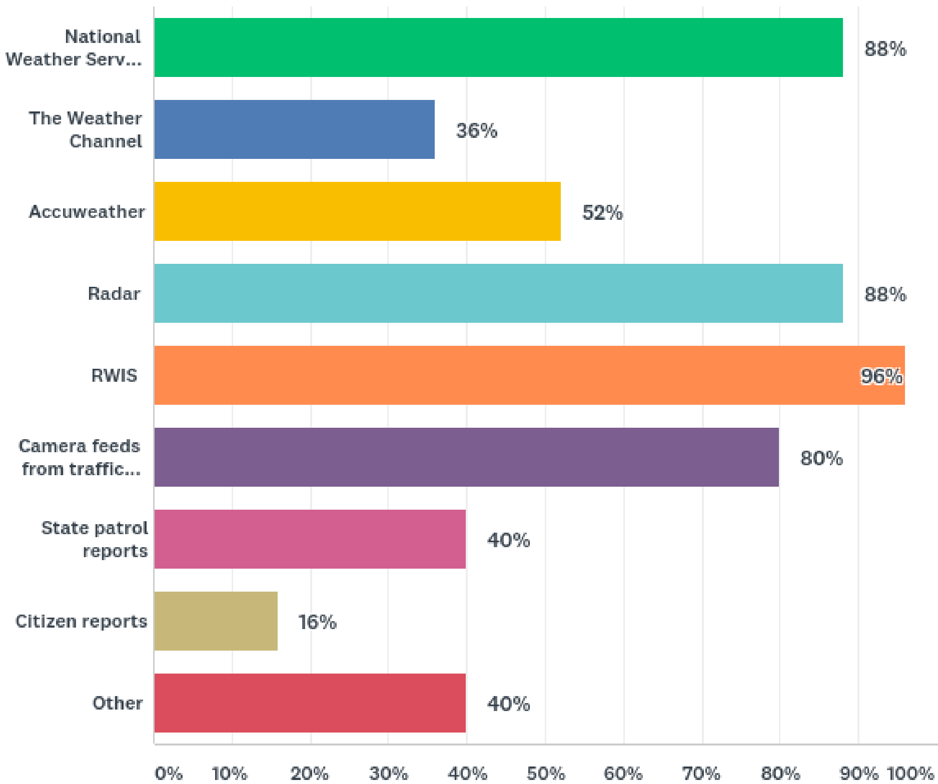

Figure 2.2 Weather Forecast Sources

Respondents also mentioned a number of other sources, including local meteorological sources that provide microclimate-level forecasting, social media, plow cameras, and automatic vehicle location and global positioning system data from nearby agencies.

One practice mentioned in these comments and in other sections is regular forecasts supplied by outside sources. Connecticut receives daily forecasts, as well as storm updates every four hours during snow and ice events. Idaho crews receive briefings from the National Weather Service on Mondays and Thursdays and construct their winter maintenance schedules around these each week. Even with regular briefings, crews and managers look to multiple sources of information.

2.3 Activation Indicators

Five survey questions focused on activation indicators and practices. Answers showed a strong commitment to quantifiable weather indicators, a high reliance on district-level activation decisions, and a reliance on high levels of fleet mobilization from one to four hours before storm arrival.

2.3.1 Activation Indicators Used

The survey presented nine potential indicators that could inform activation decisions for agencies, and each was used by at least 50 percent of the respondents (see Table 2.1). Current pavement temperature and current precipitation are each used by 96 percent of respondents, and forecast precipitation is used by 92 percent of respondents. Current air temperature and forecast air temperature were the next most commonly selected indicators, at 79 and 75 percent, respectively.

Table 2.1 Indicators for Fleet Activation

State	Indicators Used in Activation									
	Current Pave Temp	Current Air Temp	Current Dew Point	Current Wind Speed	Current Precip	Forecast Air Temp	Forecast Dew Point	Forecast Wind Speed	Forecast Precip	Other
Arizona	✓	✓			✓	✓			✓	
Colorado	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Connecticut	✓	✓	✓		✓	✓	✓		✓	
Delaware	✓	✓			✓	✓			✓	
Idaho	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Illinois	✓			✓	✓				✓	
Indiana	✓			✓	✓			✓	✓	
Iowa	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Kansas	✓	✓			✓	✓		✓	✓	
Maryland	✓	✓			✓	✓			✓	
Massachusetts	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Michigan	✓	✓		✓	✓			✓		
Missouri	✓	✓	✓		✓	✓	✓	✓	✓	
Nevada	✓	✓		✓	✓	✓	✓	✓		
New Hampshire	✓	✓			✓	✓	✓		✓	
New York	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
North Dakota	✓		✓		✓		✓		✓	
Pennsylvania	✓					✓		✓	✓	
Texas	✓	✓			✓	✓			✓	
Utah	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Vermont					✓				✓	
West Virginia	✓	✓			✓				✓	
Wisconsin	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Wyoming	✓	✓	✓		✓	✓	✓			
Percentage Using	**96%**	**79%**	**46%**	**46%**	**96%**	**75%**	**50%**	**54%**	**92%**	**21%**

Current conditions heavily influence activation decision-making. How data-driven such decisions are remains unclear, as quantitative factors may as easily support as drive qualitative factors—feeling the cold outside, looking out the window at the sky or at precipitation. Quantitative data from forecasting may be as significant a factor in activation decision-making, since every forecast indicator earned at least 50 percent support in survey responses, and forecast precipitation was the third-most-embraced indicator of the survey options.

Comments provided by some respondents indicated that RWIS, plow cameras, humidity levels, asphalt or concrete pavements, soil temperatures, frost triggers, wind direction and more may also be used as indicators or to amplify indicator data in decision-making.

2.3.2 Activation Indicator Value Thresholds

Twenty-three agencies provided detail on value thresholds at which the indicators they track trigger activation decisions for fleets. Four of these 23 did not include any numerical values, instead describing conditions that they consider, often contingent on other factors.

Of the indicators involving current conditions, the most popular indicators assigned value thresholds were current air temperature, with 18 values, and current pavement temperature and current precipitation, with 17 values each (see Table 2.2).

Table 2.2 Value Thresholds for Activation (Current Conditions)

State	Value Thresholds for Activation (Current Conditions)				
	Current Pave Temp (F)	Current Air Temp (F)	Current Dew Point (F)	Current Wind Speed (mph)	Current Precip
Arizona	In relation to temps, conditions, forecast	35-40 and falling	Increasing with air temp	Upslope winds	In area
Colorado	Depends on area, known problem areas. Below 35	Depends on area, known problem areas. Below 35	Depends on area, known problem areas	Depends on area, known problem areas. Gusts above 50 trigger CMV warnings and closures	Depends on type of precip. Any drizzle is worrisome; snowfall above 1"/hour triggers additional personnel
Connecticut	32	32	Air temp +/- 5		
Delaware	34	34			
Idaho	Use to decide amount of salt and brine	Watch to adjust for colder temperatures with our material		No material placed if 15 and drifting	Sleet, snow, heavy fog

State	Value Thresholds for Activation (Current Conditions)				
	Current Pave Temp (F)	Current Air Temp (F)	Current Dew Point (F)	Current Wind Speed (mph)	Current Precip
Illinois	< 35			10 with recent snow	Snow > 1/2" or freezing rain
Indiana	high	low	low	high	high
Iowa	-	-	-	-	-
Kansas	< 32	< 32			any
Maryland	≊ 32 with frozen precip current or forecast	≊ 32 with frozen precip			Any frozen precip with pave ≊ 32 F
Massachusetts	≤ 34	40, trending lower	Close to air temp	Sustained higher wind speeds = blowing snow	Any precip with cold pave
Michigan	34	34		5	0.2
Missouri	> 33	> 33	> 36		any
Nevada	34	34		40	
New Hampshire	32	35			wet
New York	-	-	-	-	-
North Dakota	32				
Pennsylvania	≤ 32	≤ 32	NA	> 40	freezing
Rhode Island					sticking to road
Texas	≤ 35	≤ 35 with chance of precip	NA	NA	any with temps ≊ 32 F
Utah	32	35		20	
Vermont					any icing or snow
West Virginia	30-35, 15	33, 18			
Wisconsin	34			15	> 0
Wyoming	If precip will stick or freeze on impact	Cold enough for snow	Depends on air temp to predict precip	Blowing and drifting snow	Based on observation

On current pavement temperatures, 17 of 21 agencies that placed a value on this indicator identified a temperature threshold at or near freezing; all of these responses ranged from “less than 32” degrees to 35 degrees Fahrenheit, with one describing the value as “below 35” but also contingent on known problem areas. On current air temperature, 15 of 18 indicated at or near freezing as the threshold. Assigned values ranged from 40 degrees F and falling to 32 or less. Current dew point attracted only seven responses describing a value for its use.

Current wind speed was described by 12 agencies, ranging from over 40 mph to 5 mph. Current precipitation was described in 17 responses, but mostly entailed contingencies, as only three agencies affixed this a specific value.

Of the forecast indicators, the most widely used was forecast precipitation, with 20 values provided, followed by forecast air temperature, with 16 values assigned (see Table 2.3).

Table 2.3 Value Thresholds for Activation (Forecast Conditions)

State	Value Thresholds for Activation (Forecast Conditions)				
	Forecast Air Temp (F)	Forecast Dew Point (F)	Forecast Wind Speed (mph)	Forecast Precip	Other
Arizona	35-40 and falling; depends on storm duration and forecast			Watch with future models of temps	
Colorado	Depends on area, known problem areas. Below 35	Depends on area, known problem areas. Below 35	Depends on area, known problem areas	Depends on type of precip. Any drizzle is worrisome, snowfall above 1"/hour triggers additional personnel	
Connecticut				Snow within 2 hours	
Delaware	33			Snow, ice, sleet, freezing rain	
Idaho	34				All apply; varies with location and forecast
Illinois				Freezing rain or snowfall > 1/2"	
Indiana	low	low	high	high	
Iowa	-	-	-	-	-
Kansas	< 32	< 32		any	
Maryland	≅ 32 with frozen precip forecast			Any frozen precip with pave ≅ 32 F	

State	Value Thresholds for Activation (Forecast Conditions)				
	Forecast Air Temp (F)	Forecast Dew Point (F)	Forecast Wind Speed (mph)	Forecast Precip	Other
Massachusetts	≤ 34	≊ or below air temp	Blowing snow	Any that could make roads slick	Grip ≤ 0.5 and falling
Michigan	34		5	0.2	
Missouri	> 33	> 36		Sleet, snow or ice	> 95% humidity
Nevada			40		
New Hampshire	32			Snow, ice, rain	
New York	-	-	-	-	-
North Dakota				Any	
Pennsylvania	≤ 35	NA	Gusts ≥ 40	Snow, freezing rain	
Rhode Island				coating	
Texas	≤ 35	NA	NA	≥ 20% chance	
Utah	35		20		contingent on forecasts to nearest hour
Vermont				Any unsafe potential	
West Virginia	33, 18			> 40% chance	
Wisconsin			15	> 0% chance	
Wyoming	Based on how fast temps will drop or rise; when; how high/low the temp will be	Based on how it matches air temp to determine when precip may occur	When wind direction turns and picks up velocity	Based on duration of storm event	

Forecast air temperature values were identified by 16 respondents. Numerical values were described in 13 responses, and ranged from 40 degrees F and falling to less than 32. Forecast dew point factors were described by six respondents, with numerical values ranging from greater than 36 degrees F to less than 32. Forecast wind speed factors were described in nine responses, with values ranging from greater than 40 mph down to 5 mph. Forecast precipitation was described by 20 respondents, but specific numerical values for precipitation thresholds were only provided by six agencies.

In the text box accommodating other indicators not listed, comments included that all thresholds apply, but vary depending on location and forecast; a friction value at 0.5 and falling; humidity at over 95 percent; and values contingent on forecasts to the nearest hour.

2.3.3 Maintenance Jurisdictions

At most of the responding agencies, the decision to activate or deactivate crews is made at a regional or district level. Over 70 percent of responses indicated that anti-icing, deicing and plowing operations were directed at a district/region level; see Figure 2.3. Many of these agencies coordinate these regional responses with state and sub-district (county or designated subarea) levels.

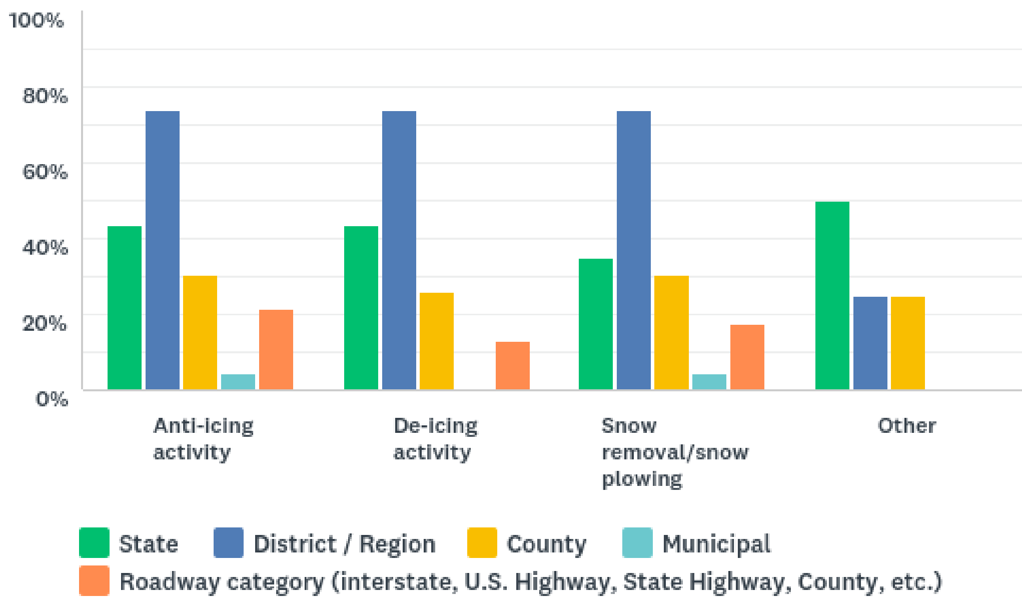

Figure 2.3 Winter Maintenance Jurisdictions

Comments focused primarily on relationships between area and state authority. PennDOT indicated that it relies on a National Incident Management System in which an Area Command Center is activated by the state's emergency management agency; the center coordinates PennDOT plans with neighboring states.

In Iowa, garage supervisors make activation choices and a district manager determines when resources should be shifted from one garage area to another. Indiana follows a similar pattern, with district and sub-district management of winter operations and central office oversight on coordination between districts.

The six maintenance districts in Massachusetts mobilize independently, and the state monitors and occasionally challenges their plans. In Wyoming, maintenance shops make their own choices, but inexperienced foremen (e.g., less than five years in the position) work with MDSS, while highly experienced foremen (e.g., 30 years of experience) do not, and in every case the state monitors activity.

Vermont has recently begun taking input from its head of transportation on anti-icing and deicing. Otherwise, plans are sent from the state maintenance office to district garages, where supervisors decide on specific actions to take.

2.3.4 Activation Level

More than half of respondents indicated that they activate 50 percent or more of their maintenance resources before the arrival of a severe storm; see Figure 2.4. Forty percent of agencies activate 100 percent of their maintenance fleet before the arrival of a forecasted severe storm.

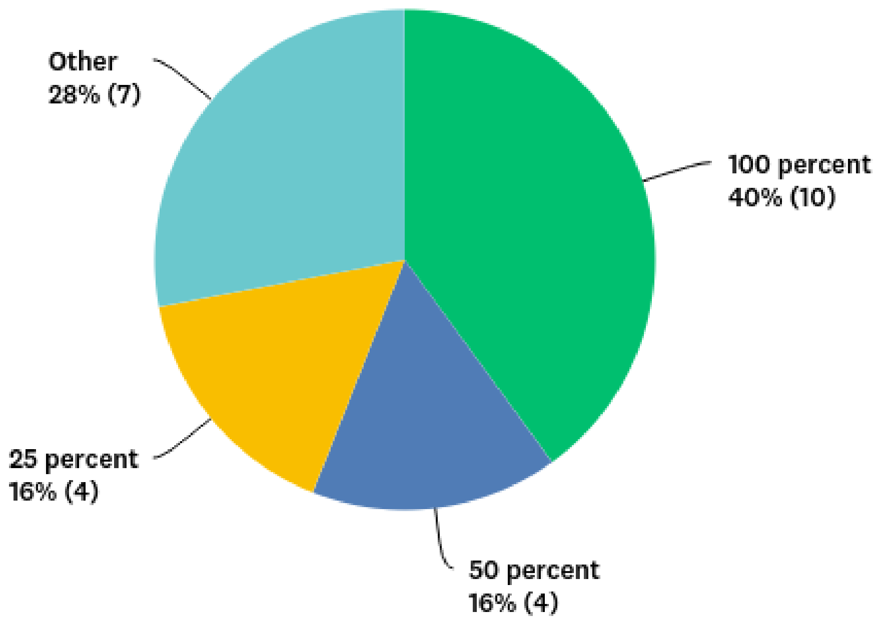

Figure 2.4 Fleet Activation Level Before Storm Arrival

Comments describe variations in standard responses, indicating less severe storms, late-in-shift arrival and shop personnel force size may trigger partial fleet activation at first. Shift length may be limited to 12 hours, or in severe situations, even 16. Rhode Island indicated that it activates the entire fleet, and calls in contract crews as needed during a storm.

2.3.5 Workforce Arrival

Two-thirds of respondents ask crews to come in up to two hours before a significant winter storm hits the maintenance area in which they work. About 22 percent ask crews to come in between two and four hours of the storm strike (see Figure 2.5).

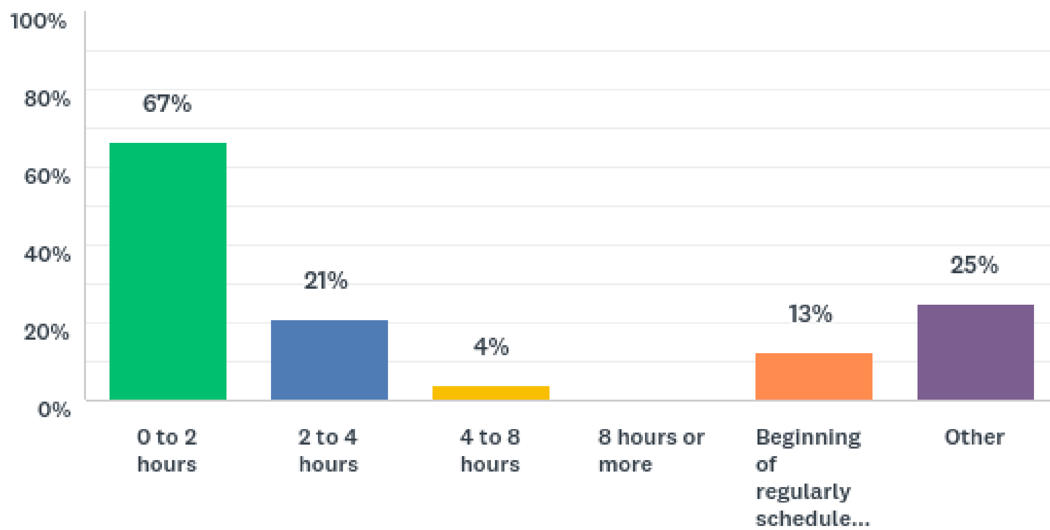

Figure 2.5 Workforce Arrival Requirements

Comments indicate that storm severity, crew size and shop supervisor discretion inform decisions about calling in employees early for shifts that will confront severe storm work. It is not clear which direction these activation workforce arrival windows are trending—as data availability grows, this window may tighten to less than two hours as data becomes more precise or microclimate-focused, or it may widen to, say, four hours as data describes expected storm intensity and expected intensity grows.

2.4 Deactivation Indicators

Two survey questions focused on deactivation indicators, although the previously described information on activation jurisdictions assumes deactivation responsibilities also fall within the same organizational strategy.

A technical issue with the survey contributed to the lower response level to these questions. Another factor concerns the diminished reliance on forecasting, as described below. Supervisors may reasonably rely during the last stages of a storm on qualitative and empirical information—looking out windows rather than at temperature gauges—not considered useful when a storm's arrival is anticipated and widely forecast.

2.4.1 Deactivation Indicators Used

Thirteen agencies responded to a question about deactivation indicators. Forecast precipitation and a "pavements clear" determination emerged as the most widely embraced indicators used in deactivation decision-making; see Table 2.4.

Table 2.4 Indicators for Fleet Deactivation

State	Indicators Used in Deactivation										
	Current Pave Temp	Current Air Temp	Current Dew Point	Current Wind Speed	Current Precip	Pave Clear	Traffic Speed	Forecast Air Temp	Forecast Dew Point	Forecast Wind Speed	Forecast Precip
Arizona	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Connecticut						✓	✓				✓
Delaware	✓	✓			✓	✓		✓			✓
Idaho						✓					
Iowa					✓	✓	✓				✓
Kansas	✓			✓	✓	✓		✓		✓	✓
Maryland	✓	✓			✓	✓		✓			✓
New Hampshire	✓	✓			✓	✓		✓			✓
New York						✓					✓
North Dakota					✓						✓
Pennsylvania						✓		✓			✓
Utah	✓	✓	✓	✓	✓			✓	✓	✓	✓
Wisconsin					✓	✓	✓				✓
Percentage Using	**46%**	**38%**	**15%**	**23%**	**69%**	**85%**	**31%**	**54%**	**15%**	**23%**	**92%**

As with activation decisions, the role of data in deactivation decisions remains difficult to unpack from qualitative judgment. The four forecast indicators enjoy less relevance to respondents than do the six current-conditions indicators, although the quantitative values—pavement and air temperatures, dew point and wind speed—for current and forecast conditions are embraced in equal numbers. The scales toward current conditions are tipped by the wide embrace of “pavements clear” as a threshold value.

Dew point and wind speed play much larger roles in activation decisions than in deactivation decisions; current pavement and air temperature suffer a similar proportionate drop in emphasis from their roles as factors in activation to roles in deactivation.

2.4.2 Deactivation Indicator Value Thresholds

Twenty-three agencies provided detail on value thresholds at which the indicators they track trigger deactivation decisions for fleets; see Table 2.5. Nine of these 23 did not include any numerical values, describing conditions that they consider, often contingent on other factors like shift lengths and subjective pavement conditions.

Table 2.5 Value Thresholds for Deactivation (Current Conditions)

State	Value Thresholds for Deactivation (Current Conditions)						
	Current Pave Temp (F)	Current Air Temp (F)	Current Dew Point (F)	Current Wind Speed (mph)	Current Precip	Pave Clear	Traffic Speed
Arizona	Rising over 32 (with other factors)	32 and rising	Falling	Wind is not blowing snow	Little to none on radar	Black and wet	Returning to normal flow
Colorado	Depends on area, forecast, known problem areas.	Depends on area, forecast, known problem areas.	Depends on area, forecast, known problem areas.	Depends on area, forecast, known problem areas.	Depends on area, forecast, known problem areas.	Depends on LOS, road category. At 95% bare pave, road considered clear.	Tied to Pave Clear; depends on traffic volume, road category.
Connecticut	NA	NA	NA	NA		Clear mainline; some snow left in shoulder	Traffic speeds near or at speed limit
Delaware	33	33			Not freezing/ frozen	Yes; might shift to "cleanup" mode	
Idaho	Determines amount of material to put down						
Illinois				< 10; monitor for blowing snow		Scale back once LOS targets met	
Indiana	high	low	low	high	high	high	
Iowa							
Kansas						Bare pave	

State	Value Thresholds for Deactivation (Current Conditions)						
	Current Pave Temp (F)	Current Air Temp (F)	Current Dew Point (F)	Current Wind Speed (mph)	Current Precip	Pave Clear	Traffic Speed
Maryland	> 32 current and forecast, with pave free of snow and ice	> 32 current and forecast, with pave free of snow and ice			Pave free of snow and ice with no frozen precip	Free of snow and ice	
Massachusetts	≥ 32	Any, with dry roads and dew point much higher than current	Above current air and pave temps	Location-specific; ≤ 20	≅ 0	Yes, if no blowing snow, no dew point threat	When reasonable, and state patrol has relaxed temporary speed limits
Michigan	34	34		4	0		
Missouri	> 33	> 33	> 36		Sleet, ice or snow		
Nevada	34	34		40			
New Hampshire	> 32	> 32			No snow or freezing rain	Dry, or black and wet	
New York						Yes, after cleanup operations	
North Dakota							
Pennsylvania	> 32	> 32	NA	< 15	None	White lane to white lane on interstate	NA
Rhode Island	Maintained above freezing				None	Black and wet	Normal

State	Value Thresholds for Deactivation (Current Conditions)						
	Current Pave Temp (F)	Current Air Temp (F)	Current Dew Point (F)	Current Wind Speed (mph)	Current Precip	Pave Clear	Traffic Speed
Texas	35 and rising	35 and rising	NA	NA	Non-frozen precip with rising temps	All clear	NA
Utah	33 and rising	36 and rising		< 20 and decreasing			
Vermont					None		
West Virginia							
Wisconsin					Close to 0. Some routes deactivate at night; see Table 2.4.2b	Yes. If pave clear, may deactivate or shift to "cleanup" mode	
Wyoming							

For current pavement temperatures, 11 of 16 agencies have a numerical threshold for deactivation, ranging from 32 to 35 and rising. Nine agencies assigned a specific value to current air temperature, ranging from 32 to 36 and rising; three other agencies assigned a non-numerical value to air temperature. Only five agencies assign current dew point a deactivation value, and the only numerical value is over 36 degrees. Four of seven agencies that consider a threshold value for wind speed assign it a numerical value, from 10 mph to 20 mph. Fourteen agencies assign current precipitation thresholds a value, but only three give it a number, which in every case is zero. Pavements clear, a value embraced by 15 agencies as a deactivation threshold, earns descriptions from fully clear to black and wet. Five agencies recognize traffic speed as a deactivation threshold, with “normal” being the most common value threshold.

Respondent agencies use value thresholds for forecast conditions almost as frequently as for current conditions in deactivation decisions; see Table 2.6.

Table 2.6 Value Thresholds for Deactivation (Forecast Conditions)

State	Value Thresholds for Deactivation (Forecast Conditions)				
	Forecast Air Temp (F)	Forecast Dew Point (F)	Forecast Wind Speed (mph)	Forecast Precip	Other
Arizona	Above 32 and clear	Dry			Depends on many variables
Colorado	Depends on area, forecast, known problem areas.	Depends on area, forecast, known problem areas.	Depends on area, forecast, known problem areas.	Depends on area, forecast, known problem areas.	
Connecticut				Clear	
Delaware				Non-freezing	
Idaho	varies		varies	varies	
Illinois			10; monitor for blowing snow		
Indiana	low	low	high	high	
Iowa					Near normal winter driving conditions
Kansas			<15		
Maryland	> 32 current and forecast, with pave free of snow and ice			Pave free of snow, ice; no frozen precip	
Massachusetts	Any with dry roads; > 32 F if roads wet	Above current air and pave temps	Location-specific; ≤ 20	Any if pave temp > 32	
Michigan	35		4	0	
Missouri	> 33	> 36		Sleet, ice or snow	
Nevada	34		40		

State	Value Thresholds for Deactivation (Forecast Conditions)				
	Forecast Air Temp (F)	Forecast Dew Point (F)	Forecast Wind Speed (mph)	Forecast Precip	Other
New Hampshire	> 32			No more winter weather	
New York					
North Dakota					
Pennsylvania	> 32	NA	< 15	none	NA
Rhode Island				clear	
Texas	35 and rising	NA	NA	Varies with temp	
Utah	36 and rising		< 20 and decreasing		Rely on forecasts to nearest hour
Vermont					Unless ice storm or freezing rain, reduced staffing on most roads 10 pm to 3 am
West Virginia					
Wisconsin				Forecast precip = 0 for at least 4 hours	Some 18-hour, some 24-hour routes; may deactivate on 18-hour routes around 10 pm even if storm is not over
Wyoming					Road condition determines operator end time

Ten of 13 agencies responding assign a numerical value to forecast air temperature as a deactivation indicator, from above 32 to 36 degrees F and rising, sometimes contingent on pavement conditions. One of the five agencies that assign a value to forecast dew point for deactivation gives it a numerical value: over 36 degrees. Forecast wind speed is assigned a threshold value for deactivation by 10 agencies, with seven assigning it a numerical value, ranging from 4 mph to 40 mph. Fourteen states assign a threshold deactivation value to forecast precipitation, and eight of them put that value as zero or no precipitation, sometimes with contingencies for time or pavement condition.

Six agencies provided an additional value threshold for deactivation decisions, and these relate to maintenance shifts, time since last precipitation, and similar conditions. Iowa, which does not assign a threshold value to any indicator, relies on pavement conditions reaching a level of near normality. Craig Bargfrede, Iowa DOT's Winter Operations Administrator, explains it this way:

> Deactivation is when we have the road surface back to near normal winter driving conditions. Here is our definition: Reasonably Near Normal Surface – A pavement surface sufficiently free of snow, ice, frost or slush, permitting reasonable vehicle control when the vehicle is operated within the framework of existing laws and regulations. Some isolated spots or strips of packed snow or ice may be present.

2.5 Supplemental Information

Additional comments and materials supplied by respondents were limited. The respondent from Vermont noted that the agency has been steering away from use of anti-icing materials on locations other than areas with a history of problems; crews in Vermont react when precipitation begins by using anti-icing or deicing material to prevent the bonding of ice or snow with pavement.

Four agencies provided links to codified specifications or procedures.

- Connecticut: http://ctcase.org/reports/WinterHighway2015/winter-highway-2015.pdf
- Missouri: http://epg.modot.org/index.php?title=Category:133_Snow_and_Ice_Control
- Vermont: http://vtrans.vermont.gov/sites/aot/files/documents/Snow%20%20Ice%20Control%20Plan%202017%20FINAL%20DRAFT.PDF
- Wisconsin: http://wisconsindot.gov/Pages/doing-bus/local-gov/hwy-mnt/mntc-manual/chapter06.aspx

3 Literature Search

3.1 Overview

Recent research in this area focuses on forecasting and winter weather in relation to routing snowplows and scheduling crews and equipment, on technological tools for winter maintenance planning and real-time maintenance responses to weather changes, and on weather indicators and maintenance performance. Studies devoted to MDSS, RWIS and other information technology tools look at how these systems integrate weather information into planning and scheduling activity and may pertain to individual storm response planning and scheduling activation.

Below is a sample of recent research on these topics, as well as a pair of articles from 2008 on Utah's program for including winter weather information in its maintenance operations. Utah's approach included the work of an in-agency meteorologist who helped direct maintenance priorities toward weather forecasts.

The citations in this literature search are grouped into four categories:

- **Routing, Planning and Weather.** These documents consider performance indices, case studies and winter maintenance standards.

- **Utah's Approach.** Two articles from TRB publications detail the Utah model of integrating weather forecasting and characterization into roadway maintenance activities.
- **Decision Support and Weather Information Systems.** Maintenance decision support systems (MDSS), road weather information systems (RWIS) and other information technology tools integrate weather information with decision-making software and modeling.
- **Operational Performance.** These documents consider performance indices, case studies and winter maintenance standards.

3.2 Routing, Planning and Weather

The studies cited in this section consider snowplow and maintenance routing and scheduling in terms of weather and real-time weather monitoring. Such research focuses on optimizing and adjusting maintenance activities in relation to winter weather and its severity but does not explicitly focus on activation and deactivation plans and standards.

Three of the studies listed below focus on schedule planning and real-time weather information. **Optimal Routing for Minimum Service Time of Winter Road Maintenance with Truck Capacity and Fleet Size Constraints**, from the Transportation Research Board annual meeting in 2013; **Optimal Workforce Planning and Shift Scheduling for Snow and Ice Removal** from the Minnesota Department of Transportation in 2010; and **Optimizing winter road maintenance operations under real-time information** from the *European Journal of Operational Research* in 2009 may be the citations most likely to address the topic of activation planning.

Snow and Ice Removal Route Optimization in Kentucky. Blandford, Benjamin; Lammers, Erin; Green, Eric. Kentucky Transportation Center, KTC-17-18/SPR 16-529-1F, August 2017, 34pp
https://uknowledge.uky.edu/cgi/viewcontent.cgi?article=2582&context=ktc_researchreports
Abstract: Each year the Kentucky Transportation Cabinet (KYTC) spends $40-$80 million removing snow and ice from the state's roadways. Snow and ice removal are accomplished through a system of snow and ice removal routes that are designed to account for location and the attributes of trucks, facilities, materials, and roadways. To identify strategies that will improve and optimize KYTC's snow and ice removal operations, Kentucky Transportation Center (KTC) researchers used ArcGIS and its Network Analyst extension to study the performance of the Cabinet's current routing procedures. Building from this investigation, researchers developed optimized snowplow routings for four counties located in KYTC Districts 6 and 7 using Arc's Network Analyst and the Vehicle Routing Problem toolset. Optimized routings were developed for individual counties, with snowplows assigned to routes based on truck type and route priority. Researchers experimented with several routing iterations before arriving at a final version. The routing solution developed will result in KYTC being able to treat all roadways using fewer trucks. Once successfully implemented, the potential cost savings—for the four counties in which optimized routings were developed—could reach $225,000 per year. Generating optimized routings throughout the state of Kentucky could potentially result in millions of dollars saved for the Cabinet.

WeatherEVANT: Real-Time Weather Related Event Visualization and ANalytics Tool. Demiroluk, Sami; Ozbay, Kaan; Bartin, Bekir; Maggio, Matthew D; Nassif, Hani; Hesslein, Daniel L. *Transportation Research Board 96th Annual Meeting*, Transportation Research Board, 2017, 17p
http://docs.trb.org/prp/17-00114.pdf
Abstract: Weather related events cause major disruptions to our overall transportation system. During the recent winter seasons, the east coast of the United States has struggled with heavy snowstorms, which has drawn attention to the efficiency of storm operations. In this paper, the authors describe a

web-based tool called WeatherEVANT that was developed as a result of past research efforts conducted by the authors of this paper for the New Jersey Turnpike Authority (NJTA). The tool extracts the information residing in the snow operations database, which is updated frequently by NJTA maintenance operators, and provides various visualizations of this real-time data on its web-based interface integrated into GoogleMaps. WeatherEVANT also takes advantage of real-time data available from other sources including traffic cameras, weather reports, traffic data, and incident data among others. In that sense, it is a real-time data integration tool with extensive visualization and reporting capabilities. It can also automatically generate a variety of performance reports for the use by decision makers, such as salt usage, storm information, equipment usage, etc. One important salient feature of this tool is that it is being actively used by NJTA for the last two years, and improvements are implemented as a result of active feedback from its everyday users during the winter season.

Snow Model Analysis. Chien, Steven I-Jy; Meegoda, Jay; Gao, Shengyan. New Jersey Institute of Technology; New Jersey Department of Transportation; Federal Highway Administration, 2014, 71p
https://www.nj.gov/transportation/refdata/research/reports/FHWA-NJ-2014-001.pdf
Abstract: This study developed a new snow model and a database which warehouses geometric, weather and traffic data on New Jersey highways. The complexity of the model development lies in considering variable road width, different spreading/plowing patterns for mainlines and ramps, actual (traffic dependent) and recommended plowing/spreading speeds and the use of mixed truck types. On the other hand, the complexity of the developing database lies in extracting geometric details of study road sections, estimating/mapping traffic speed considering the severity of weather (i.e. snow intensity), time of a day (i.e., peak/off-peak period and weekday/weekend), and roadway type (i.e., urban/rural freeways/arterials). The developed model was applied to three maintenance yards in New Jersey which demonstrates its dynamic and flexibility in adapting to various circumstances (i.e., geometry, weather, and traffic) in estimating needed fleet size for salt spreading and snow plowing operations for various scales (i.e., section, crew, yard, region, and statewide). The model outcomes can be used to assist managers to determine the required number of contractor trucks before a winter season and during/after a snow storm based on forecasted weather and traffic condition. The objective of this study is to assist the New Jersey Department of Transportation (NJDOT) in developing a method to estimate quantity of salt and fleet size for winter highway maintenance in the State of New Jersey.

Network Routing of Snowplow Trucks with Resource Replenishment and Plowing Priorities: Formulation, Algorithm, and Application. Hajibabai, Leila; Nourbakhsh, Seyed M; Ouyang, Yanfeng; Peng, Fan. *Transportation Research Record: Journal of the Transportation Research Board*, Issue 2440, 2014, pp 16-25
Citation at https://trid.trb.org/view/1343375
Abstract: The routing of snowplow trucks in urban and regional areas encompasses a variety of complex decisions, especially for jurisdictions with heavy snowfall. The main activities involve dispatching a fleet of snowplow trucks from a central depot or satellite facility to clean and spread salt and chemicals on the network links (i.e., snow routes). In this paper, a mixed integer linear program model is proposed to minimize the total operation time of all snowplow trucks needed to complete a given set of snow routes with multiple plowing priorities and to reduce the longest individual truck operation time. Customized construction and local search solution algorithms are developed and used to design snow routes for an empirical application. The computational results show that the proposed solution approach is able to solve the problem effectively and the model result outperforms the current solution in practice. The proposed models and algorithms are also incorporated into the development of a state-of-the-art snowplow routing software that can help planners optimize snow routes and evaluate options for resource allocation.

Optimal Routing for Minimum Service Time of Winter Road Maintenance with Truck Capacity and Fleet Size Constraints. Chien, I-Jy; Yu, Haifeng. *Transportation Research Board 92nd Annual Meeting*, Transportation Research Board, 2013, 18p
Citation at https://trid.trb.org/view/1241430
Abstract: To improve road safety under adverse weather (e.g., snow and ice condition), a designated network have to be anti-iced/de-iced before and/or after the arrival of a snow storm or freezing rain. A model is developed to optimize vehicle routing that minimizes the service time needed for anti-icing/anti-icing/de-icing operation, subject to truck capacity and fleet size constraints. With network transformation techniques and the fair workload concept, the study vehicle routing problem can be solved via dynamic programming (DP). The solution approach was tested on a general network with practical operational data. The results are promising and computationally efficient. A sensitivity analysis is conducted by varying the model parameters, including fleet size, truck capacity and operating speed.

Research on Best Practices for Winter Weather Operations. Perkins, Judy A; Mwakalonge, Judith; Jasek, Debbie; Carson, Jodi; Obeng-Boampong, Kwaku; Pesti, Geza. Texas Department of Transportation; Federal Highway Administration; Texas A&M Transportation Institute; Prairie View A&M University, 2012, 218p
https://static.tti.tamu.edu/tti.tamu.edu/documents/0-6669-1.pdf
Abstract: There is a growing need to identify actionable practices relative to winter weather operations. Because of the potential and inherent hazards during cold weather, it has become increasingly important to ensure that these practices can be effectively employed as well as protect the health and safety of employees working in extreme conditions. The research objective was to develop a winter weather operation manual for the Texas Department of Transportation (TxDOT) districts that are vulnerable to weather-related emergencies. A synthesis of the best practices related to winter weather operations and transferable best practices are documented in the operations manual to help maintenance crews better understand how to work in challenging weather-related events. In addition, a playbook for winter storms in Texas was developed to be used for general public awareness of winter storm operations.

A Guidebook for Airport Winter Operations. [Project.] Federal Aviation Administration, Airport Cooperative Research Program. Start date: July 1, 2012.
Citation at https://trid.trb.org/view/1231462
Abstract: Winter weather has the potential to disrupt operations at airports of all sizes; and recent events at several airports have again illustrated the importance of preparing for, operating during, and recovering from winter events. Lack of preparation by an airport for these events can result in potential safety issues. In addition, it is well known that dealing with winter operations can represent a significant cost to airports. For example, at a larger airport facility, the cost of delaying flight operations to permit snow clearing has been estimated in some cases to exceed $300,000 per hour--a factor which can support a decision to increase investment in snow removal so as to reduce the time required to clear a runway. To prepare for these events, airports have to develop a variety of procedures based on individual or unique requirements. Examining the range of existing procedures and evaluating effectiveness would help airports in general respond to a continuing winter operations requirement. Research is needed to develop a guidebook that would provide a useful tool in preparing an effective winter operations plan. Such a guidebook would help to ensure that, based on best practices, optimal investments are being made at airports of varying sizes. The objective of this research is to prepare a guidebook to help airports prepare for, operate during, and recover from disruptive winter events, as well as manage airport user expectations. The guidebook will identify and evaluate best practices in

airport airside and landside winter operations, as well as provide guidance on how to manage overall passenger experience within a framework of safety and efficiency. The guidebook will also provide guidance to airport operators on determining the optimal level of investment necessary to implement an effective program, given expected winter conditions and the nature of the aviation activity at that particular airport. The audience for this guidebook will include managers, operators, and users of small to large airport facilities. At a minimum, the guidebook should address the following program elements as components of an effective winter operations plan adaptable to a variety of airports: (1) Operational consideration (friction, weather, and other factors); (2) Strategies and tactics (equipment, chemicals, drift control, and other related factors); (3) Operational guidelines (personnel, timing, human factors, and other related issues); (4) Economic and finance considerations (budget analysis, benefit-cost analysis, risk analysis); (5) Environmental issues (permitting and other applicable regulations).

Optimal Workforce Planning and Shift Scheduling for Snow and Ice Removal. Gupta, Diwakar; Tokar-Erdemir, Elif; Kuchera, Dustin; Mannava, Arun Kumar; Xiong, Wei. University of Minnesota, Twin Cities; Minnesota Department of Transportation, 2010, 154p
http://www.dot.state.mn.us/research/TS/2011/2011-03.pdf
Research brief at http://www.dot.state.mn.us/research/TS/2011/201103TS.pdf
Abstract: Shrinking budgets and high equipment, fuel, and labor costs have raised the importance of workforce planning and efficient deployment of available workforce for county-level winter maintenance operations. This project focused on developing methodologies for the estimation workforce requirements, and economic evaluation of the impact of using contract employees, split shifts and staggered shifts. In order to achieve these goals, a fundamental question that needed to be addressed was the determination of the amount of work induced by different types of storms that occur in Saint Louis County, Minnesota. Researchers obtained relevant storm data from a variety of weather reporting sources and extracted parameters relevant for determining plow speeds and sand/salt consumption. These parameters were used to determine optimal workforce deployment strategies that balance overtime and delay costs, which in turn provided estimates of the amount of plowing time needed for the goal of clearing roads within 24 hours after the end of snow fall. Plowing time calculations were subject to rules concerning when call outs can occur during off-shift hours. Plow time estimates were subsequently used to develop efficient algorithms to calculate workforce requirements.

Optimizing Winter Road Maintenance Operations Under Real-Time Information. Fu, Liping; Trudel, Mathieu; Kim, Valeri. *European Journal of Operational Research*, Vol. 196, Issue 1, July 2009, pp332-341
Citation at https://www.sciencedirect.com/science/article/abs/pii/S0377221708002427
Abstract: This paper introduces a real-time optimization model that can be used by maintenance managers to develop and evaluate alternative resources allocation plans for winter road maintenance operations. The model takes into account a wide range of road and weather condition factors such as road network topology, road class, weather forecasts, and contractual service levels, and produces a vehicle dispatch schedule that is optimal with respect to operating costs and quality of service. The model is then used in an analysis on a realistic case to illustrate the potential impact of improved information on winter maintenance operations.

Severe Weather Index. [Project.] Maryland Department of Transportation State Highway Administration. Start date: February 15, 2018.
Citation at https://trid.trb.org/view/1500372
Abstract: Maryland Department of Transportation State Highway Administration collects a number of datasets requiring analyses for reporting winter operations. It is difficult to assess varying degrees of winter severity after an event, or to compare from year to year. The objective of this project is to

develop a severe weather index, by area, by shop, for every winter storm event (to be easily calculated after a weather event has happened). The index will consider costs incurred, resources (labor, equipment and material) deployed, and contracts used for both snow and ice events. It will also consider traffic volume, wind speed, pavement temperature, geography, topography, and public expectation. Based on the indices for all weather events in a winter, an annual winter severity index will be developed.

3.3 Utah's Approach

About 10 years ago a pair of researchers published papers on Utah's weather operations program, which includes an in-house meteorologist that helps integrate weather information into traffic operations and maintenance activity. These two citations provide detail on the Utah approach.

Benefit-Cost Analysis of Weather Information for Winter Maintenance: A Case Study. Strong, Christopher; Shi, Xianming. *Transportation Research Record: Journal of the Transportation Research Board*, 2008, pp119-127
Citation at https://trid.trb.org/View/847996
Abstract: Surface transportation in the United States is continuously affected by adverse weather conditions, which contribute to thousands of highway fatalities and billions of dollars in economic loss every year. Winter weather has its own peculiar challenges, to which transportation agencies respond through winter maintenance operations. Recent trends toward proactive winter maintenance operations have placed a premium on the value of timely and accurate weather information that reflects current and forecast conditions in the roadway environment. However, few studies have sought to quantify this value and compare it to the costs of obtaining such customized weather information. The Utah Department of Transportation (DOT) implemented a weather operations program that assists the agency's operations, maintenance, and construction functions by providing detailed, often customized, area-specific weather forecasts. This program's genesis provides a useful case study to quantify the cost-effectiveness of weather information. Described is the application of an artificial neural network model using winter maintenance cost data from dozens of Utah DOT maintenance sheds for the 2004 to 2005 winter to estimate the cost-effectiveness of this program. The model estimated the value and additional saving potential of the Utah DOT weather service to be 11% to 25% and 4% to 10% of the Utah DOT labor and materials cost for winter maintenance, respectively. On the basis of the program's cost, the benefit—cost ratio was calculated at over 11:1. The results highlight the potential benefits that may be realized by an agency using improved weather information to direct its winter maintenance activities.

Integrating Weather Into Transportation Operations: A Utah Department of Transportation Case Study. Strong, Christopher K.; Shi, Xianming. *Transportation Research E-Circular*, Issue E-C126, 2008, pp318-333
http://www.diva-portal.org/smash/get/diva2:674046/FULLTEXT01.pdf#page=330
Abstract: Recent years have brought increased awareness of the impacts of weather on surface transportation operations. A variety of approaches to improve the utilization of weather information have emerged, including investments in technologies, such as road weather information systems and decision support systems, and an increasing array of private-sector and public-sector sources of weather information, including emerging initiatives such as Clarus. One recent trend, documented in federal studies, is the idea of integrating weather information into transportation operations decisions. This is a promising direction for improving the reliability and safety of the transportation system. The Utah Department of Transportation (UDOT) has taken an innovative step in this direction through the

creation of a weather operations program as a part of UDOT. The weather operations program utilizes an in-house meteorologist, augmented by private-sector forecasting support, to provide customized weather information to a variety of users within UDOT, ranging from winter maintenance to construction to operations. A research project was conducted to examine this unique program more closely to see how its services were used by DOT customers to change and improve business practices. The project included surveys of many UDOT maintenance foremen and construction engineers, as well as a quantitative benefit–cost analysis based on data collected regarding winter maintenance activities and outcomes. The results of the research showed that the weather operations program provides significant benefits to UDOT merely from a winter maintenance perspective. There are additional benefits of the weather operations program to other functions within UDOT that, though not quantified in the research project, were clearly indicated. This paper describes the findings of the research project, with the idea of applying it as a case study for consideration by other states. The paper will integrate other recent studies that have explored the question of how weather can support transportation operations and will highlight directions for promising innovations in this direction on the basis of what was learned in the UDOT experience.

3.4 Decision Support and Weather Information Systems

Part of the body of research on winter storm maintenance activity and weather and traffic indications and influences on maintenance focuses on information systems for support of operations and maintenance planning and decision-making, including MDSS and RWIS. These nine citations offer a sampling of the research focus on information technology-based support tools in snow and ice removal operations. Some, such as the first listed, address fleet size in response to storm characterization and anticipation of peak storm demands.

Optimization of Winter Road Maintenance Under Traffic and Weather Information. Nourinejad, Mehdi; Roorda, Matthew J. *Transportation Research Board 94th Annual Meeting*, Transportation Research Board, 2015, 15p
Citation at https://trid.trb.org/view/1337518
Abstract: The total estimated direct annual cost of winter maintenance amounts to $1 billion for Canada and $2 billion for the United States. Municipalities seek technology-based solutions such as information systems to optimize operations and reduce costs. As an example, Advanced Road Weather Information Systems provide real time weather forecasts which, coupled with traffic information systems, can be influential in reducing maintenance costs. The authors present, in this paper, a model for managing winter road maintenance operations under weather and traffic information. The model captures the interactions between plow (spreader) trucks, height of snow on ground, and corridor traffic. An extension of the original model is formulated which considers multi-segment corridors with on-ramps and off-ramps. Results show that traffic is barely affected in cases where the storm peak occurs later than the traffic peak. The model also indicates the benefits of sending multiple plow (or spreader) trucks. In general, dispatching multiple maintenance trucks is justified in cases where the storm peak is relatively close to the traffic peak. Sensitivity analysis on the multi-segment corridor model shows that having a higher number of maintenance trucks increases dispatching flexibility which can consequently reduce delays extensively.

Assessment and Evaluation of Maintenance Decision Support System Recommendations. McClellan, Anthony K; Hershey, Benjamin W; Hart, Robert D; Mewes, John J. *Transportation Research E-Circular*, Issue E-C162, 2012, pp 374-388
Citation at https://trid.trb.org/view/1139463

Abstract: Since the late 1990s there has been an effort to develop and deploy a system integrating maintenance and weather data for winter maintenance operation decision makers to conduct safe and effective maintenance strategies on the roadway. In 2002, a group of state departments of transportation (DOT) created the Pooled-Fund Study (PFS) maintenance decision support system (MDSS) to develop a system that could augment current winter operation techniques and provide decision makers with a one-stop shop for road weather information. The primary objective was the integration of road, weather, maintenance actions, and traffic information to generate the most cost-effective maintenance recommendations for snow and ice control. The PFS MDSS solution was developed as a cooperative research program and has evolved into an operational decision support tool for the seventeen states that have participated in the program. As part of the ongoing evaluation of the program the DOT participants in this study have asked "Are DOT personnel who make the final maintenance treatment decisions using the recommendations; and, if not, why not?" An evaluation tool was developed to capture whether maintenance personnel accepted or rejected the MDSS recommendations during routine operations and, if they rejected the MDSS recommendations, why the MDSS recommendation was declined. This paper discusses how the evaluation tool was developed and the results from the evaluation. It addresses the process developed to assess how, when, and what recommendations would be evaluated and who would participate in the evaluation. Case studies were done on the road weather conditions concurrent with and prior to the evaluated recommendations to provide greater insight into the DOT selection regarding whether to use or not use the recommendation. The paper discusses the findings of these case studies and the complexities involved in assessing whether to honor an MDSS recommendation or use alternative maintenance actions.

Maintenance and Operations Decision Support Tool: Clarus Regional Demonstrations. Department of Transportation; Research and Innovative Technology Administration, 2011, 2p
https://rosap.ntl.bts.gov/view/dot/3341
Abstract: Weather affects almost all maintenance activity decisions. The Federal Highway Administration (FHWA) tested a new decision support system for maintenance in Iowa, Indiana, and Illinois called the Maintenance and Operations Decision Support System (MODSS). MODSS can dramatically improve how an agency schedules its maintenance activities based on real-time and predictive weather conditions, which saves departments of transportation labor and materials costs, time, money, and frustration. Most maintenance activities have their own set of rules on the conditions under which they operate. These rules can involve surface temperature, air temperature, wind speed, humidity, precipitation, and visibility. In some cases, knowing the conditions 24 hours before and after a weather event may be critical to the safety and operating conditions of the roadway. The objective of MODSS is to expand decision support beyond snow and ice control and incorporate Clarus weather data that can assist maintenance-, operations-, and construction-related scheduling decisions during other weather events such as rain, fog, wind, etc.

Maintenance Decision Support Systems: A Proven, Cost-effective Tool for State and Local DOTs.
Pisano, Paul A. Federal Highway Administration, 2010, 2p
Citation at https://trid.trb.org/view/930616
Abstract: When state or local departments of transportation (DOT) prepare for a snow or ice storm, they do more than operate snow plows. Timely decisions must be made on when to call in crews, whether overtime will be required, what kinds and how much material to load on trucks, whether and when to pretreat the roads, and how to optimize equipment assignments. During a storm event, supervisors also make ongoing tactical decisions based on a storm's progress and the effectiveness of maintenance activities, all of which has immediate and vital consequences for the agency, the traveling public, and the environment. A proven, cost-effective tool called the Maintenance Decision Support System (MDSS)

is increasingly being used by state and local maintenance departments for reliable and accurate decision-making under stressful weather and adverse roadway conditions.

A Decision Support Tool for Optimizing Winter Maintenance Operations. Kuchera, Dustin; Gupta, Diwakar. *Transportation Research Board 88th Annual Meeting*, Transportation Research Board, 2009, 17p
Citation at https://trid.trb.org/view/882180
Abstract: This paper describes the development of a decision support tool to assist snow removal operations. In the setting described in the paper, all roads that need to be plowed are divided into routes and each route is attached to a depot. Plow operators traverse each route in one or multiple passes until all its road segments are cleared of snow and sanded (salted). Multiple passes may be required because time and vehicle sand/salt capacity constraints can prevent a plow from completing all road segments of a route in a single pass. Because plow speeds and sand/salt application rates depend on storm conditions, and different road segments carry different amounts of traffic, it is not a priori clear which road segments should be plowed in the first pass and which segments should be plowed in subsequent passes. The decision support tool developed in this research classifies storms into a small number of storm types, calculates an optimal plowing regimen, and displays each pass for each route for every storm type. The required sand/salt amounts, the time-until-completion, the deadhead time, and the number of turnarounds for each pass are also displayed. This tool can be used by managers to determine the number of snowplow operators needed, the amount of sand/salt required, and the number of hours needed to clear roads upon knowing the type of an approaching snowstorm. Operators can use the tool to know the sequence in which to plow various road segments within a route.

Maintenance Management 2009. *Transportation Research E-Circular*, Issue E-C135, 2009
http://onlinepubs.trb.org/onlinepubs/circulars/ec135.pdf
Description: One facet of this 2009 publication's maintenance management focus was winter maintenance decision-making and various information tools in its support. These two citations offer a sampling.

> **Integrating Maintenance Management Systems with Maintenance Decision Support Systems.** Pisano, Paul A; Hoffman, William H; Stern, Andrew D. *Transportation Research E-Circular*, Issue E-C135, 2009, pp 245-254
> http://onlinepubs.trb.org/onlinepubs/circulars/ec135.pdf#%5B%7B%22num%22%3A259%2C%22gen%22%3A0%7D%2C%7B%22name%22%3A%22FitR%22%7D%2C-3%2C266%2C616%2C773%5D
> *Abstract:* During the last decade, many maintenance managers have had the opportunity to work with increasingly sophisticated software systems which assists in keeping track of assets, tracking funding, and making day-to-day maintenance decisions. Two systems in particular are changing maintenance practices by increasing efficiencies and providing new insight into operational planning: the maintenance management system (MMS) and the maintenance decision support system (MDSS). Both MMS and MDSS provide maintenance managers with tools and technologies to maintain a safe and efficient transportation system. MMS sets performance targets, measures outcomes in times of limited budgets, and provides recommendations for tasks with competing needs. MMS now serves as a critical planning and management tool for public agencies, aiding in mid- and long-term maintenance decision making. On the other hand, the MDSS focuses on real-time maintenance decision making, providing decision support for winter maintenance activities. It uses weather forecasts and

other data to generate recommendations based upon specific routes and customized rules of practice surrounding maintenance activities. Output from MDSS is used to optimize day-to-day and hour-to-hour anti-icing or deicing operations in winter. And while the current focus of MDSS is on winter maintenance, efforts are underway to expand its functionality to support nonwinter maintenance activities, e.g., determining when it's best to do crack sealing. For MMS to be effective, it relies on the input of high-quality data on expended resources, materials, and equipment in order to generate completed work activities and budget forecast reports. Such data entry is very time intensive for maintenance personnel, is needed while maintenance personnel are in the midst of fighting a storm and is prone to errors. Similarly, for MDSS to be effective it needs up-to-date, near-term maintenance needs (i.e., data on the immediate maintenance actions to be taken and their location). Since such data inputs are often the output of the other system, integrating the two systems would minimize time demands for data entry, enable staff to focus on storm fighting, reduce data transfer errors, and lead to improved output from each of the systems. Such results will apply to the whole before–during–after timeline of snow fighting and will ultimately improve and optimize the efficiency of existing maintenance resources and practices. This paper explores the benefits that may be gained by integrating these two systems, and the technical steps necessary to achieve this integration, building upon the strengths and capabilities of each.

Use and Cost-Benefit of Weather Information in Winter Maintenance. Ye, Zhirui; Shi, Xianming; Strong, Christopher K. *Transportation Research E-Circular*, Issue E-C135, 2009, pp 255-256
http://onlinepubs.trb.org/onlinepubs/circulars/ec135.pdf#%5B%7B%22num%22%3A269%2C%22gen%22%3A0%7D%2C%7B%22name%22%3A%22FitR%22%7D%2C-3%2C261%2C616%2C768%5D
Abstract: Weather has broad and significant effects on the roadway system. Significant weather-related costs are also incurred by maintaining and operating the nation's highways. Weather observations and forecasts are important inputs for developing more effective and efficient treatment strategies in winter maintenance. Recent trends toward proactive winter maintenance operations have placed a premium on the value of timely and accurate weather information that reflects current and forecast conditions in the roadway environment. However, few studies have sought to quantify this value, and compare it to the costs of obtaining such customized weather information. For this reason, a project led by Iowa Department of Transportation, on behalf of the Aurora Program, seeks to evaluate benefits and costs associated with the use of weather information. This paper first summarizes weather information sources for winter roadway maintenance through nationwide surveys. Two case study states were then selected for evaluation purpose. The winter maintenance data during the 2006–2007 winter season were obtained from various maintenance units (e.g., cost center, crew) in these states. This paper applies the neural network and sensitivity analysis methods to model winter maintenance costs. The explanatory variables of the models include maintenance lane miles, level of service, weather severity index, frequency of weather use, accuracy of weather information (observations and forecasts), anti-icing, etc. Benefits of weather use are analyzed by using different scenarios, which have different frequency of weather use and different accuracy of weather information. Analysis results shows that the direct benefits of using weather information outweigh the costs.

Surface Transportation Weather and Snow Removal and Ice Control Technology. *Transportation Research E-Circular*, Issue E-C126, June 2008
http://onlinepubs.trb.org/onlinepubs/circulars/ec126.pdf

Description: This entire issue of the Transportation Research Board's electronic journal focuses on weather, operations, and winter maintenance. It focuses on RWIS, MDSS and other information systems and tools for management operations and planning. These two citations offer a sampling.

Maintenance Decision Support System Is Not Just for State Departments of Transportation. Kennedy, William. *Transportation Research E-Circular*, Issue E-C126, 2008, pp 240-249
http://www.diva-portal.org/smash/get/diva2:674046/FULLTEXT01.pdf#page=252
Abstract: Maintenance decision support systems (MDSS) are becoming important tools in the winter weather response strategies of many state departments of transportation. Their value can be extended to local agencies as well. The City and County of Denver, Colorado, has incorporated MDSS with other technological aids to support snow response and provide the citizens of Denver with a safer driving environment and increased level of service. Denver contracts its MDSS service from the university component of the National Center for Atmospheric Research (NCAR), the University Corporation for Atmospheric Research (UCAR) in Boulder, Colorado. This MDSS has been established to provide weather prediction and treatment recommendations on statewide, regional, and local levels. The weather prediction module of the system utilizes numerous forecast elements and melds these together to form an accurate forecasting model. The system goes much further than just predicting the weather for the next 48 h. Existing atmospheric and roadway conditions are available from dozens of locations statewide. Denver has also provided the staff at UCAR with typical response strategies and material usage, which they incorporate into their predictive models. The treatment module provides a recommended treatment strategy to keep roadways at an optimum condition during the course of an event. Included in the software is a treatment selector that allows city staff to examine different response strategies to see what effect they may have on roadway conditions prior to implementation. The city has not limited its use of technology aids in snow response to just MDSS. The city has invested in pavement sensors that provide surface and subsurface temperatures, moisture phase, and residual chemical concentrations. All these provide information important in the decision process of when and what deicer chemicals to deploy. These data will be integrated into the UCAR MDSS for the winter of 2007–2008. The city has also developed a geographic information system application to monitor the status of plowing operations for the 1,800 lane miles of designated snow routes within the city. At this time the data are only used internally, however, it is anticipated that at some point these data will be made available to the general public. Currently the snow route status is manually entered into the database that feeds the application, but this will become automatic with the implementation of in-cab Global Positioning System–automatic vehicle location equipment. These technologies are exciting tools, but they do not serve the public if they cannot be used to positively affect the level of service provided to citizens. There are two ways that a direct benefit to the public can be seen: cost and safety. The ability to provide timely response, especially in the area of storm pretreatment, can significantly increase the safety of the public during inclement weather. Costs can escalate if crews are mobilized too early or material is placed when unnecessary. MDSS gives access to critical information that aids in decision making for storm response. Proper use of these innovative tools allows Denver to provide its citizens with a cost-effective and beneficial response to winter weather.

An Approach to Terrain Classification to Improve Road Condition Forecasts of Maintenance Decision Support Systems. Perchanok, Max S. *Transportation Research E-Circular*, Issue E-C126, 2008, pp 337-350
http://www.diva-portal.org/smash/get/diva2:674046/FULLTEXT01.pdf#page=349

Abstract: Recently introduced maintenance decision support systems for winter maintenance operations incorporate the outcome of planned plowing and salting operations on meteorological forecasts of highway snow cover to provide a route-specific, tactical plan for storm events. The forecast is limited by meteorological input at the scale of roadway weather information system (RWIS) stations that does not address local variance due to drifting snow. This study investigates the influence of roadside terrain on snow accumulation and proposes a terrain classification approach for predicting local differences. This study uses surface friction measurements to estimate snow cover continuously along maintenance routes at repeated intervals through winter storms. Relationships between friction, roadside terrain features, and meteorological conditions are demonstrated using mapping, spatial correlation, and frequency domain analyses. This approach to mapping snow cover and classifying terrain can be applied to more accurately interpolate snow cover information between RWIS stations, and predict differences in demand for maintenance equipment or requirements for road salt between RWIS stations.

3.5 Operational Performance

These four citations describe research focused on winter maintenance performance standards, performance indices and case studies. Each focuses on snow and ice maintenance in the U.S. or Canada.

Snow Removal Performance Metrics: Past, Present, and Future. Xu, Gang; Struges, Leigh; Chapman, Michael; Albrecht, Chris; Bergner, Dave; Shi, Xianming. *Transportation Research Record: Journal of the Transportation Research Board*, Issue 2613, 2017, pp61-70
Citation at http://trrjournalonline.trb.org/doi/abs/10.3141/2613-08
Abstract: Snow and ice maintenance operations are among the most critical functions of state transportation agencies and municipalities in cold regions. The use of snow removal performance metrics is of increasing interest to transportation practitioners and academics. For this paper, a comprehensive literature review and a survey were conducted to gather information on the performance metrics used in winter highway maintenance activities by different transportation agencies. Performance goals for snow and ice control were identified in the survey, with average rankings as follows (in descending order): safety, mobility, economy, essential functions, environment, infrastructure, and livability. The survey results were also tabulated and analyzed to identify best practices and future trends in the agencies. Restoring safety and mobility consistently remains a priority of nearly all agencies. At present, the time taken to reach an established level of service is the most commonly used metric of different agencies. Because of the relatively high effectiveness, reliability, and timeliness of outcome-based and severity index–based performance metrics, more agencies are moving toward these types of metrics. Performance measurement by geographic area was also investigated but no clear trend was found.

Making Winter Driving Safer - Establishing Performance Standards for Winter Maintenance. Otto, S. *TAC 2015: Getting You There Safely - 2015 Conference and Exhibition of the Transportation Association of Canada,* Transportation Association of Canada, 2015, 24pp
http://conf.tac-atc.ca/english/annualconference/tac2015/s24/otto.pdf
Abstract: In a series of collaborative trial projects that started in the winter of 2013/14, Alberta Transportation and the province's highway maintenance contractors developed and tested performance standards for winter highway maintenance. Drivers will benefit from the introduction of performance standards for winter maintenance through anticipating, and experiencing, more consistent driving conditions during the winter. Performance standards will also allow consistent educational and public

awareness messaging, which will in turn promote safer trip planning. Various types of performance measures are either in place or are being tested in Alberta, ranging from input measures (i.e. material stockpiling) through process measures (i.e. response times), output measures (i.e. time to return to specified conditions), surrogate outcome measures (i.e. surface friction) and true outcome measures (i.e. travel speeds). Alberta benefited from experience with established technologies like Automated Vehicle Location Systems, Traveler Information Systems, and precision forecasting/Maintenance Decision Support Systems when developing the trial performance standards. In addition, supporting management tools were developed as part of the performance standards trials. These include a Winter Severity Index that can be used on both provincial & local scales, and Storm Classification that allows the contractors to work towards different performance targets, depending on the severity of each storm event. The paper will describe performance standards that are under development for various phases of winter maintenance work planning and execution and discuss some of the implications of using performance standards in a contracted delivery system. Results of the different trial projects are presented, with concluding remarks on the safety benefits from the introduction of formal performance standards.

Sustainable Winter Maintenance and a 22-in. Blizzard: Case Study. Nixon, Wilfrid A; DeVries, R Mark. *Transportation Research E-Circular*, Issue E-C162, 2012, pp11-19
Citation at https://trid.trb.org/view/1138890
Abstract: On February 1 and 2, 2011, a particularly severe winter storm occurred across a broad swath of the United States. The storm hit the Midwest particularly hard, and areas around Chicago, Illinois, received close to 2 ft. of new snow. Additionally, winds during the storm were very high, with wind speeds in excess of 50 mph not uncommon. Snowfall began on Tuesday, February 1 and for the most part had ended in the Chicago area by 9:00 a.m. on Wednesday, February 2. Many roads in the area were blocked with abandoned cars and other vehicles, and drifts in excess of 6 ft. in height were not uncommon. For example, as shown in many news reports (See http://latimesblogs.latimes.com/chatter/2011/02/lake-shore-drive.html, http://www.examiner. com/community-life-in-chicago/lake-shore-drive-chicago-reopened-after-blizzard-car-claiminfo, and http://www.huffingtonpost.com/2011/02/04/chicago-blizzard-stranded_0_n_818577. html as examples), several hundred vehicles were caught in deep drifts on Lakeshore Drive in Chicago. McHenry County, Illinois, is located about 50 mi north of Chicago and received 22 in. of new snow in this storm. The County Division of Transportation has been implementing sustainable winter maintenance practices over the past several years, with a particular (although not exclusive) emphasis on limiting chemical usage. This paper reports on how McHenry County handled this storm, emphasizing how planning guided the storm response, and the end results of the activities. By 6:00 p.m. on Wednesday, February 2, all county roads were passable, and more than 70% of the lane miles were in a bare and wet condition. This makes clear that application of the principles of sustainability does not have to mean a reduced level of service for road users in winter conditions.

Development of Winter Maintenance Demand and Performance Indices. [Project.] South Dakota Department of Transportation. Start date: May 1, 2010.
Citation at https://trid.trb.org/view/1229692
Abstract: Transportation agencies are often asked to quantify the severity of a winter storm or season. An objective characterization of severity can help agencies judge whether the cost and effort of their maintenance responses are commensurate to the maintenance need imposed by winter conditions. Objective characterization is essential to agencies' long-term efforts to evaluate and improve their effectiveness and efficiency. Several distinct approaches have been attempted. The first calculates a winter severity index based upon weather conditions such as temperature, precipitation, and wind,

either alone or in combination with each other. Although such indices describe weather, they do not reliably describe the effect of weather on road conditions and the need for winter maintenance. For instance, they may not account for situations where more demanding maintenance needs exist at temperatures near freezing than at colder temperatures. Other approaches try to portray the impact of weather conditions on maintenance demands by calculating an index as a weighted combination of specific weather events or conditions. Weights are chosen on the basis of relative impact, as determined from expert opinion or statistical methods. A freezing rain event, for example, might be weighted more strongly than snowfall at colder temperatures. A more recent approach employs an automated Maintenance Decision Support System (MDSS) to objectively independently estimate the maintenance demand created by winter events or seasons. By simulating the accumulation of snow and ice on pavement surfaces and the effect of applied maintenance treatments, the MDSS estimates the amount of effort and expense necessary to achieve or maintain a defined level of service on the roadway. An estimate based on standard treatment capabilities and levels of service could constitute a baseline for comparison to actual or other potential maintenance strategies. Regardless of the approach employed, practitioners have found it difficult to develop indices that are transferable across geographic and temporal domains. In many cases, different definitions have been needed among different regions even within single states. Likewise, approaches involving subjective perceptions have lacked the temporal stability necessary to gauge long-term performance. The utility of some indices to support agencies' business decisions has also been limited. The South Dakota Department of Transportation (SDDOT) has not historically calculated or used an index to characterize winter severity or maintenance demand. However, the recent combination of customer expectations, fiscal pressure, and newly available technology has led SDDOT to adopt new winter maintenance approaches and to seek a means to evaluate their effectiveness. Research is needed to identify and evaluate potential methods for characterizing winter maintenance demand and for assessing the efficiency and effectiveness of SDDOT's maintenance activities. The objectives of this project are to: (1) identify candidate indices for characterizing the severity or maintenance demand of winter storms and seasons and the effectiveness of maintenance responses; (2) demonstrate and evaluate candidate indices through use of available historical data and data collected during the winter of 2010-2011; and (3) recommend winter severity or maintenance demand indices along with methodology for their application to support SDDOT business decisions. Research tasks of the project are as follows. (1) Meet with the project's technical panel to review project scope and work plan. (2) Through a literature review and interviews with transportation officials, identify practices recently and currently employed by state and local transportation agencies to quantify winter severity and maintenance demand. (3) Through interviews with selected supervisors and managers in SDDOT, identify business purposes for which calculated indices will be applied. (4) Prepare and present to the project's technical panel a technical memorandum that describes and evaluates candidate indices on the basis of objectivity, data availability and cost, geographical applicability, temporal stability, and ability to support business decisions. (5) Upon direction of the project's technical panel, analyze available historical data to demonstrate the behavior of candidate indices in recent winters. (6) Establish and execute procedures for tracking candidate indices and demonstrating their application in one Area Office within each of SDDOT's four geographic Regions during the winter of 2010-2011. (7) Midway through the winter of 2010-2011, prepare and present to the project's technical panel a technical memorandum summarizing the historical analysis and a partial analysis of 2010-2011 winter. (8) On the basis of the evaluation of historical data and data obtained during the entire winter of 2010-2011, recommend preferred indices for characterizing the severity or maintenance demand of winter storms and seasons and the effectiveness of maintenance responses. (9) Prepare a final report summarizing the research methodology, findings, conclusions and recommendations. (10) Make an executive presentation to SDDOT's Research Review Board at the conclusion of the project.

CLEAR ROADS
research for winter highway maintenance

Effective Practices for Activating Snow and Ice Personnel and Equipment for Winter Storms

Experience with Storm Activation

Thank you for participating in Clear Roads' Effective Snow & Ice Personnel and Equipment for Storm Activation survey. This survey will identify best practices for activating crew and equipment for snow and ice maintenance in anticipation of winter storms. You can learn more about this project at the Clear Roads Web site.

Clear Roads members are interested in how agencies activate their snow and ice maintenance fleets and personnel as they prepare for a forecasted winter storm. This survey explores weather forecasting practices, storm monitoring roles, snow and ice maintenance jurisdictions, activation and deactivation standards. By activation, we refer to when maintenance crews are called in to report for duty for a specific storm event.

Please complete the portion of the survey relevant to your own experience. If you cannot complete a portion of the survey but know who can, please forward the survey to that person. You can use the PDF attached to the email announcing this survey to preview the online survey and seek input from colleagues. **Please use the PDF for review purposes only and submit your responses using the online survey.**

We would appreciate receiving your responses by **Friday, June 15, 2018.**

We may follow up with you to request additional information about some of your survey responses. If you have any questions about the survey, please contact Matt Mullins at matt.mullins@ctcandassociates.com.

Once complete, survey results will be included in a report that will be posted on the Clear Roads web site at CR 17-S3 Storm Activation. Thank you very much for your participation.

1. Please provide your name and contact information.

Name

Organization

Position

E-mail address

Phone number

2. Does your winter maintenance operations group or division work with a storm monitor, meteorologist or weather manager?

- ◯ Yes
- ◯ No

If "yes," please describe the responsibilities and the title of the storm monitor, meteorologist or weather manager as they pertain to snow and ice removal operations.

3. Please indicate the professional status of the storm monitor, meteorologist or weather manager.

- ◯ Consultant
- ◯ State transportation agency employee
- ◯ Other state agency employee

If "other state agency employee," please identify the state agency that employs the storm monitor, meteorologist or weather manager.

4. Does you agency use Maintenance Decision Support System (MDSS) tool or similar software tool in winter maintenance operations?

- ◯ Yes
- ◯ No

5. Is your agency able to use the MDSS or similar tool in activation and deactivation planning for your winter storm maintenance operations?

- ◯ Yes
- ◯ No

If "yes," please describe how your MDSS or similar tool helps in planning an activation and/or deactivation plan.

6. Which of the following indicators does your agency use in determining winter storm maintenance response ACTIVATION? (Please check all that apply.)

- [ ] Pavement temperature
- [ ] Current air temperature
- [ ] Current dew point
- [ ] Current wind speed
- [ ] Current precipitation
- [ ] Forecast air temperature
- [ ] Forecast dew point
- [ ] Forecast wind speed
- [ ] Forecast precipitation
- [ ] Other

Please identify other indications or standards used.

7. Which of these services does your road maintenance division rely upon for weather forecasting or weather responses? (Please check all that apply.)

- [ ] National Weather Service (NOAA)
- [ ] The Weather Channel
- [ ] Accuweather
- [ ] Radar
- [ ] RWIS
- [ ] Camera feeds from traffic operations or other agencies
- [ ] State patrol reports
- [ ] Citizen reports
- [ ] Other

Other (please describe)

8. Please describe the values at which these indicators trigger ACTIVATION of snow and ice maintenance operations.

Pavement temperature

Current air temperature

Current dew point

Current wind speed

Current precipitation

Forecast air temperature

Forecast dew point

Forecast wind speed

Forecast precipitation

Other

9. At what organizational level or category are winter maintenance activities directed when a storm is anticipated? (Please check all that apply.)

	State	District / Region	County	Municipal	Roadway category (interstate, U.S. Highway, State Highway, County, etc.)
Anti-icing activity					
De-icing activity					
Snow removal/snow plowing					
Other					

Other (please describe)

10. Which of the following indicators does your agency use in determining winter storm maintenance response DEACTIVATION? (Please check all that apply.)

- ☐ Pavement temperature
- ☐ Current air temperature
- ☐ Current dew point
- ☐ Current wind speed
- ☐ Current precipitation
- ☐ Forecast air temperature
- ☐ Forecast dew point
- ☐ Forecast wind speed
- ☐ Forecast precipitation
- ☐ Pavements clear
- ☐ Traffic speed
- ☐ Other

Please identify other indications or standards used.

11. What percentage of the snow and ice maintenance fleet personnel is activated before arrival of a significant forecasted winter storm?

- ○ 100 percent
- ○ 50 percent
- ○ 25 percent
- ○ Other

Other (please describe)

12. Please describe the values at which these indicators trigger DEACTIVATION of snow and ice maintenance operations.

Pavement temperature

Current air temperature

Current dew point

Current wind speed

Current precipitation

Forecast air temperature

Forecast dew point

Forecast wind speed

Forecast precipitation

Pavements clear

Traffic speed

Other

13. How many hours before a significant storm's expected arrival do you require maintenance crews to arrive to work to prepare for snow and ice removal on your roadways? (Please check all that apply.)

- [ ] 0 to 2 hours
- [ ] 2 to 4 hours
- [ ] 4 to 8 hours
- [ ] 8 hours or more
- [ ] Beginning of regularly scheduled shift
- [ ] Other

Other (please describe)

14. Please include links to documents that describe or detail activation and/or deactivation steps in your agency.

15. Please add any more pertinent information you would like to this survey.

research for winter highway maintenance

Lead state:

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St. Paul, MN 55155